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Global carbon footprints

Methods and import/export corrected results from the Nordic countries in global carbon footprint studies

Glen Peters and Christian Solli

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Nordic Council of Ministers
Ved Stranden 18
DK-1061 København K
Phone (+45) 3396 0200
Fax (+45) 3396 0202

Nordic Council
Ved Stranden 18
DK-1061 København K
Phone (+45) 3396 0400
Fax (+45) 3311 1870

www.norden.org

Nordic co-operation

Nordic co-operation is one of the world's most extensive forms of regional collaboration, involving Denmark, Finland, Iceland, Norway, Sweden, and three autonomous areas: the Faroe Islands, Greenland, and Åland.

Nordic co-operation has firm traditions in politics, the economy, and culture. It plays an important role in European and international collaboration, and aims at creating a strong Nordic community in a strong Europe.

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Preface

There is increasing public, media, and policy interest in the concepts of carbon footprints and the emissions associated with international trade. Given the well-known growth in international trade in recent years, many wonder if our growing consumption of imported products offsets our gains in climate policy. A wide variety of publications suggest that emission reductions in rich countries are offset by increased imports; in other words, our national carbon footprint is growing while our territorial emissions are getting smaller. Some refute this claim stating that the methods and data are unreliable, while others acknowledge the issue but argue it is not important for climate policy. Who is correct? Or is there a correct answer?

This report, financed by the Nordic Council of Ministers, aims to dispel some myths about carbon footprints and trade-adjusted emission inventories. A review of studies finds large variations between studies of the Nordic countries, but closer inspection shows that many of the variations are due to inconsistent definitions and non-comparable methods. Calculations using a consistent global model provide updated estimates for the Nordic countries in 1997, 2001, and 2004. The report covers a variety of definition, method, and data issues and makes recommendations on how analysts can assure consistent and robust estimates and policy makers can make the most use of the estimates.

The project was led by Glen Peters at the Center for International Climate and Environmental Policy – Oslo (CICERO) and was co-authored with Christian Solli at MiSA AS. Several authors of existing studies helped to understand their estimates. Peters led the work in Chapters 1, 2.3, 2.4, 4 and Solli 2.1, 2.2, 3 with both for Chapters 5 and 6. All results and conclusions are those of the authors.

November 2010,

Øyvind Lone
Chairman, the Working Group on Environment and Economy under the Nordic Council of Ministers

Alec Estlander
Chairman, the Climate and Air Quality Group under the Nordic Council of Ministers

Executive Summary

The overall aim of the project "Global carbon footprints: Methods and import/export corrected results from the Nordic countries in global carbon footprint studies" is to present comparable, accurate and timely estimates of the carbon footprint of consumption in the Nordic countries and detail the greenhouse gas implications of exports and imports for the Nordic countries. To meet this goal requires an assessment of methods to estimate carbon footprints and emissions from the production of exported and imported products. A review of existing studies, particularly when compared with updated and consistent calculations, allows an independent comparison of definitions, methods, and data. Finally, based on the review and calculations the project makes a series of recommendations for the future application of carbon footprints and trade-adjusted emission inventories.

Definitions

Over the last three decades, several research disciplines have been using concepts which could be today called "carbon footprints". The exponential increase in the use of the phrase "carbon footprint" is only a recent phenomenon and stakeholders should constantly be aware of the rich scientific literature on concepts which are the foundation of today's "carbon footprint".

Despite the long history of the carbon footprint concept, uniform and agreed definitions at a variety of scales are not existent. It is true that some fields have defined a carbon footprint, but these definitions do not necessarily apply at different scales. The field of Life Cycle Assessment routinely calculates carbon footprints and has an ISO standard, but this is a product focussed definition and does not easily generalise to the concept of a national carbon footprint. The field of Input-Output Analysis has also routinely calculated carbon footprints of nations, but the definitions do not necessary apply to product-based assessments. Between these two extremes there are numerous other methods focusing on different scales which routinely calculate carbon footprints of companies, cities, regions, and so on.

There have been several recent attempts to define a carbon footprint more generally, and in this report we use a specific realisation of a definition:

> The "carbon footprint" of a nation is the total global long-lived greenhouse gas emissions aggregated using 100-year global warming potentials required to use (direct) and produce (indirect) products and services to satisfy annual national consumption.

This specific definition is for the carbon footprint of a nation (not a product), focuses only on a subset of emission sources which effect climate (long-lived components), compares different sources of greenhouse gases using a specific (and value-based) climate metric, covers the global supply chain and is interested specifically in national consumption in one year.

Within this definition of the carbon footprint there are still some areas of ambiguity, for example, what part of the supply chain is covered by "indirect emissions" and what is "consumption"? The title of this project actually mentions two distinct research issues, carbon footprints and import/export corrected results, which could be viewed as ambiguous in the definition of indirect emissions and consumption. To clarify the meaning of these terms actually requires more specific knowledge of the research question of interest.

In this report, we follow two types of research questions in the methods, review, and implications. One research question focuses on consumption (carbon footprint) and the other on international trade (export/import corrected results). These research questions can be specified more concretely:

> *Research Question 1*: What are the global greenhouse gas emissions to produce the products and services entering final consumption in the Nordic countries?
>
> *Research Question 2*: What are the trade-adjusted emission inventories in the Nordic countries?
> a) What are the territorial greenhouse emissions in the Nordic countries to produce products and services which are exported?
> b) What are the territorial greenhouse emissions outside of the Nordic countries to produce products and services which are imported into the Nordic countries?

Methods

There are as many methods to estimate carbon footprints as there are definitions. In many cases, the method often matches directly to the definition. The definition of the carbon footprint as used by Life Cycle Assessment matches directly with the methods used in Life Cycle Assessment, likewise for the carbon footprint of a business (GHG Protocol), a city (ICLIE), or a nation (Input-Output Analysis). Almost as a direct consequence, specific methods are suited to a specific problem: the definitions and methods used in Life Cycle Assessment will be the most appropriate for a product-based life cycle comparison, and similarly for the other methods.

This project is focused on national level results, and not surprisingly, most method reviews and comparisons find that for national level results a top-down method called "multi-regional input-output analysis" (MRIOA) is the most appropriate. This is since the method was specifically designed to answer Research Questions 1 and 2. MRIOA also has a long history (back to the 1950's or earlier) and its inventor received the Nobel Memorial Prize in Economics Sciences (Wassily Leontief, 1973) and the same award for its use in the system of national accounts (Richard Stone, 1984). The method has been used in numerous carbon footprint studies (though under different names) most notable during the energy shocks in the 1970's and 1980's, and the field has grown exponentially in recent times due its application to understanding global environmental problems.

Previous research has shown that many of the methods can be represented under the same theoretical framework. We support this notion and used a detailed MRIO model to show the strengths and weaknesses of various methods and assumptions. There is also a belief that MRIO models are simply too data intensive and inaccurate for policy applications, but we show that to answer Research Questions 1 and 2 an MRIO model of modest size is sufficient. For national level studies in the Nordic countries, an MRIO model with ten countries each with around 50 economic sectors may be sufficient. Several ongoing projects in the EU and some more globally are building detailed global datasets which will be able focus on more detail on the minimum data requirements for a robust study.

Review

We compiled a list of recent studies to assess the current state of knowledge of carbon footprint analysis in the Nordic countries. We found significant variations between some studies, though an explanation for much of the variation is inconsistent definitions. Many studies do not sufficiently specify if they are answering Research Question 1 or 2 and the definition of the carbon footprint used is often unclear. A simple change in definition could change emission estimates by large amounts, for example, whether international transport is included or not can change the Danish carbon footprint by around 40%.

An important question is whether studies using different methods are actually comparable. Estimates of a national carbon footprint using process-based Life Cycle Assessment may systematically underestimate emissions due to well-known cut-off errors, and this may make a comparison with a top-down MRIO without cut-off errors futile. Similarly, due to different data sources the carbon footprint of Finland and Denmark, for example, may not be comparable even if both used process-based Life Cycle Assessment.

While many of the reviewed studies were country-specific (e.g., Swedish carbon footprint), it is likely that the method used cannot be scaled up to a global level. If some of the country-specific methods were applied globally then the estimated global carbon footprint would be different to the global emissions or exported emissions would be different to imported emissions. This means some methods either double count some emissions or miss some emissions (particularly for international trade).

The review of studies was particularly useful in highlighting the need for specific definitions and consistent methods for comparable studies. A weakness of almost all the studies was a clear definition of the research question. A weakness in many of the studies was a lack of detail on the methods, particularly when hybrid approaches were used that combined many different methods. Another weakness of many studies was the lack of applicability if applied globally.

We recommend that future studies be benchmarked against a Multi-Regional Input-Output (MRIO) model. A global MRIO accounts for all global emissions and ensures consistency in definitions and methods. If the analyst wants more detail, then it is possible to disaggregate the MRIO into more detail (a hybrid model). One key advantage of the global studies reported here is that one can be more confident that consistent definitions and methods are used for all countries. This gain in consistency may come at the expense of decreased detail (and perhaps accuracy) for some countries, but we feel that the gain in consistency is more important particularly considering the modest MRIO needed for accurate estimates as reported in the Methods.

It is important to emphasize that the variation in the carbon footprints in the review often relate more to inconsistent definitions and methods and not to inherent uncertainty in carbon footprint estimates.

Results

For the project we estimated the carbon footprint (Research Question 1) and trade-adjusted emission inventories (Research Question 2) for the main Nordic countries (Denmark, Finland, Norway, and Sweden). The estimates were made using a global MRIO model based on the well-known GTAP database. This is a top-down model which covers all countries in the world. We made estimates for 1997 (66 regions and CO_2 only), 2001 (87 regions and CO_2, CH_4, N_2O, and fluorinated gases) and 2004 (112 regions CO_2, CH_4, N_2O, and fluorinated gases). The most recent estimates (2004) are the most accurate, followed by 2001 and then by 1997. The model, method, and data have been peer reviewed several times and are constantly updated as better data becomes available (so the numbers reported here may differ to some earlier estimates).

The method used here, and in the majority of carbon footprint estimates, applies the concepts in the United Nations System of National Accounts (SNA). The SNA makes definitions for standard economic quantities, like the Gross Domestic Product. However, the most common emission inventories used in climate policy (UNFCCC) are known to be inconsistent with the SNA. Less widely known are the emissions statistics consistent with the SNA (National Accounting Matrix with Environmental Accounts, NAMEA). The Nordic countries all report both the UNFCCC and NAMEA emission inventories and generally publish a “bridge table” which shows the links between the two. In the Nordic countries the UNFCCC inventories and NAMEA’s often differ substantially due to international transportation. Economic studies of greenhouse gas emissions should technically be based on NAMEAs, and not UNFCCC inventories, to retain consistency with the SNA. The estimates presented here are based on NAMEAs which include international transportation (Figure ES1).

When comparing the results of the Nordic countries, great care needs to be taken comparing individual countries. We present all the results in absolute terms, but the Nordic countries differ in area, population, economic output, and so on. Sweden has almost twice as many people as Denmark, Finland, and Norway, while Iceland has only around 250,000. In absolute terms GDP is similarly ranked as population (Sweden highest, with Denmark, Finland, and Norway scattered in the middle, followed by Iceland), but on a per capita basis Norway has the highest at around 50% higher than the lowest Finland. Other than Norway (and Iceland), the Nordic countries have similar absolute greenhouse gas emissions. Per capita greenhouse gas emissions are similar, except for Sweden which is almost half the other Nordic countries. All the Nordic countries are net exporters. In terms of relative changes, population is only slowly changing in the Nordic countries with growth rates much lower than growth in GDP. Greenhouse gas emissions are relatively stable, though this depends on whether the UNFCCC or NAMEA inventories are used. The fastest growing variables in all the Nordic countries are international trade, both exports and imports. The value of exports and imports both grow faster than GDP, with a constant battle between exports and imports on which grows faster. This background information is an important basis for interpreting the results that follow.

Research Question 1 (carbon footprint)

The carbon footprint of the Nordic countries has grown faster than territorial-based emissions (NAMEA). The reasons for this important point will be returned to later, but the main focus on a carbon footprint should be an analysis of emission drivers and not a responsibility blame game between developed and developing countries.

A quality of a carbon footprint is that it allocates emissions to consumed products and not emission sources (Figure ES2). This provides a different perspective on emissions. In the more common source-based estimates electricity, mining, and key energy-intensive sectors are always important despite the fact that they are rarely associated with consumer purchases (except electricity). These primary sectors often act as inputs into secondary and tertiary sectors which consumers ultimately purchase. Consumers purchase processed food and not primary agriculture, for example, and so in a carbon footprint processed food becomes important as it includes the emissions in the supply chain (agriculture, fertilizer, machinery, transport, electricity, etc) required to produce the food that consumers purchase in the supermarket. Likewise, consumers purchase manufactured products like motor vehicles, computers, or clothes, and thus in a carbon footprint these sectors become important while primary manufacturing becomes less important.

The different focus of a carbon footprint allows the policy maker to address the consumption patterns and volume that is behind the production process and source-based emissions. Within a carbon footprint it is also possible to analyze the source-based emissions from the perspective of a carbon footprint. This highlights that a large share of the carbon footprint occurs domestically. In the Nordic countries, however, much of the growth in the carbon footprint is due to growth in the carbon footprint occurring outside of the Nordic countries, particularly in China and other developing countries. In terms of sectors, the purchase of light manufactured products like motor vehicles, electronics, toys, and clothing (particularly from China) is a key factor increasing the carbon footprint. Carbon footprint analysis allows the policy maker to quantify the effect of rapid economic growth in developing countries on consumption and emissions in the Nordic countries.

Research Question 2 (trade-adjusted emission inventories)

When focusing explicitly on the carbon footprint (global emissions to produce the final consumption), it is easy to loose track of direct trade flows. For example, is the rapid growth in the share of the carbon footprint occurring in China due to direct trade between the Nordic countries and China or due to trade via other countries (e.g., the Nordic countries buy a computer from Japan with components from China)? In this context, a carbon footprint is not directly related to bilateral trade flows which are routinely used in policy. Research Question 2 reframes the carbon footprint concept to focus directly on bilateral trade flows and to do this without double counting it only considers domestic supply chains (e.g., "what are the domestic emissions to produce exported/imported goods and services").

As generally small and open economies, the Nordic countries have a large share of their domestic territorial emissions due to the production of goods and services which are exported. Around one-half of the Nordic emissions are exported, and this share has remained relatively static over time. The shares are highest in Denmark (51% in 2004) and Norway (61% in 2004) due to the large international transport industries in those countries, and in the case of Norway the large oil and gas sector. Compared to total territorial-based emissions, the Nordic countries import the equivalent of around 70% of their domestic emissions, a share which is growing over time. As a consequence, the Nordic countries are net importers of emissions and this net import is growing over time. Sweden, with the lowest greenhouse gases per capita, has the largest share of imported emissions relative to domestic emissions (93% in 2004).

The report considers detailed individual results on the main Nordic countries, but many of the trends are the same (Figure ES3). The change in exported emissions over time is roughly consistent with the change in territorial emissions over time. This implies that efficiency gains are felt uniformly across the economies and not applied differentially across sectors. In terms of imports, all the Nordic countries had a rapid growth in the emissions occurring in other countries to produce imported products. Consistent across all the Nordic countries is the importance of imported manufactured products from China. Growth in embodied emissions from the Russian Federation was strong, with India and Brazil also important. There was a decline in imported emissions from the USA, and the European Union was generally static despite large variations with individual countries. Products which accounted for most of the growth in imported emissions were chemicals, primary and secondary metals, machinery, and electronic products. There were some outliers for specific Nordic countries which relate to their unique relationships with other countries; for example, the Russian Federation was particularly important for Finland and Poland for Sweden.

Implications for Definitions, Methods, and Data

The report highlighted several areas where more work is needed in terms of definitions, methods, and data and areas where policy applications could have the most impact. We framed these issues in a series of recommendations.

The first three recommendations relate primarily to the importance of definitions and clearly stating research questions.

> *Recommendation 1*: Base the theoretical background of the carbon footprint and embodied emissions around input-output analysis, while allowing the analyst to decide what method to use in final estimates.

> *Recommendation 2*: Studies should specify clearly the treatment of imports, both to intermediate and final consumers, and specify whether the method applied gives a match between global exports and imports when applied equally to all countries.

> *Recommendation 3*: A consensus working group or task force process is needed to clearly define a set of definitions that would meet the needs of a wide group of policy makers and interest groups.

As discussed the definitions and methods are often closely related. The definition should not necessarily directly specify the method to use, as long as the method meets quality controls, but it is clear that a certain minimum criteria are needed to consistently link methods and definitions.

> *Recommendation 4*: A consensus working group or task force process is needed to clearly define a set of methods and minimum criteria that can meet the needs of a wide group of policy makers and interest groups.

Data issues are often cited as a weakness of carbon footprint estimates. Not withstanding the issues on consistent and robust definitions and methods, data issues do need to be addressed. In many cases, the data is available but it requires consistency and harmonization. The following recommendations are far reaching and some long-term but they would lead to many advantages for all users of economic statistics.

> *Recommendation 5*: Make the submissions of consistent NAMEA's obligatory for all countries reporting to the System of National Accounts.

> *Recommendation 6*: Set up a single repository for the SNA Main Aggregates, SUT's, IOT's, international trade data, and NAMEA's, most obviously at the UN Statistics Division.

> *Recommendation 7*: At a high level strive to obtain consistency of the SNA Main Aggregations, SUT's, IOT's, international trade data, and NAMEA's.

> *Recommendation 8*: Assess the option of having a single global MRIO maintained and regularly updated by one institute (perhaps in collaboration with others).

Implications for policy

While the report does not attempt to do detailed policy analysis, an implication of producing results is the ability to make policy connections. We have drawn on a variety of policy applications where we believe a carbon footprint type analysis can provide information that is useful for policy makers and generally not available using existing economic studies.

> *Application 1 (drivers):* Use input-output models to reallocate emissions from the producer to consumer to give new insight into the consumption patterns which have the greatest carbon footprint.

> *Application 2 (monitoring emission transfers or carbon migration):* The impacts of greenhouse gas emissions are essentially independent of location (global pollutants) and multi-region input-output models can be used to track if policy has unintentionally caused emissions to increase outside of an administered area (system boundary).

> *Application 3 (country and sector comparisons):* A multi-region input-output model represents the production technologies in numerous countries and sectors in a consistent way and therefore the models allow detailed comparisons of countries and sectors which include the global supply chain consistently.

> *Application 4 (assess risk to carbon pricing):* A multi-region input-output model represents the production technologies in numerous countries and sectors in a consistent way and therefore by applying a tax rate in various countries and sectors gives a quick assessment of how the tax may change prices in different countries and sectors.

> *Application 5 (basis for in-depth studies):* A multi-region input-output model can act as a starting point for analyzing country specific key sectors and value chains in more detail.

Summary

The report has covered a variety of issues related to carbon footprints and trade-adjusted emission inventories. National carbon footprints provide value to a variety of policy areas, but a lack of consistency across existing studies has given a perception of poor quality. Using existing definitions, data, and methods it is possible today for all the Nordic countries to give consistent and robust estimates of carbon footprints and trade-adjusted emission inventories and to apply these in a variety of policy areas. However, the value of these will be greatly enhanced if a concerted effort is put in place to improve definitions, method consistency, and datasets. The community of researchers estimating carbon footprints needs to work together to agree on consistent and robust definitions and methods applicable to a variety of stakeholders. A series of processes need to be put in place to ensure the long-term viability of the underlying statistics, a goal which should benefit statistical offices, researchers, policy makers, and other stakeholders using these and similar statistics.

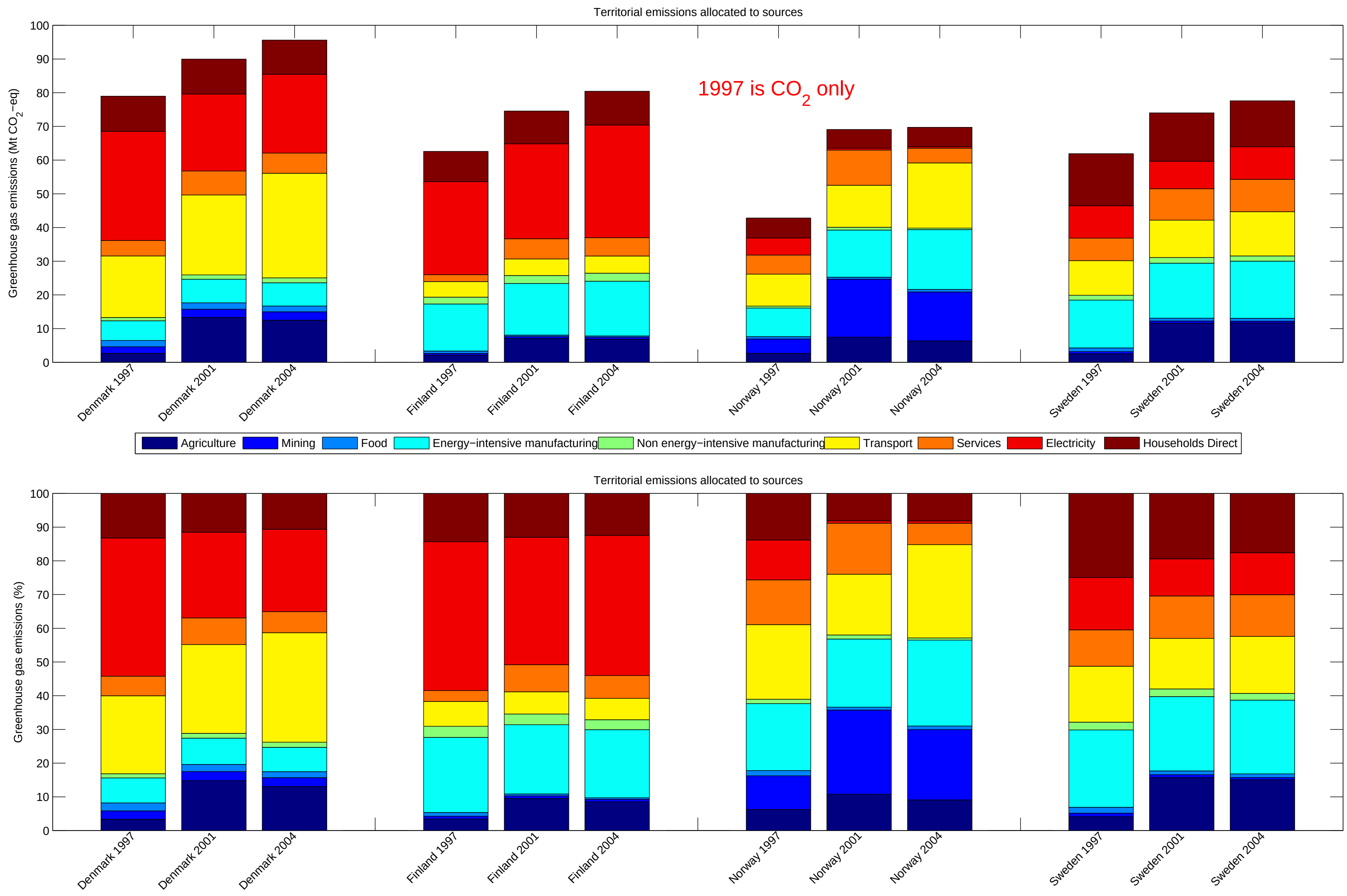

Figure ES 1: Territorial-based NAMEA emissions allocated to economic sectors; absolute emissions (top) and sector distribution (bottom).

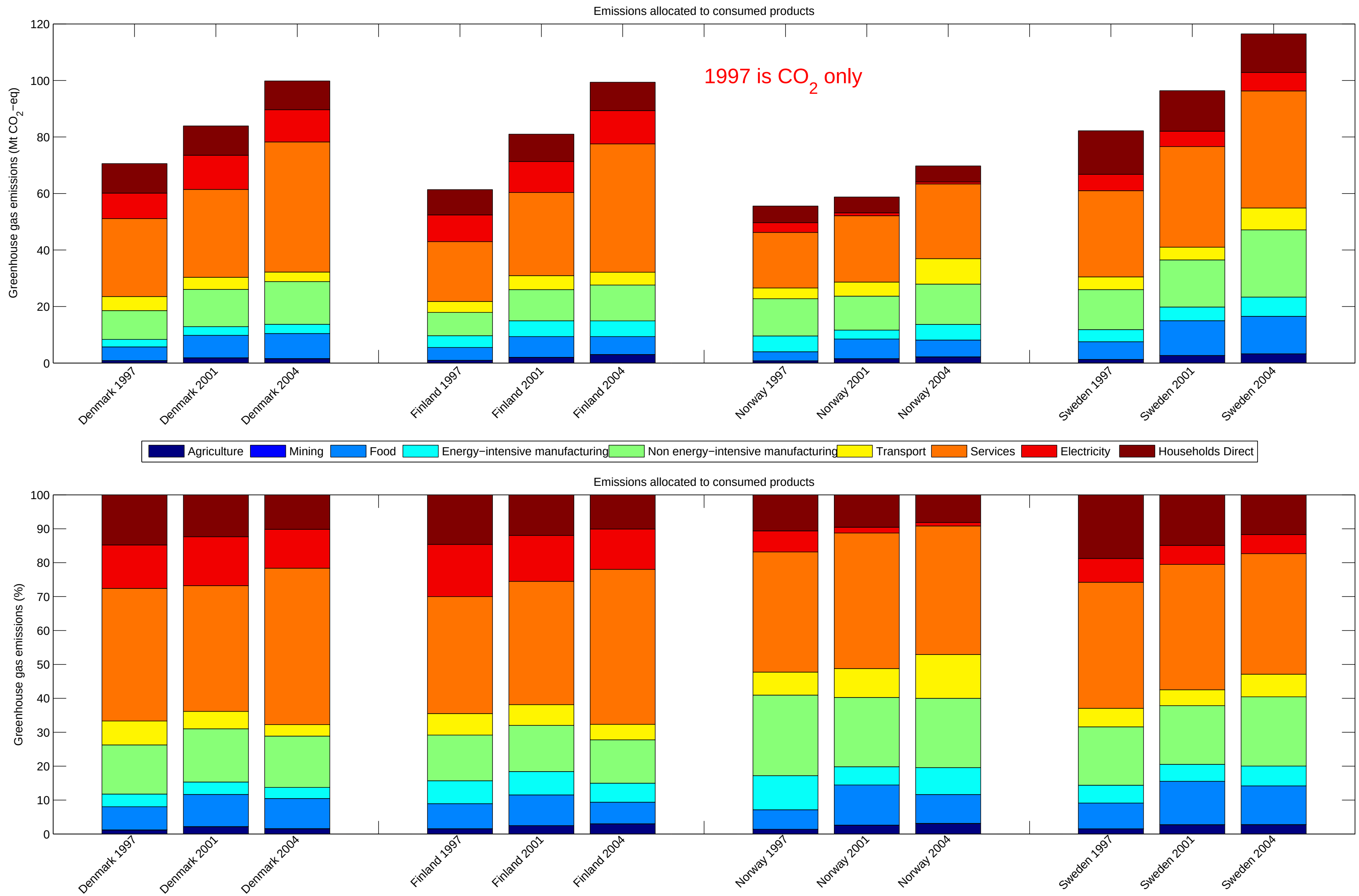

Figure ES 2: Total consumption in the Nordic countries, covering households, governments, and capital investments. Imported emissions are included in these totals

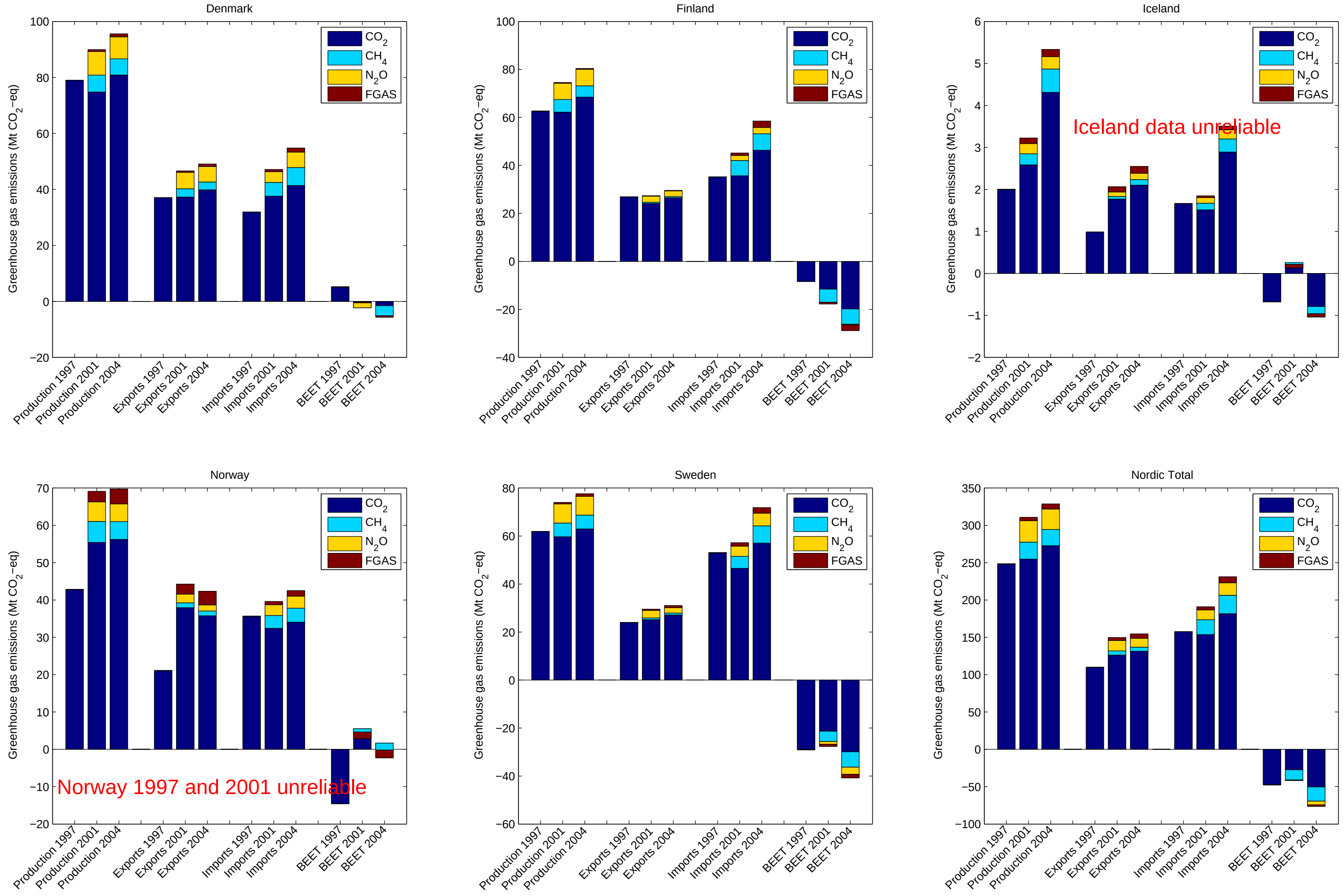

Figure ES 3: The territorial emissions, exported emissions, imported emissions, and trade balance for the Nordic countries. Not that the scale is different in each region.

1. Introduction and Background

1.1 What is a Carbon Footprint?

A widely accepted and concrete definition of a carbon footprint does not exist. The term “footprint” in relation to indirect environmental effects was first coined by William Rees (Rees 1992) and then developed by Mathis Wackernagel in his PhD thesis (Wackernagel and Rees 1996). Wackernagel and Rees introduced the term “ecological footprint” as an aggregate measure of the total environmental impact of a product, service, nation or any other entity. The term “carbon footprint” is derived from this metaphor as well as other types of footprints such as “water footprint” or “energy footprint”. The metaphor, however, does not provide any consistent definition of the term and leaves the computational aspects open with regards to system boundaries and methodology used to arrive at the footprint (Wiedmann and Minx 2008).

Several issues arise when attempting to define a carbon footprint, and based on a disciplinary background, people often have a pre-defined concept of a carbon footprint. It is not entirely clear what the “carbon” in a carbon footprint may refer to; it could refer to the elemental carbon, carbon dioxide, greenhouse gases converted to carbon dioxide equivalents, or even more general climate metrics. A generic definition of the carbon footprint needs to deal with a variety of scales. A carbon footprint can be calculated for a car or for the European Union. In both cases different methods may be used and the exact definition of the footprint may vary. In the case of a car, the objective may be to compare two cars with different drive chains and fuel inputs (e.g., electric versus biofuel). At the European Union level, the objective may not be to compare to another country or region, but to assess the emissions that arise outside of the European Union to produce products which are consumed within the European Union. The system boundary may vary for carbon footprints of different scales, both temporally and spatially. In terms of a temporal system boundary, the carbon footprint of a car may be based on the lifetime of the car, while in the case of a country it may be for consumption in a given year. The notion of a “life cycle” of a product (production, use, and disposal) does not make sense for the carbon footprint of a country and consequently the “life cycle” thinking in some definitions of the carbon footprint may not be relevant. In terms of a spatial system boundary, one may be interested in the emissions that occur within a certain part of the supply chain (e.g., don’t include input of services in the manufacture of a car) or at the country level maybe the emissions occurring within direct bilateral trade partners are of interest. Putting all these and related issues together, it may be a futile exercise to uniquely and specifically define the carbon footprint.

Ultimately, the definition of the carbon footprint may change depending on the specific research question but arguably all carbon footprints should have some key characteristics. An open definition of carbon footprint that attempts to allow for all possible applications (functional units) across scales is (Peters 2010a):

> The "carbon footprint" of a functional unit is the climate impact under a specified metric that considers all relevant emission sources, sinks, and storage in both consumption and production within the specified spatial and temporal system boundary.

In the context of this report the definition can be specified more precisely: analysis will be on consumption at the national scale; the metric will be long-lived greenhouse gas (GHG) emissions (CO_2, CH_4, N_2O, and the fluorinated gases) measured in 100-year global warming potentials (as in the Kyoto Protocol); only emission sources will be considered; the system boundary will be global; and the temporal scale will be one year. With these additional constraints, the carbon footprint used in this report is defined more explicitly as:

> The "carbon footprint" of a nation is the total global long-lived greenhouse gas emissions aggregated using 100-year global warming potentials required to use (direct) and produce (indirect) products and services to satisfy annual national consumption.

This definition, however, is not yet fully complete. In particular, as we discuss in Chapter 2, the terms "indirect" and "consumption" need to be clearly defined and these definitions can have a big effect on the estimated carbon footprint (see Chapters 2, 3 and 4).

Other definitions exist, both more formally and informally. The definition we use here attempts to be as generic as possible by not specifying a method. Many definitions, such as the British (BSI 2008) and International Standards (ISO 2010), are embedded in product-based Life Cycle Assessment and use definitions from those fields, e.g., "Life cycle GHG emissions [carbon footprint] are the emissions that are released as part of the processes of creating, modifying, transporting, storing, using, providing, recycling or disposing of goods and services" (BSI 2008). Though, such definitions are usually ambiguous with respect to key assumptions and require a more extensive goal and scope definition (Rebitzer et al. 2004). While it is natural to think of a carbon footprint in the context of life-cycle assessment, there are several issues of using a product-based definition in a national level study, for instance, what is the "life cycle" of a nation? Other organizations use the notion of the carbon footprint, but this may include only the direct (Scope 1) and not the life cycle emissions (Scopes 1, 2, and 3) (WRI and WBCSD 2004). Due to the rapid increase in popularity of the term carbon footprint, it is likely a multitude of definitions will exist in the short term. It is not our intention to enter a debate on definitions, but the reader should be aware that different organizations and commercial interests may use different definitions to serve their immediate interests. For the purpose of this report, we use the definitions above with more specific details discussed below and in Chapter 2.

At the national level, the term “carbon footprint” can sometimes refer to the direct territorial-based emissions emitted by a country. The carbon footprint, as defined above, differs from the territorial-based emission statistics reported to the United Nations Framework Convention on Climate Change (UNFCCC) in two key ways (Peters 2008b; Peters and Hertwich 2008b); 1) UNFCCC inventories only include the emissions on administered territory, while the carbon footprint considers emissions in all regions to use and produce a given consumption; and 2) UNFCCC inventories allocate emissions to technology-based sectors (like energy and transport), while a carbon footprint allocates emissions to economic sectors (like electronic products or government services). Territorial emissions still have a critical role and are the foundation of any carbon footprint, but a carbon footprint contains additional information not found in a traditional territorial emission inventory.

A carbon footprint considers all the GHG emissions along the global supply chain required to produce the products and services under the scope of the carbon footprint. Consequently, a carbon footprint not only requires a model and data to construct territorial-based emission estimates (IPCC 2006), but also a model and data to enumerate the global supply chain (Turner et al. 2007; Peters 2008b; Peters and Hertwich 2009). All carbon footprints are ultimately based on (and hence contain) territorial-based emission estimates, thus a carbon footprint contains additional information which is not currently reported in standard emission estimates (Peters et al. 2009).

A carbon footprint has many applications which will be discussed later in Chapter 5, but the main applications cover: understanding emission drivers from the perspective of consumption (Hertwich and Peters 2009) and understanding the role of international trade in redistributing who is responsible for emissions (Peters and Hertwich 2008a; Davis and Caldeira 2010). A carbon footprint is able to answer questions of why and how emissions occur, while in an unmodified form territorial-based emission inventory generally only reveal when and where emissions occur (Peters et al. 2009).

Following the definition of a carbon footprint is the notion of “embodied carbon”, “carbon flows”, “embedded carbon”, “virtual carbon”, and similar terms. Historically, the emissions that occur along the supply chain of a functional unit have been said to be “emissions embodied” in the functional unit. A carbon footprint and embodied emissions are synonyms under consistent definitions. The emissions are not a physical part of the functional unit, but are *associated* with the functional unit via the production network.

1.2 Historic development of the carbon footprint

The term "carbon footprint" is new and evolved from the term "ecological footprint" (Wiedmann and Minx 2008). Despite the new and trendy term, the carbon footprint has existing for almost half a century under the terms of consumption-based emissions (Kondo et al. 1998; Munksgaard and Pedersen 2001) and embodied emissions (Ayres and Kneese 1969; Leontief 1970).

In the context of environmental issues, the notion of a carbon footprint has been studied since around 1970 (Ayres and Kneese 1969; Leontief 1970) and heavily influenced by a branch of economics known as input-output analysis (IOA; Wiedmann 2009a). The Nordic countries have a long history of IOA (e.g., Bjerkholt 1995) and some pioneering environmental IOA applications were performed in Norway (Herendeen 1978). Many energy-based input-output studies were motivated by the oil shocks (Carter 1974; Bullard and Herendeen 1975; Herendeen and Tanaka 1976) and later applied to more specific environmental applications.

In terms of climate policy, early studies recognized the importance of carbon leakage (Wyckoff and Roop 1994) though different notions of carbon leakage now exist (Peters and Hertwich 2008c). This motivated pioneering studies on the role of international trade in climate policy and in particular the comparison between consumption-based and production-based emissions (Kondo et al. 1998; Munksgaard and Pedersen 2001). Numerous studies on individual countries emerged (Wiedmann et al. 2007), and later studies with global coverage (Ahmad and Wyckoff 2003; Peters and Hertwich 2008a; Hertwich and Peters 2009; Nakano et al. 2009; Davis and Caldeira 2010). These studies generally use terms like "consumer emissions" or "consumption-based emission inventory" (Peters 2008b; Peters and Hertwich 2008b). In the meantime, the term "carbon footprint" had emerged in the popular media (Wiedmann and Minx 2008) before appearing in a more formal way in academic publications (e.g., Weidema et al. 2008; Finkbeiner 2009; Hertwich and Peters 2009).

The term carbon footprint is now becoming more popular in the academic literature and applied at a variety of scales (Peters 2010a). Despite the emergence of a new term, one must keep in context that the concepts and methods are well established and the favoured methodology used to estimate carbon footprints at the national level (Wiedmann 2009a) was behind Wassily Leontief's Nobel Memorial Prize in Economic Sciences in 1973. In other words, carbon footprints are well established under different nomenclature with the term "carbon footprint" becoming popular outside of academia in only recent years.

Due to the usefulness of carbon footprint analysis to understanding environmental problems, the field of IOA has had a resurgence in recent years (Wiedmann 2009a). The interconnections of the global economy are of particular interest, and the underlying multi-regional methods were developed in the 1950's (Isard 1951). The greatest challenges have been in data availability and while some have made use of existing global databases (Ahmad and Wyckoff 2003; Peters and Hertwich 2008a; Hertwich and Peters 2009; Nakano et al. 2009; Davis and Caldeira 2010) others are involved in major data projects to build more detailed and accurate global datasets (Tukker et al. 2009; Peters et al. 2010b). It is likely that this renewed interest will continue in the decades to come as policy makers have increased need to understand emission drivers.

1.3 The carbon footprint, consumption, international trade, and carbon leakage

The rapid emergence of several research fields from different disciplines has led to a generally poor understanding of key terms and concepts. Authors have used different terms for essentially the same thing (e.g., carbon footprint, consumer emissions, and consumption-based emissions) and consensus has yet to settle on the favoured term. Authors have also used the same term to mean different things as in the case of carbon leakage originating in either economics (Barker et al. 2007) or IOA (Wyckoff and Roop 1994). Attempts have been made to differentiate terms (Peters and Hertwich 2008a), but other fields have used yet new terms (Meyfroidt and Lambin 2010).

The different definitions for related terms are essentially due to different disciplines answering similar research questions but with a different paradigm. To avoid confusion, some additional definitions are useful (Peters 2010b). We will refer back to these definitions at numerous times throughout the report and hopefully this can dispel a few myths about carbon footprints and also promote more productive discussions between researchers from different disciplines (e.g. economics and environmental sciences). These definitions are not new (Peters 2008b), but are subject to change as consensus is built.

The notion of carbon leakage has been used differently in different fields and clearer definitions that distinguish the two are needed (Peters 2008b; Peters and Hertwich 2008c, a; Peters 2010b):

> *Weak carbon leakage* (or demand-driven carbon leakage (Meyfroidt and Lambin 2010)) in country R are the greenhouse gas emissions outside of R to meet consumption in R. Temporal changes are made to the change in territorial emissions in R (positive or negative).

> *Strong carbon leakage* (or policy-induced carbon leakage (Meyfroidt and Lambin 2010)) in country or region R are the increase in greenhouse gas emission outside of R due to climate policy in R. Comparisons are made to the (modelled) change in emissions in R due to climate policy only (positive or negative).

Weak carbon leakage considers all international trade flows into R regardless of the economic or policy driver, while strong carbon leakage only considers a subset of international trade due explicitly to the imposition of climate policy. Most studies of strong carbon leakage use static computable general equilibrium models (Barker et al. 2007), while studies of weak carbon leakage use attribution models (Wiedmann et al. 2007; Wiedmann 2009b).

For comparisons, it is also useful to refer to different emission inventories (Peters 2008b, 2010b):

> *Territorial-based emissions* are the emissions occurring in the administered territory of R.
>
> *Consumption-based emissions* (or carbon footprint) are the global emissions to produce final consumption in R.
>
> *Trade-adjusted emission inventory* are the territorial-based emissions minus the BEET in R (the territorial-based emissions in R minus the emissions embodied in exports from R plus the emissions embodied in imports to R).
>
> *Emissions embodied in exports* are the territorial-based emission in R to produce products which are exported from R
>
> *Emissions embodied in imports* are the emissions embodied in exports from all regions to R.
>
> *Balance of Emissions Embodied in Trade (BEET)* are the emissions embodied in export from in R minus the emissions embodied in imports to R.

Using these definitions, the relationship between strong and weak carbon leakage with the carbon footprint can be clearly separated. Weak carbon leakage represents the difference between territorial- and consumption-based emissions and is independent of the policy driver. Strong carbon leakage is related to a specific policy driver, climate policy, and is a subset of weak carbon leakage. It is also possible to have a situations arise where there is no strong carbon leakage and considerable weak carbon leakage. This is arguably the current situation (Peters 2010b).

The use of two seemingly related carbon footprints or emission inventories (consumption-based and trade-adjusted) is seemingly more confusing then it needs to be. However, later in this report, the importance of such a distinction will become apparent. Both the definitions answer a different research question (Peters 2008b) and when analysts use the same or similar language for the different research questions it can appear that “carbon footprint” estimates are widely inaccurate when they in fact use different definitions. An additional issue is that the concepts in the two definitions are often (unknowingly) blended together giving an inconsistent carbon footprint. Often, analysts are not clear which definition they are using and why. This issue is highlighted in Chapter 3.

The two types of "carbon footprint" mentioned here represent different perspectives (Peters 2008b); consumption (Hertwich and Peters 2009) and international trade (Peters and Hertwich 2008a). These perspectives are used to answer a different type of research question and these are now briefly explained. The different perspectives relate to the different definitions above, and more explicitly how "indirect emissions and consumption are defined.

1.3.1 The consumption perspective

Many analysts that perform a carbon footprint analysis generally have a research question along the lines "what are the global emissions to produce the products which are consumed in country C". A key ambiguity here is the definition of consumption. A variety of products are consumed in a country and for different purposes. A more formal definition (United Nations 1993) separates between products which go to final consumption (households, government, and capital investments) and products which go to intermediate consumption and are further transformed before going to either exports or final consumption. This distinction is clearly important for imported products, which may either go to 1) final consumption directly, 2) intermediate consumption and after transformation to final consumption, and 3) intermediate consumption and after transformation to exports. It is important to note, and this point is often missed by analysts, that exports are the imports of another country and thus exports must also be separated in these three categories based on how they are "consumed".

From the consumption perspective, analysts really need to ask "what are the global emissions to produce the final consumption of country C" (see definition above). As we discuss in Chapter 2, this seemingly simple research question is a difficult for many methods and is a key factor describing the variation between studies. Since the consumption perspective should enumerate the global supply chain, the distinction between the intermediate and final consumption of traded products is important and can make a large difference in estimated emissions (Peters 2008b; Peters et al. 2010b).

1.3.2 Trade perspective

The notion of international trade is often closely linked to bilateral trade flows. Bilateral trade statistics show the trade flows between a country and its immediate trading partners (for example, between A and B). It is unusual to take a supply chain perspective in trade statistics, for example, trade statistics for the Nordic countries do not show the relationship between Australia and Chinese trade even if Sweden imports a Chinese product containing products originally imported from Australia (trade between B and C is not relevant for the bilateral trade statistics of A). Since the consumption perspective in the previous section considers global supply chains (links between A, B, and C), the exported and imported emissions may not correlate to the bilateral trade statistics (the trade link A to B will include trade from C). For example, if the Netherlands imported crude oil from Norway, refined it into petroleum and then sold it to other European countries, a consumption perspective in the countries using the refined petroleum would show a strong relationship with Norwegian emissions even though there was no bilateral trade flow (as the trade was via the Netherlands). Because the "imported" emissions in the consumption perspective relate to where the emissions occurred, and not where the trade flow occurred, the connection with a carbon footprint and bilateral trade flows can be obscure.

To focus purely on a bilateral trade perspective requires a different research question. If the research question is "what are the territorial-based emissions in country C to produce goods and services which are exported" and the inverse "what are the territorial-based emissions in exporting countries to produce the imported goods and services to C" then a direct link between emissions and bilateral trade flows is made. This approach does not split the trade flows into intermediate and final consumption (as for the consumption perspective above) since it considers bilateral trade as a whole. In the example of Norway, with a trade perspective there would be a large flow of emissions from Norway to the Netherlands due to crude oil exports and a flow from Netherlands to the importers of the refined petroleum which would only include the emissions within the Netherlands for the refinery step (not the emissions in Norway which are allocated to the Netherlands). A trade-perspective keeps the trade flows in their bilateral linkages and not transferred along the global supply chain.

1.3.3 Summary of the consumption- and trade-perspectives

Since global supply chains are not analysed, but bilateral trade flows are, the trade perspective is not capable of answering questions about consumption. Likewise, it is difficult to answer questions about trade using a consumption perspective. Thus, the two perspectives answer different questions and neither is right or wrong. Global emissions are the same in both methods, but the allocation of trade in intermediate consumption is different. These issues will be returned to at several occasions throughout the report and the results of both perspectives will be shown.

1.4 Content of this report

This report is focused on the carbon footprint of the Nordic countries, both individually and collectively. The main research questions and objectives are:

- Chapter 2: What are the best methods to estimate a national carbon footprint?
- Chapter 3: What is the available evidence on the carbon footprint of the Nordic countries?
- Chapter 4: What are the carbon footprint and trade-adjusted emissions in the Nordic Countries?
- Chapter 5: What are the main methodological challenges for robust carbon footprint analysis and what are the main applications of the carbon footprint concept?
- Chapter 6: Summary of the report.

Given the resources available for the project, this is an ambitious task. The method review largely draws on existing comprehensive studies completed in recent years. The carbon footprint estimates are based on updates of an existing model, but provide a Nordic focus. With additional resources, the analyses provided for each country can be considerably more detailed. The methodological challenges will draw on experiences of the authors, colleagues, and recent studies. Only a brief overview of potential applications will be provided without going into details.

A carbon footprint is an emission inventory of past activities. Most analysts use an economic technique, input-output analysis, to estimate the national carbon footprint. A carbon footprint does not, however, require economic modelling and we do not perform any economic modelling. In this report we do not evaluate policy instruments or recommend specific policies that could be built around a carbon footprint. We only look at past emissions from the perspective of consumption and international trade to quantify how they have evolved over time. The temporal development of a carbon footprint and its causes may be very relevant for climate policy, but it is not our goal to analyze this in the report.

2. Methodology Review

2.1 Overview of relevant methods

There are many methods available that possess, partially or completely, the ability to calculate emissions embodied in products and services, i.e. carbon footprints. Recently there have been some reviews and evaluations of these methods (Blanc et al. 2009; Wiedmann et al. 2009) and we draw upon these in our description and coverage of the available methods.

The various methods differ along several dimensions, most notably in the level of specificity or aggregation, but also regarding system boundaries, spatial and temporal resolution, data availability, and computational complexity. The methods span from very product specific, detailed life cycle assessments (LCA), to highly aggregated material flow analyses, physical input-output models and environmentally extended input-output models. There are also approaches that are presented as methods when they actually are indicators or a reporting standard that may use several methods for its calculation. One such example is the term "ecological footprint", which is an aggregated indicator of environmental impact, but can be calculated via many of the existing methods for embodied emissions and land use calculations.

The following sections present an overview of the existing methods for calculating carbon footprints and embodied emissions. We discuss each methods applicability and usefulness at a national level. We then use a global model to assess various assumptions. It is important to highlight, that if the research question is at a different scale (e.g. product level) then a different method may be recommended.

2.1.1 Life Cycle Assessment (LCA)

Life cycle assessment has its root in analyses of cumulative energy use in the late 1960's. A multi-criteria analysis of Coca Cola was performed by Harry Teastley Jr. in 1969 (unpublished) including environmental impacts from cradle to grave. One early study was done in Norway (Nunn 1980) on packaging material. As interest grew in the Society of Environmental Toxicology and Chemistry (SETAC), method development started and guidelines were developed (Consoli et al. 1993). Guidelines for the Nordic countries came out quite early (Nord 1992, 1995). The methodology has evolved significantly the last 15 years resulting in revised ISO standards for life cycle assessment (ISO 2006a, b), handbooks (Guinee 2002) and new standards for carbon footprint of companies (ISO 2006c) and products (ISO 2009) as well as environmental product declarations based on LCA (ISO 2000). Finnveden et al. (2009) summarizes some of the developments in the method.

LCA aims at calculating the total direct and indirect environmental impacts associated with the delivery of a so-called *functional unit*. This functional unit can be fulfilled by a service, product or any combination thereof (referred to as *reference flow*). With regards to dimensions such as time and geography, this *can* be treated with country- and time specific LCA databases. Most common, however, is the construction of a *foreground system* (defined by the influential sphere of the studied entity, a specific region, etc) that is modelled very specifically, and the foreground system in turn requires materials, energy and services from a generic background LCA database. In this way sufficient detail is provided on parts of the system connected to the product or service under study. Usually a life cycle assessment always includes a carbon footprint as one of several indicators of environmental performance. In principle the methodology therefore *can* be used on a national level but the bottom-up nature of the approach leads to substantial data needs and the conventional process-based life cycle assessment approach suffers from system-boundary issues (Suh et al. 2004). It is therefore not suitable for analyses on a national level, unless supplemented by other approaches which in turn make the method more complex and less transparent.

2.1.2 Greenhouse Gas Protocol

The Greenhouse Gas (GHG) Protocol (WRI and WBCSD 2004) provides standards and guidelines for corporate accounting of greenhouse gases classified into 3 different scopes: 1) direct emissions, 2) indirect emissions from consumption of electricity and 3) all other indirect emissions. Scope 3 may also include downstream effects (typically in the use phase of a product). The GHG protocol is not a method as such, but lends terminology and methodological definitions from existing methods, such as life cycle assessment (LCA). Its usefulness is therefore more related to a common reporting standard for businesses than as a method for calculating emissions embodied in goods and services.

2.1.3 Material flow analysis (MFA)

Material flow analysis is a systematic method for logging the stocks and flows of materials within a system defined in space and time (Brunner and Rechberger 2004). Often it is aimed at studying society's metabolism of certain specific material over time (Bergsdal et al. 2007a; Bergsdal et al. 2007b) which includes the dynamics between stocks and flows of materials. However it can also be used on an aggregate national level (Rubli and Jungbluth 2005) and also include emissions data (Matthews et al. 2000) or input-output data (Kytzia et al. 2004). MFA is at least partially a bottom-up approach and is hence not practical to be used for calculation of embodied emissions with full activity coverage, unless combined with other methods. Generic and regularly updated datasets for MFA at the national level do not exist and hence applications of MFA are usually focused on specific research projects.

2.1.4 Input-Output Analysis (IOA)

As a top-down approach, input-output analysis takes as a starting point the national economic statistics and uses this to derive a table of transactions between sectors in a national economy (or region); called an input-output table. This table is usually constructed by the national statistics offices as part of the system of national accounts (United Nations 1993). The table can be used to find the induced economic activity in each sector of the economy from a given final demand. The idea of using input–output analysis for environmental calculations was developed in 1970's (Leontief 1970) by the same man who received a Nobel Memorial Prize in Economic Sciences for the development of input-output analysis, Wassily Leontief (Leontief 1928; Leontief 1936). Since IOA can find the induced economic activity in each sector from a final demand it can easily be combined with emission statistics to estimate the total induced emissions from a given final demand. The top-down nature of the method ensures completeness with regards to which types of activities are included (all sectors of the economy, all commodities with a value connected to it) and is well suited to calculate aggregated embodied emissions at a national level.

Within IOA imports have traditionally been treated in a way that has not accounted for the different technology level of a nation's trading partners. Often the simple assumption that imports are produced with domestic technology is made (Wiedmann et al. 2007; Andrew et al. 2009; Wiedmann 2009b). The general reasoning behind this assumption has been the lack of reliable trade and IO data for trade partners. This leads to incomplete system boundaries when it comes to geographical coverage, and it would be preferable to increase the resolution of imported emissions. For emissions embodied in exports this error does not arise, unless one wants to additionally estimate the emissions to produce imports used as inputs to the production of exports. Recent improvement in databases has enabled the development of multi-region input-output models that complete the embodied emissions picture with actual emissions occurring in other regions; discussed further below.

2.1.5 Multi-Region Input-Output Analysis (MRIOA)

Multi-regional input-output analysis is an extension of IOA to a multi-regional level. This is not a particularly new concept (Isard 1951), but its prevalence in recent times reflects the importance of international trade and investment flows linking countries. The study of environmental problems in particular, has created renewed interest in large scale global models. Multi-regional input-output analysis is an extension of standard IOA to cover the production systems in multiple countries. Most detailed studies today cover over 100 countries and regions (Hertwich and Peters 2009; Davis and Caldeira 2010) and many new data projects now exist (see the overview in Peters et al. 2010b). MRIOA is often referred to as the best default method for national-level carbon footprint studies (Wiedmann 2009b; Wiedmann et al. 2009).

2.1.6 Physical input-output analysis

There has been some debate about whether it would be preferential to have physical- or mixed unit input-output models instead of purely monetary ones (Hubacek and Giljum 2003; Giljum et al. 2004; Suh 2004; Weisz and Duchin 2006). Instead of basing the analysis on monetary flows between sectors, physical input-output tables are based on the exchange of mass or other types of physical output. The two methods would yield identical results if the prices of all commodities are the same for all sectors (Weisz and Duchin 2006). If, however, the price of a commodity varies across purchasing sectors, the methods yield different results.

The use of a physical input-output table is basically a question of whether embodied emissions should be allocated on the basis of physical quantities or economic value. Neither of the approaches can be said to be 100% “correct” in the sense that they both assume one generic output from each sector, valued in either a physical quantity or money. If one sector in reality purchases a low volume of high value products from a sector that in reality produces both high and low value products, it is not clear (unless causal relationships within the specific sector are established) whether it would be fair to give the low volume, high value purchase low embodied emissions (based on physical quantity) or higher embodied emissions (based on the higher value and implied more resource demanding production).

Minx et al. (2010) summarizes the main difference between the physical and monetary methods. While physical IOTs arguably capture the correct mass flows, they consequently miss services and this can be significant even for sectors that one would assume the main output to be mass. IOT’s, on the other hand, lack unvalued flows in the economy; this is particularly evident in the waste sector. Establishing physical input-output tables requires substantial data efforts, as these tables are not published by statistical offices, but must be constructed from a combination of IOT and other approaches and statistics. One such study has been performed for Denmark (Pedersen 1999).

2.1.7 Mixed unit input-output analysis

To overcome the shortages of purely physical input-output model, a mixed unit system can be constructed. Some sectors and commodities can be represented by physical data, while others are best represented by monetary data. This way the model can obtain better resolution in some areas, depending of the scope of the study. This is the approach recommended by Weisz and Duchin (2006) where each sector is recommended to have an output based on its sectoral characteristics, though many sectors in aggregated IOTs have a mix of physical and monetary flows.

Practical examples of mixed input-output models includes the EU research project FORWAST (2010), with an aim of providing information on the historic accumulation of material in EU27 and make projections for the future, has resulted in a mixed-unit input-output model of EU27 and Denmark. The model has physical information for the material and waste sectors, and monetary data for more service based sectors. The Finnish ENVIMAT project (Seppälä et al. 2009) uses a similar framework. Hawkins et al. (2007) also used an input-output model in combination with materials data to construct a mixed unit model for the material flow analysis of lead and cadmium in the US.

2.1.8 Hybrid life cycle assessment

While LCA is traditionally performed as a process based analysis (bottom up) several authors pointed to the fact that this approach leads to cut-off errors since information is often lacking on service inputs and upstream processes. This has resulted in several methods to combine process based data with input-output data to gain both specific information in one area (process based part of inventory) while ensuring completeness in terms of system boundaries (using input-output data). An overview of different types of hybrid LCA can be found in Suh et al. (2004). The method has been applied in numerous studies (Marheineke et al. 1998; Nakamura and Kondo 2002; Solli et al. 2006; Stromman et al. 2006; Michelsen et al. 2008; Peters 2008c; Lenzen 2009; Peters et al. 2010a).

The difference between mixed unit IOA and some of the different types of hybrid LCA is not clearly evident, but one distinction could be made with regards to how data is collected and inventories constructed. The aim of hybrid LCAs will often be to gain more insights into the environmental impacts of one particular production system, while mixed-unit analyses may be more focused on the aggregated policy level. Generally, if constructed as a bottom-up procedure it may fall in the hybrid LCA category, while top-down models could be seen as mixed unit IOA. This distinction is, however, not of major importance.

2.1.9 Some comments on the ecological footprint

Since the introduction of the term ecological footprint (Rees 1992) this has often been referred to as a method. The ecological footprint is not a method, but an aggregated indicator intended to be a proxy of environmental impact by estimating a hypothetical area (footprint) needed to support the consumption of products and services, or at the aggregate, countries. Its calculation can in principle be based on any method for calculating embodied emissions. Its popularity is clearly based on communicational purposes; having an area based approach enables comparison with total area of the globe to support statements like “we currently consume x times more than earth can supply” or similar. Within the ecological footprint network there is increasing recognition that using LCA, IOA, or related methods is an efficient and consistent way to estimate ecological footprints (Wackernagel 2009).

2.2 The selection of a method

To select a method requires a clear statement of the research question. For a product-level carbon footprint LCA may be the best first choice (e.g., compare two types of chairs for use in an office). To analyze the operations of a company the GHG Protocol may be a good first choice (WRI and WBCSD 2004), although one would need to combine with other methods to successfully estimate scope 3 emissions. To compare different cities, one may be interested in the city specific guidelines (ICLEI 2009). At the national level, IOA may be more desirable. And in some cases, a combination of a variety of methods may be an option.

Our short overview of existing methods for calculating embodied emissions shows that there is a comprehensive toolbox for this type of analysis. The choice of preferred method depends on what types of question under investigation, as well as data requirements and availability. Most method reviews generally come to the same conclusion: multi-regional input-output analysis acts as a robust starting point for most studies and at the national level is the desired method (Minx et al. 2008c; Blanc et al. 2009; Wiedmann et al. 2009)

The SKEP funded EIPOT-report (Wiedmann et al. 2009) provides a nice figure showing how methods span from very detailed process-based LCA to aggregated MRIO analyses and relates it to policy relevance and information needs (Figure 1). The methods of physical input-output and MFA are not included in the figure, but would be placed at the meso level. The figure acts as a good guide to which method the analyst may consider first. If one later identifies the need for more detailed analysis in particular areas, the models can often be expanded using hybrid methods. The continuously expanding toolbox for environmental systems analysis gives improved possibilities for wide system boundaries, specificity, and dynamics.

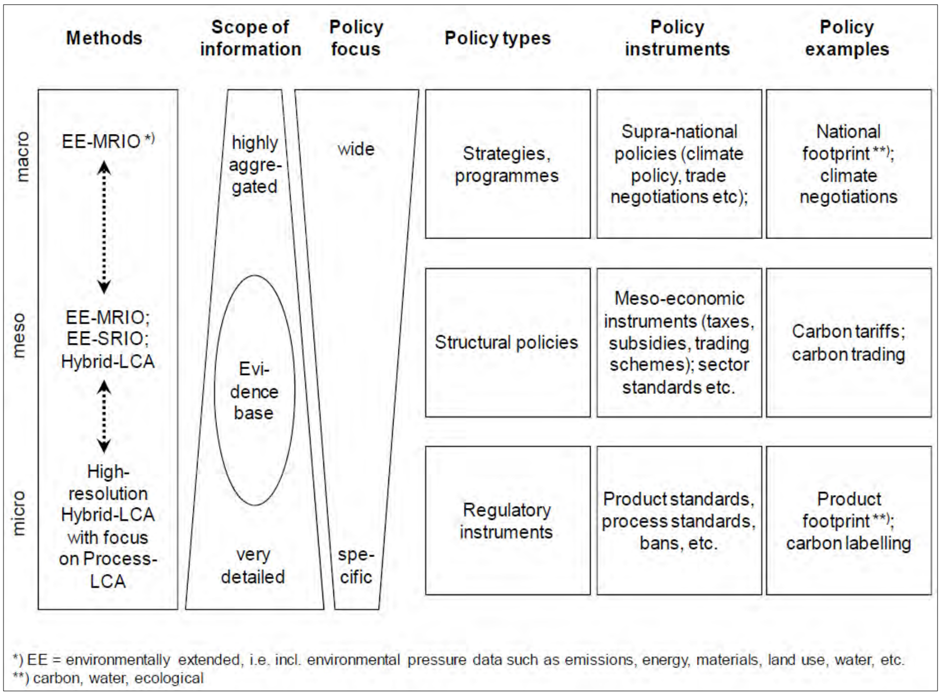

Figure 1: An overview of methods and their application (from the EIPOT project).

In this report we will take multi-regional input-output analysis (MRIO) as the default method as we are estimating national level carbon footprints and embodied flows. We expand on the reasons for this choice in the following sections and chapters.

2.3 Multi-regional input-output analysis (MRIOA)

It is perhaps not surprising that so many method reviews point to MRIOA as the favoured method for carbon footprint analysis at the national level. IOA, and more generally MRIOA, is built on the need to understand connections between sectors and enumerate global supply chains. Its application to environmental problems was a natural extension (Leontief 1970; Carter 1974).

For national level emission estimates most studies recommend MRIOA, and we will use MRIOA in this report. In this section we will first give a detailed technical description on the method and second, we use modifications of the standard MRIO model to show various strengths and weaknesses of other methods. Readers not interested in the mathematical details can skip to section 2.4.

2.3.1 Multi-region Input-Output Analysis (MRIOA)

We use environmentally extended input-output analysis to estimate the emissions from the production of exported and imported products (Leontief 1970; Wiedmann et al. 2007; Wiedmann 2009b, a). Throughout this document superscripts denote region indices and subscripts sector indices. Let C^r_i be the total greenhouse gas emissions in each economic sector *i* and region *r*, hence $\Sigma_i C^r_i$ represents the production-based territorial emissions in region *r*. Since we are performing an analysis based on economic data we use emission estimates consistent with concepts, definitions and classifications provided by the System of National Accounts (Peters 2008b).

To reallocate emissions from producing to consuming sectors requires an enumeration of the supply chain (Leontief 1970). In each region *r* products are produced for intermediate (industry) and final demand. Intermediate production is represented by an input-output table Z^r_{ij} which shows the domestic and import purchases in region *r* of sector *i* by sector *j*. The columns of the IOT depict purchases from other economic sectors, while the rows depict sales to other economic sectors. Likewise, the final demand, y^r_i, represents the domestic and imported purchases by the final consumers; households, government, and capital investments. We treat exports from region *r* to *s* as a separate final demand, e^{rs}_i. Imports to region *r* are denoted by m^r.

Summing over intermediate and final demand gives the total domestic output in each region

$$\mathbf{x}^r = \mathbf{Z}^r + \mathbf{y}^r + \textstyle\sum_s \mathbf{e}^{rs} - \boldsymbol{m}^r \tag{1}$$

This output balance contains imports in Z^r and y^r, which is why they are deducted at the end. To analyze domestic activities for a given final demand, the imports are usually removed leading to an output equation containing only domestic quantities,

$$\mathbf{x}^r = \mathbf{Z}^{rr} + \mathbf{y}^{rr} + \textstyle\sum_s \mathbf{e}^{rs} \tag{2}$$

where imports to *r* are

$$\mathbf{m}^r = \textstyle\sum_s \mathbf{Z}^{rs} + \sum_s \mathbf{y}^{rs} \tag{3}$$

To determine the output for an arbitrary final demand Leontief assumed fixed production ratios (Leontief 1970), leading to the coefficients matrix in each economy,

$$A^{rr}_{ij} = Z^{rr}_{ij}/x^r_j \tag{4}$$

where A^{rr}_{ij} represents the industry demand necessary to produce one unit of output in each region.

Standard IOA determines the output, *x*, for a given final demand, *y* or *e*. The resulting output can then be used to calculate the emissions using sectoral emission intensities. The *direct* emission intensity in each sector and each region is given by

$$F^r_{ij} = C^r_{ij}/x^r_j \tag{5}$$

Thus, the total direct and indirect *domestic* emissions to produce a unit final demand on each sector is, in matrix form (Leontief 1970),

$$\mathbf{G}^r = \mathbf{F}^{r\prime}(\mathbf{I} - \mathbf{A}^{rr})^{-1} \tag{6}$$

where the prime represents a matrix transpose and G^r_i represents the total direct and indirect (supply chain) emissions to produce one unit of final demand in sector i. Thus expression only considers the supply chain in region r and not the supply chain in other regions. Depending on the research question, there are two main treatments of the international supply chain (Peters 2008b). These are now discussed in turn.

Emissions embodied in bilateral trade (EEBT)

This method gives a "trade perspective" of emissions. Given bilateral trade data, e^{rs}, it is possible to determine the total direct and indirect emissions in region r to produce the products which are exported to region s,

$$\mathbf{C}^{rs} = \mathbf{F}^r(\mathbf{I} - \mathbf{A}^{rr})^{-1}\mathbf{e}^{rs} \tag{7}$$

The total emissions in region r to produce exports is (emissions embodied in exports)

$$\mathbf{C}^{r\bullet} = \textstyle\sum_s \mathbf{C}^{rs} \tag{8}$$

and by reversing the summation the total emissions in foreign countries to produce imports is (emissions embodied in imports),

$$\mathbf{C}^{\bullet r} = \textstyle\sum_s \mathbf{C}^{sr} \tag{9}$$

This methodology uses the technology of the producing country to estimate the emissions embodied in imports which overcomes the weaknesses of many earlier studies which assumes imports are produced with domestic technology (Wiedmann et al. 2007; Wiedmann 2009b).

The EEBT method considers the *total* exports from a country and therefore only enumerates the domestic supply chain. As an example, this method addresses the question "what are the *domestic emissions* in China to produce the products which are exported from China?" (Weber et al. 2008; Minx et al. 2009). To answer the question "what are the total *global emissions* to produce the products which are exported from China" then an extension of the described methodology is needed as the global supply chain must be enumerated for each sector (Peters 2008b).

Multi-Region Input-Output (MRIO)

This method gives a "consumption perspective" of emissions. To expand our analysis from the domestic to the global supply chain the bilateral trade data e^{rs} needs to be decomposed into exports from region r to s into intermediate and final consumption (Peters 2008b),

$$\mathbf{e}^{rs} = \mathbf{Z}^{rs} + \mathbf{y}^{rs} \tag{10}$$

As the exports from one region are imports for another region, we can expand the technology description of Equation (4) for production in region *s* through explicit consideration of the inputs from industries in region *r*,

$$\mathbf{Z}^{rs} = \mathbf{A}^{rs}\mathbf{x}^{s} \tag{11}$$

where x^s is the output of region *s* and A^{rs} describes how industries in region *s* use imports from region *r*. By substitution of the decomposed exports into Equation (3) the standard MRIO model results,

$$\mathbf{x}^{r} = \mathbf{A}^{rr}\mathbf{x}^{r} + \mathbf{y}^{rr} + \sum_{s\neq r}\mathbf{A}^{sr}\mathbf{x}^{s} + \sum_{s\neq r}\mathbf{y}^{rs} \tag{12}$$

By considering the equation in each region the matrix form is obtained:

$$\begin{pmatrix} \mathbf{x}^1 \\ \mathbf{x}^2 \\ \mathbf{x}^3 \\ \vdots \\ \mathbf{x}^m \end{pmatrix} = \begin{pmatrix} \mathbf{A}^{11} & \mathbf{A}^{12} & \mathbf{A}^{13} & \cdots & \mathbf{A}^{1m} \\ \mathbf{A}^{21} & \mathbf{A}^{22} & \mathbf{A}^{23} & \cdots & \mathbf{A}^{2m} \\ \mathbf{A}^{31} & \mathbf{A}^{32} & \mathbf{A}^{33} & \ddots & \mathbf{A}^{3m} \\ \vdots & \vdots & \vdots & & \vdots \\ \mathbf{A}^{m1} & \mathbf{A}^{m2} & \mathbf{A}^{m3} & \cdots & \mathbf{A}^{mm} \end{pmatrix} \begin{pmatrix} \mathbf{x}^1 \\ \mathbf{x}^2 \\ \mathbf{x}^3 \\ \vdots \\ \mathbf{x}^m \end{pmatrix} + \begin{pmatrix} \sum_r \mathbf{y}^{1r} \\ \sum_r \mathbf{y}^{2r} \\ \sum_r \mathbf{y}^{3r} \\ \vdots \\ \sum_r \mathbf{y}^{mr} \end{pmatrix} \tag{13}$$

where each block matrix represents the interactions between industries in each country. The off-diagonal matrix blocks show the trade between regions, while matrix blocks on the diagonal depict domestic production activities. The final demand in each region *r* is given by (households, governments, and capital),

$$\mathbf{y}^{r} = \begin{pmatrix} \mathbf{y}^{1r} \\ \mathbf{y}^{2r} \\ \mathbf{y}^{3r} \\ \vdots \\ \mathbf{y}^{mr} \end{pmatrix} \tag{14}$$

where y^{rr} is the domestic final demand of region *r*. The MRIO model endogenously calculates not only domestic output, but also the output in all other regions resulting from international trade in intermediate products. The block matrix form of the MRIO framework is analogous to standard IOA, where in the standard IOA the matrix elements represents sectors, while in the MRIO the block matrices represent regions. Each region is composed of many sectors. In general, each region can have a different number of industries, thus the diagonal matrices are always square while the off-diagonal matrices can be rectangular.

International Transport

International trade in international transport services is poorly represented in global datasets (Narayanan and Walmsley 2008). This is compounded when databases incorrectly allocate the emissions from international transport to countries (that is, they do not follow the system of national accounts as required for economic studies). International transport is poorly treated in the GTAP database (Peters et al. 2010b). In this report, we allocated international transport, where possible (see below), according to the system of national accounts. We have further reallocated international transport from producing to consuming sectors when estimating the carbon footprint (Peters et al. 2010b). In the GTAP database, international transport is either treated in the bilateral trade statistics (straightforward treatment) or via an international transport pool (for transport between *r* and *s* with transport provided by region *t*). In the case of the transport pool, the export of international transport services go to an international transport pool and users of international transport services buy directly from the transport pool. Thus, the link between the transport provider and user is not available. We estimate these bilateral linkages using proportion distribution in supply and use of the transport pool (Peters et al. 2010b).

Comparison of the EEBT and MRIO methods

Both the EEBT and MRIO methods produce the same global emissions, but the allocation between countries is different depending on the level of trade in intermediate products (see Chapter 1).

For studies on national emission inventories, policy makers are more likely to be interested in domestic emissions and total exports which suites the EEBT method (Peters and Hertwich 2008a). This approach considers domestic supply chains only and answer questions such as "how much of *Chinese* emissions are from the production of exported products including the domestic supply chain". This approach gives a trade perspective of embodied emissions.

The MRIO method enumerates global supply chains and answers questions like "what are the global emissions to produce the products consumed in a given country". The method considers imports to final consumers exogenously (Equation 14) with trade in intermediate consumption calculated endogenously (the off-diagonal elements of the matrix in Equation 13).

Consumption can be divided into intermediate (industry) and final (household, government, and capital) consumption. The intermediate consumption is the large block matrix in Equation 13 and the final consumption is the final demand on the far right hand side. The MRIO method enumerates the global production system and only considers final consumption to avoid double counting of intermediate consumption. The EEBT method considers the total trade from each region and therefore consumption includes both intermediate and final consumption (see Equation 10).

Both methods are used in this report. The consumption perspective uses the MRIO model, while the trade perspective uses the EEBT model. These methods will be referred to at several times throughout the report.

2.3.2 Model and data used in this report

The economic data for the EEBT and MRIO methods is based on the Global Trade Analysis Project (GTAP) database (Narayanan and Walmsley 2008). We use three versions all with 57 sectors in each region but with 66 regions for the year 1997 (GTAP version 5), 87 regions for 2001 (version 6), and 112 regions for 2004 (version 7.1). Detailed documentation of the GTAP databases can be found via www.gtap.agecon.purdue.edu. The manipulations to use the GTAP database for MRIO modelling and a variety of applications can be found elsewhere (Peters 2008b; Peters and Hertwich 2008a; Hertwich and Peters 2009; Peters et al. 2010b).

The CO_2 emissions are primarily based on GTAP data using the IPCC Tier 1 approach (Narayanan and Walmsley 2008), but supplemented with additional sources to cover more accurate data, cement emissions, and flaring (Boden et al. 2009). Comparisons of the GTAP CO_2 data and other national data sources show considerable variation for several reasons (Peters and Hertwich 2008a). First, the system boundary for the energy statistics differs from the economic data (Peters and Hertwich 2008b). Second, the GTAP performs various manipulations on energy data for consistency with other data. Finally, region specific emission factors and fuel contents are not used. When national specific emissions data allocated to economic activities were available we overwrote the GTAP data (Australia (ABS 2001), China (Peters et al. 2006), Japan (Nansai et al. 2003), USA (Cicas et al. 2006), and EU countries (Eurostat 2009)).

2.3.3 Uncertainty

Several authors have discussed the uncertainties in environmentally-extended IOA (Bullard and Sebald 1988; Jackson and West 1989; Lenzen 2001; Hendrickson et al. 2005; Williams et al. 2009). Uncertainty enters into our results in two keys ways: 1) the uncertainty of the input data and 2) errors in the reallocation from producers to consumers using IOA.

Despite large potential uncertainties, there is not a strong tradition of performing uncertainty analysis in IOA due to the relative lack of information on uncertainty distributions (Lenzen 2001). To circumvent the lack of uncertainty data, analysts often assume uncertainty distributions (Lenzen et al. 2010). Some studies have employed Monte-Carlo analysis to estimate uncertainties (Bullard and Sebald 1988; Lenzen 2001; Lenzen et al. 2010). These studies generally find that errors tend to cancel due to the summation and multiplication of many numbers (Peters 2007a). Thus, despite high uncertainty in individual data points, the overall result may still have relatively low uncertainty. Analysts often resort to qualitative measures of uncertainty (Hertwich and Peters 2009; Lenzen and Peters 2010) and this is often appropriate for a large dataset where the accuracy of an individual data point may be less important than the accuracy of the resulting calculation (Jensen 1980).

Additional uncertainties arise due to the structure of the IO model. Leontief assumed that the inputs are proportional to outputs (Leontief 1970). This means that irrespective of the size of the purchase, the supply chain will be identical. When dealing with average sector outputs and historic attribution, this linearity should have little impact on the results. Since we consider aggregated and large flows, this model assumption has only a small affect on the results.

Given that the uncertainty in the final result is most important factor in IOA, a robust qualitative measure of uncertainty is how our calculations compare with independent studies. Throughout the review chapter and results chapter we compare with a variety of Nordic studies. More generally across a wider range of countries, the results of our model is consistent though differences do exist (Ahmad and Wyckoff 2003; Wiedmann et al. 2007; Peters and Hertwich 2008a; Hertwich and Peters 2009; Nakano et al. 2009; Wiedmann 2009b; Davis and Caldeira 2010). As we discuss in the report, differences often relate to different definitions and when consistent definitions are used results tend to converge.

When interpreting our results, it is important to note that the uncertainty increases as we disaggregate the data and then reduces through averaging of errors as we aggregate the results again. Likewise, averaging of errors reduces the uncertainty for groups of countries (sectors) compared to individual countries (sectors), Figure 2. Since this is a top down analysis, the global emissions are known, the uncertainties are increased when those emissions are allocated to regions and sectors.

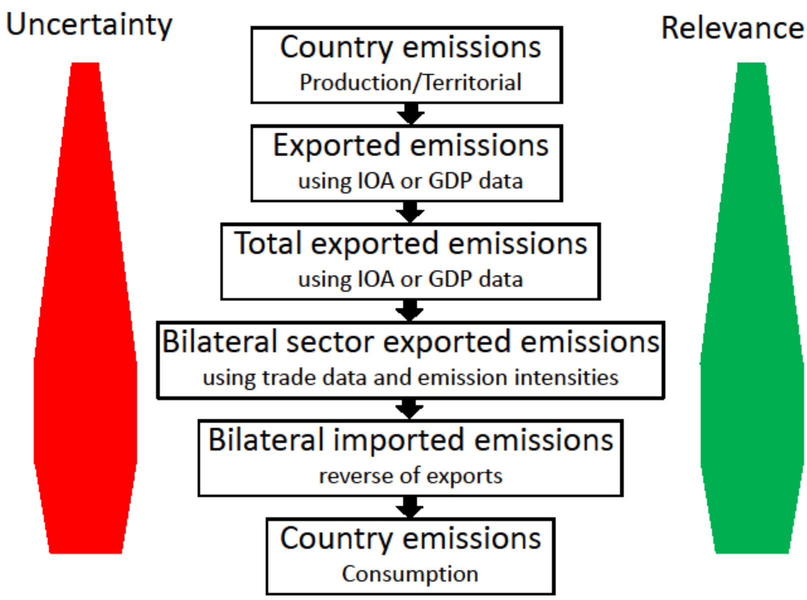

Figure 2: The propogation of uncertainty when reallocating emissions from production to consumption using IOA.

2.4 Using an MRIO model to assess other methods

The MRIO model has broad coverage and most methods cover a subset of an MRIO model. Based on this, we can use MRIOA to replicate other methods. In this section we will use the most detailed version of the GTAP database (GTAP 7.1 for 2004) to show how various assumptions can lead to incorrect estimates of the carbon footprint. We cover the following assumptions:

- Assuming imports are produced with domestic technologies
- Assuming that data is collected for only a part of the supply-chain to replicate what is known as “cut-off” error
- Inclusion of one layer of imports (uni-directional trade)
- MRIO with aggregated sectors
- MRIO with limited country coverage

For simplicity, we only perform the analysis using CO_2 emissions and we do not include emissions from the international transport pool (as in the Results chapter).

2.4.1 Assuming imports are produced with domestic technologies

A common assumption used to estimate carbon footprints is that imports are produced with domestic technologies. This greatly reduces data requirements as only information is needed for one economy. However, if that economy is a poor representation of its importing partners, then the carbon footprint estimate can be misleading. Table 1 shows the large variation in the carbon footprint when using a full global MRIO and when applying the Domestic Technology Assumption (DTA). These differences have been reported in many studies (e.g., Lenzen et al. 2004; Peters and Hertwich 2006c; Wiedmann et al. 2007; Andrew et al. 2009). Studies generally show that the differences are largest for economies that are small, specialized, dependent on imports, or have a clean energy supply.

The DTA underestimates the carbon footprint in all the Nordic countries; this is because the Nordic countries have a cleaner production system (energy supply) than the weighted average of their trading partners and are small and specialized economies. Perhaps specific to the GTAP database are notable outliers, such as Finland that has a huge increase in the carbon footprint using the DTA (c.f., Andrew et al. 2009). In the GTAP database, this happens in several countries due to a high emission intensity of gas production in countries that produce very little gas (Andrew et al. 2009). Through the Leontief inverse, outlier emission intensity affects all emission intensities that have gas in the supply chain. We have applied a "quick fix" by assuming no gas is produced in Finland (bracketed number). While this particular example may seem like a data issue, it arises since the DTA amplifies a seemingly insignificant outlier by scaling that outlier to match the level of imports. We have found this issue in several countries and sectors (c.f., Andrew et al. 2009).

While the DTA may seem like a reasonable assumption at the national level, it is not so obvious at the sector level. Table 1 also shows the DTA for the carbon footprint in two sectors. Apart from Sweden, Nordic countries do not produce motor vehicles in large quantities and thus it is unlikely that the national IOT gives a reasonable approximation of the global motor vehicle supply chain. The DTA considerably underestimates the emissions to produce a motor vehicle in the Nordic countries. Services, on the other hand, are well developed in the Nordic countries, though the DTA still has a large underestimate of the carbon footprint as it has a poor representation of imported inputs into the services sectors.

Taken together these results highlight that for the Nordic countries assuming imported are produced with domestic technologies is an inadequate assumption. It is sometimes claimed that the DTA is an appropriate assumption in some research questions (such as, "what are the emissions *avoided* by importing products"). In this case, the DTA is in fact quite similar to "no trade" assumptions made in many economic models. Our results here suggest that these assumptions, even if theoretically valid, may not be empirically rigorous particularly in disaggregated models. At a reasonable level of sector detail in small economies, sectors will be encountered that do not really exist. For example, could the Nordic countries support the current level and structure of food consumption if all agriculture and food production occurred only within the Nordic countries? If the answer to this or similar questions is “no”, then it is unlikely that the existing economic structure can be used to produce those products domestically at the necessary levels. Consequently, “no trade” or DTA assumptions, no matter how theoretically justified, will not give an empirically rigorous answer. Thus, the application of a DTA needs a strong justification, both theoretically *and* empirically.

Table 1: A comparison of a full MRIO calculation and using the DTA for the total carbon footprint, motor vehicle carbon footprint, and government services carbon footprint.

Total carbon footprint

	Production (Mt CO_2)	MRIO Consumption (Mt CO_2)	DTA Consumption (Mt CO_2)	Difference (%)
Denmark	81	95	75	-21
Finland	68	79	440 (72)	457 (-8)
Norway	56	66	49	-26
Sweden	63	94	59	-38
	268	**334**	**183**	**-45**

Motor vehicles

	MRIO Consumption (Mt CO_2)	DTA Consumption (Mt CO_2)	Difference (%)
Denmark	3.1	0.5	-84
Finland	1.6	1.1	-34
Norway	2.0	1.1	-45
Sweden	5.3	1.9	-64
	12.0	**4.6**	**-62**

Services

	MRIO Consumption (Mt CO_2)	DTA Consumption (Mt CO_2)	Difference (%)
Denmark	7.8	6.2	-21
Finland	6.9	6.3	-8
Norway	4.3	3.0	-30
Sweden	4.2	2.7	-36
	23.2	**18.2**	**-22**

2.4.2 “Cut-off” error

Many bottom up methods, such as a process-based LCA, need to collect data on each layer (or tier) of the supply chain. In process-based LCA, the analyst collects data for a given process and continually moves down the production line or supply chain until they believe they have covered an adequate share of emissions. Often an LCA database is used to estimate upstream emissions. In addition service inputs are often poorly covered. The difference between the estimated emissions with a limited supply chain and the hypothetical case where the entire supply chain is collected is known as “cut-off” error (Lenzen 2001). In the case of a carbon footprint of a country, this cut-off error will occur in all sectors of the economy and may be significant at the national level.

Using IOA, or matrix-based LCA calculations, it is possible to estimate the "cut-off" error by performing the calculations for each layer of the supply chain individually (Lenzen 2001; Peters and Hertwich 2006a). Figure 3 shows a tier-wise expansion of the carbon footprint of the Nordic countries using the full MRIO model. The zero-th tier refers to the direct emissions in the factory plant, that is, there is no supply chain. Each new tier adds a new layer in the supply chain. The figure shows it takes around five-tiers to get 90% of the carbon footprint and around ten-tiers there is almost full coverage of the carbon footprint. This share is roughly constant for all the Nordic countries. For LCA-structured systems the number of tiers to reach 90% may actually be much higher (Stromman et al. 2006).

An earlier report on embodied emissions by Statistics Norway (Straumann 2003) only considered direct emissions and hence essentially considered only the zero-th tier in the tier-wise expansion (applied in Bruvoll and Fæhn 2006; Fæhn and Bruvoll 2009). Though this was only applied to imports, the implication of this assumption can be clearly seen in Figure 3. At the sector level this assumption would mean, for example, there was no electricity used to produce aluminium or a car factory did not have any inputs into production. In the case of motor vehicle production in Japan, Figure 3 shows that almost none of the emissions occur directly at the factory manufacturing the motor vehicle, but they occur in upstream processes (such as electricity to power the factory or metal to produce the engine and so on). It takes almost 10 tiers to capture 90% of the emissions to produce a motor vehicle in Japan.

These results show that in a global study cut-off errors can be significant if using a bottom-up approach. Since a bottom up study may need to perform a sector analysis over hundreds, if not thousands, of products, the human effort required collect the data is overwhelming. For a carbon footprint at the national level, to avoid compounding "cut-off" errors over numerous sectors, it is unlikely that a purely bottom-up method will be sufficient unless supplemented with other data in a hybrid approach.

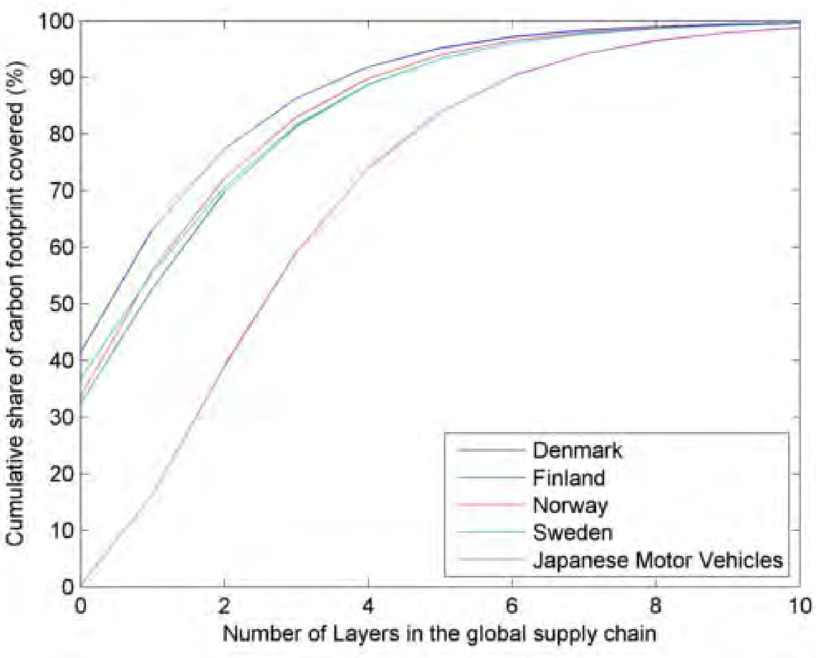

Figure 3: A tier-wise expansion of the carbon footprint of the Nordic countries using the full MRIO model.

2.4.3 Inclusion of one layer of imports (uni-directional trade)

Analysts that have constructed their own MRIO have often resorted to what is known as the "uni-directional trade assumption" which includes the trade between the country under analysis and the import partner, but not trade between the import partners themselves (e.g., Finland's trade with Russia and China, but Russia and China trade is not reported in the model). This assumption requires more data then the DTA, but less than a full MRIO. This type of model was tested in a study on Denmark (Lenzen et al. 2004), used in an early set of studies on Norway (Peters and Hertwich 2006b; Peters and Hertwich 2006d, c), and has since been tested for a variety of countries (Andrew et al. 2009).

Table 2 shows that for the Nordic countries, assuming unidirectional trade underestimates emissions compared to a full MRIO. In the upper table, where a full uni-directional trade assumption is used, an underestimate was expected as we did not represent the trade links between third countries at all. In the lower table, we represent trade between the third countries using the DTA in the country producing the imports. In this case the estimates are more accurate, except for Norway. These results show that even though the unidirectional trade approach can improve the accuracy of the estimates, it still is not sufficient to guarantee accuracy. The accuracy of a uni-directional model is not known without doing a full calculation as shown for the case of Norway. However, based on the calculations here, it is better to use a uni-direction model in conjunction with a DTA.

The uni-directional model is often erroneously compared to the EEBT method discussion earlier. The uni-directional model (with or without the DTA) is an approximation to a full MRIO model. The EEBT method does not attempt to approximate a full MRIO, but rather asks a different research question. See the discussions in Section 2.3.

Table 2: The errors introduced by assuming uni-directional trade (alone) and by assuming uni-directional trade with a DTA.

Total carbon footprint				
	Production (Mt CO_2)	MRIO Consumption (Mt CO_2)	Uni Consumption (Mt CO_2)	Difference (%)
Denmark	81	95	82	-14
Finland	68	79	70	-12
Norway	56	66	54	-19
Sweden	63	94	77	-18
	268	**334**	**283**	**-15**

Total carbon footprint				
	Production (Mt CO_2)	MRIO Consumption (Mt CO_2)	Uni+DTA Consumption (Mt CO_2)	Difference (%)
Denmark	81	95	96	1
Finland	68	79	74	-6
Norway	56	66	87	31
Sweden	63	94	91	-3
	268	**334**	**349**	**4**

2.4.4 MRIO with aggregated sectors

A key question when constructing any IOT is how many sectors to include. Some countries publish tables with 20–30 sectors, others up to 500 sectors (such as Japan and the USA). Most Nordic countries publish tables with 60 sectors, but internally statistical office may have more detailed tables. Some have argued that sector detail is very important (Lenzen 2001; Williams et al. 2009), while others claim that sector detail is not as important in a global model (Su et al. 2010). The GTAP-MRIO has “only” 57 sectors in each country, while some new datasets will have considerably more detail (e.g., EXIOPOL) and others less (e.g., WIOD).

To test the importance of sector aggregation, we compared the full MRIO model with 57 sectors in each region with an aggregated MRIO model with 8 sectors in each region. Table 3 shows that the difference in the carbon footprint for the Nordic countries is small. A comparison over all countries in the GTAP database shows that the maximum error is 17% in Cambodia and the most significant error in an industrialized country is Australia with a 9% error. Thus, our findings suggest that for a *national level carbon footprint* the MRIOT probably does not need to a high level of sector detail and the current publically available Nordic IOT’s are probably sufficient for most applications (~60 sectors). With our MRIO model it is not possible to determine what the error would be going from a hypothetic 500 sectors in each region to the 57 sectors we have. Errors at the sector level will be higher, and to perform specific sector analysis (such as on the global supply chain of motor vehicles) more sector detail may be required. Thus, as long as the primarily objective is the aggregated carbon footprint at the national level, only a modest level of sector detail is necessary.

Table 3: The carbon footprint of the Nordic countries with different levels of sector aggregation.

Total carbon footprint				
	Production (Mt CO_2)	MRIO Consumption (Mt CO_2)	8-sector Consumption (Mt CO_2)	Difference (%)
Denmark	81	95	94	-1
Finland	68	79	80	1
Norway	56	66	69	3
Sweden	63	94	96	2
	268	**334**	**339**	**1**

2.4.5 MRIO with limited country coverage

In our analysis we use the GTAP database with 112 countries and regions. Analysts who construct country specific MRIOT's, generally include less countries (of the order of five or ten). A recent paper used the GTAP-MRIO model to compare the results with different levels of regional detail (Andrew et al. 2009), ranging from 2 regions, to 3, to 4, and so on up until 87 regions (using the GTAP6 database). The results show that, assuming the correct countries are chosen, the five to ten most important trading partners are probably sufficient to include in an MRIO. Since the Nordic countries will generally include similar countries in the MRIO (e.g., Russia, Germany, China, USA, etc) then it is possible to have a focused MRIOT for the Nordic countries that has around 10 regions explicitly represented. It is also possible to extend a ten region detailed MRIO to around 100 regions using existing datasets such as the GTAP database.

2.5 Summary of Methods

In this Chapter we have provided an overview of the different methods that can be used to perform a carbon footprint analysis, described in detail the top-down multi-regional input-output model to be used in this report, and used the MRIO model to highlight important features required to get a realistic carbon footprint estimate.

Before selecting the method to use in carbon footprint analysis it is important to have a clearly stated research question. If the research question is about the carbon footprint of a product, then a process-based or hybrid LCA would most likely be the most appropriate method. If the research question is about the carbon footprint of a country or group of countries, then the most appropriate method is likely to be a top-down multi-regional input-output approach. This project is concerned carbon footprints and estimates of exported and imported emissions at the national level. Thus, a top-down multi-regional model is most widely recommended.

We described the basic structure of a multi-regional input-output model and highlight two different approaches that can be taken. One approach focuses on the traditional "carbon footprint" concept and estimates the global emissions to produce the goods and services which go to final consumption in a given country. The other approach focuses on bilateral trade flows and considers the territorial emissions in each country to export or import goods and services. The global emissions are the same in both methods, but they use a different method of allocation for international trade in intermediate consumption (industry consumption). Neither method is correct or incorrect, but they each answer a distinct research question. Both methods will be used throughout this report.

Finally, we used the full MRIO model to consider various approximations to the MRIO model to essentially "mimic" different methods to estimate the carbon footprint. We found that the inclusion of the supply chain is very important for accurate estimates, particularly at the sector level. This highlights problems with using purely bottom-up methods in national carbon footprint estimates. We considered various approximations to the MRIO model: assuming imports are produced with domestic technologies is inadequate in most cases and only a modest level of sector and regional detail is needed for national carbon footprint estimates.

While there is a perception that MRIO models are simply too data intensive for practical use, the calculations in this chapter hopefully show otherwise. For studies focused on the Nordic countries, it is probably sufficient to have a Nordic specific (or European specific) MRIO. For national level carbon footprint estimates, the existing 60 sectors in the IOTs and NAMEAs should be sufficient and an MRIO with 10 regions may be adequate. Some existing projects (EXIOPOL and WIOD) are building specific European focussed MRIO models with either a high level of sector detail (EXIOPOL) or in time-series (WIOD). In this report we use the already existing GTAP database and other analysts have used the already existing OCED database. Thus, at least for the Nordic countries, data availability should not be seen as an issue. The methods and data already exist, and will improve over time, it is just a case of a concerted effort to construct and maintain a Nordic or European focussed MRIOT.

3. Literature Review

3.1 Overview of the literature

There have been numerous studies of carbon footprints emissions embodied in trade in the research community the last decade (Wiedmann et al. 2007; Wiedmann 2009b). Most of the studies tend to focus on individual countries and a variety of methods have been used, though IOA or MRIOA are by far the most common. Other than the Nordic countries, we will not consider individual country studies here.

In recent years there have been a number of global studies. These studies usually cover all global emissions and explicitly represent most key countries (including the Nordic countries). The advantage of the global studies is that they allow a consistent comparison between the carbon footprints in different countries. Unlike with individual country studies, a global study has consistent definitions, methods, and data quality in all the countries covered. The most common global studies are from the OECD for the years 1995, 2000, and soon 2005 (Ahmad and Wyckoff 2003; Nakano et al. 2009). The OECD studies have not yet been through a peer review process and, while they use MRIO, the underlying methods are unconventional. There have been several studies using the GTAP database covering 2001 (Peters and Hertwich 2008a; Hertwich and Peters 2009) and 2004 (Davis and Caldeira 2010). Many new studies using the GTAP database are likely to appear in the near future. During 2011 the next version of the GTAP database will be available for the year 2007 allowing updated carbon footprint estimates.

All the global studies, supported by the many country specific studies, have the same conclusion. There is a large net transfer of embodied emissions from poor to rich countries. In rich countries, consumption-based emissions tend to grow faster than production/territorial-based emissions. Much of the growth in embodied emissions is due to China exporting manufactured products. We will focus on these issues more specifically for the Nordic countries in Chapter 4 and the implications in Chapter 5.

There are also several new database projects ongoing, see Table 4 (Peters et al. 2010b), that will allow more detailed studies for single years or studies in time-series. Thus, the availability of sufficient MRIOTs for consistent country specific studies and country comparisons is not a problem. The only potential issues are the background competence and resources to perform the necessary calculations. Due to the new projects, there is likely to be a prevalence of carbon footprint studies in the coming years. A key challenge will be ensuring comparability and consistency across studies by using well-defined definitions and methods

Table 4: An overview of the main MRIO databases either currently available or soon to be released.

	Years	Regions	Industries	Products	Source data	Price system	Economic Satellites	Environmental Satellites	Release date	Future outlook
AIIOT	1985 1990 1995 2000 2005	9 Asia, USA, ROW	24 78 78 76 76	24 78 78 76 76	Symmetric IOTs	Current (producer's price)	Labour	None	Every five years	Ongoing
GTAP	1992 1995 1997 2001 2004	45 45 66 87 113	50 50 57 57 57	50 50 57 57 57	Symmetric IOTs	Current	Land, labour, capital, resources	Greenhouse gases, energy, land, forestry	Every few years	Ongoing
OECD	1995 2000 2005	31 OECD, 15 non-OECD, ROW	~35 (max 48)	~35 (max 48)	Supply and Use Tables	Current	None	Water and CO_2 (not public)	Every five years	Ongoing
EXIOPOL	2000	27 EU, 16 Others, ROW	124	124	Supply and Use Tables	Current	Labour, capital, rents, royalties	100+	2011	Funding dependent
WIOD	1995-2007 (annual)	27 EU, 13 Others, ROW	35	59	Supply and Use Tables	Current Constant (MER and PPP)	Labour, capital, investments	Energy, emissions to air, water, land use, resource use	2012	Funding dependent
AISHA	1970-2007 (currently from 1990)	~200 countries	Most available (20-500)	Most available (20-500)	Supply and Use Tables	Current Constant	All primary inputs; country-dependent	Greenhouse gases, energy, land, footprints, etc	2012	Funding dependent

3.2 Review of Nordic studies

We have compiled an overview of studies performed on the Nordic countries, and compare them in terms of results, methods, level of peer review, system boundaries, base year, greenhouse gas coverage and exported and imported emissions. We give each study a subjective "quality rank" (QR) from 1 (low) to 5 (high). *The QR is not a ranking of the study or method as such, but merely an indication of the applicability to consistently calculate carbon footprints and emissions embodied in trade at a national level.* Thus, for a different research question the QR may change. There are Nordic studies that employ methods that can be used to calculate embodied emissions at a national level, but the aim of the study has been to compare other product systems, so no national results are available. These studies are not included in the overview.

To ensure comparability we have attempted to compare all the results using consistent definitions. As discussed earlier, we use two definitions: the "carbon footprint" considers the global emissions to produce goods and services which go to final consumption in the given Nordic country (based on the MRIO method), and the "embodied emissions" are the territorial-based emissions in each country to produce goods and services which are exported or imported (based on the EEBT method). A comparison of the different definitions and methods is shown in Table 5.

For some of the studies it has not been possible to fully understand, interpret or recalculate the results into a carbon footprint or embodied emission estimate with consistent definitions as in Table 5. Consequently, not all studies are directly comparable and we state when this is the case. As far as possible we have tried to break down the results from the different studies so that they produce a carbon footprint. For studies that are unclear on the definitions they use, a lower quality rank is used.

None of the reviewed studies present results in a way that makes it possible to establish exported and imported emissions that are consistent. For example, if some of the methods were applied globally, exports and imports would not balance. Comparing import and export numbers across the studies must therefore be done using special care since the studies vary in what is included in imports and exports. For this study results will be presented both in a consumption perspective and trade perspective; see the Chapter 4 for more information. In the plots and summary table the carbon footprint is based on the consumption perspective, while import and export numbers are based on the trade perspective.

Table 5: The definitions and methods with which we compare the different studies.

	Carbon footprint	Export	Import
Trade-oriented (EEBT)	Emissions occurring domestically minus domestic emissions to produce exports plus emissions occurring in trade partners to produce imports. Globally all carbon footprints add to global emissions.	Export emissions include emissions occurring domestically to produce exported gods and services.	Includes emissions occurring domestically in the countries producing the imports (mirror image of the exports). Imports required to produce imports are not transferred beyond bilateral trade partners. There is no double counting and all emissions are allocated so that global imports balance global exports.
Consumption-oriented (MRIO)	Includes all direct and indirect emissions globally required to produce goods and services that go to final consumption. Globally all carbon footprints add up to total emissions. Often this number is compared to the official direct emissions statistics of the country (UNFCCC).	"Exports" include all emissions to produce exports to final consumption in other countries. This includes imports to produce exports, but to avoid double counting only exports to final consumptions are considered in final consumption and exports to industries are included in the model calculations. The exports do not correlate to bilateral trade flows.	"Imports" are the total emissions occurring in other countries to produce the domestic final consumption. The emissions may be embodied in imports from third countries and the imports do not therefore match bilateral trade flows.

In the comparison plots we have tried to ensure comparability between studies by scaling down studies that include a complete GHG to only CO_2 (except the studies where we have exact emissions of each gas). This has been done using the global average distribution of GHGs, so the results are only indicative (but comparable). Generally the plots will have square markers or full lines for CO_2 emissions and dotted lines or triangular markers for GHG emissions measured in CO_2-equivalents using a 100-year Global Warming Potential.

Table 6 (at the end of the chapter) shows a summary of all the studies included in the review. Note that some of the authors have published similar results in other studies, so the list is not exhaustive. The included studies are however more than sufficient to get an overview of the difference between methods, system boundaries and assumptions which is the main purpose of this review.

The results from various global studies are also shown in the table, even though those studies were not in focussed particularly on the Nordic countries. The global studies are based on GTAP (Peters and Hertwich 2008a; Hertwich and Peters 2009; Davis and Caldeira 2010) or the OECD (Nakano et al. 2009). The OECD has examined the carbon footprint of all the Nordic countries except Iceland with a 41 region model of 17 sectors. They use a different data set than the multiregional studies of Hertwich and Peters and Davis and Caldeira. Their model also yields different results in several of the Nordic countries. It is unclear exactly how they perform their calculations, as they use an iterative method to adjust emissions coefficients. This is not necessary with a standard multiregional model. The OECD study receives a lower quality rank, than the other global studies.

The following sections summarize the results from Table 6 and show graphically the differences between the studies. For each country we plot the carbon footprint for all the studies together with UNFCCC and NAMEA emission data. Dashed lines and triangles indicate the original carbon footprint of the study (all included GHGs) and solid lines and squares indicate CO_2 only. For studies that include more GHGs than CO_2, we have downscaled the result by the global CO_2 share from 2004 (72.7%) to make them comparable.

3.2.1 Denmark

The study by Munksgaard and Pedersen (2001) gives the first estimate of Denmark's carbon footprint for a base-year of 1994. They use the domestic technology assumption and hence it is not really possible to assess the emissions from imports in a consistent way. Later, other studies include multiregional data producing a more realistic estimate of emissions embodied in imported products (Lenzen et al. 2004; Hertwich and Peters 2009; Nakano et al. 2009; Davis and Caldeira 2010).

Statistics Denmark estimated the emissions embodied in Danish trade with a multi-regional approach containing major trade partners (Rørmose et al. 2009). To get full country coverage, some nations were based on proxy data (for example, using the technology of China or the USA). The Statistics Denmark study removed emissions from international transport from the NAMEA, and hence from the estimated exported and imported emissions. To make this study comparable with the others, we used the NAMEA CO_2 emissions including international transportation but used the exports and imports from the Rørmose study. This makes the carbon footprint of this study less comparable as there is a large contribution from international shipping. If shipping is included in the exports, the CO_2 footprint is reduced as in Table 14 (Rørmose, personal communication) giving emissions of around 60Mt CO_2. This is quite low compared to this study and the study by Davis and Caldeira, but most notably much lower emissions embodied in imports. The study also examined the effect of various assumptions regarding imported goods and revealed large differences between the DTA, adjusting foreign emissions factors, and full regional technologies models. This is in line with the findings of this study.

The mixed unit input-output database resulting from the EU project FORWAST (FORWAST 2010) is included in the LCA software Simapro (www.pre.nl). We were able to calculate aggregate carbon footprint results (for 2003) from this model and place it in the plot. It uses an average EU27 table for imports. It generally produces lower results than the other studies and this could be due to the assumption of imports being produced using EU27 technology.

A WWF funded study was published for Denmark (Frese et al. 2008). This study gives results more or less in line with the other studies for the same or proximate reference years.

For Denmark the treatment of shipping emissions is important, since emissions within this sector have increased significantly, Figure 9. Some studies have therefore completely removed the shipping emissions (Rørmose). In this study international shipping emissions have been included in the NAMEA's (to be consistent with the system of national accounts), and for the carbon footprint the transport emissions are reallocated to consuming countries.

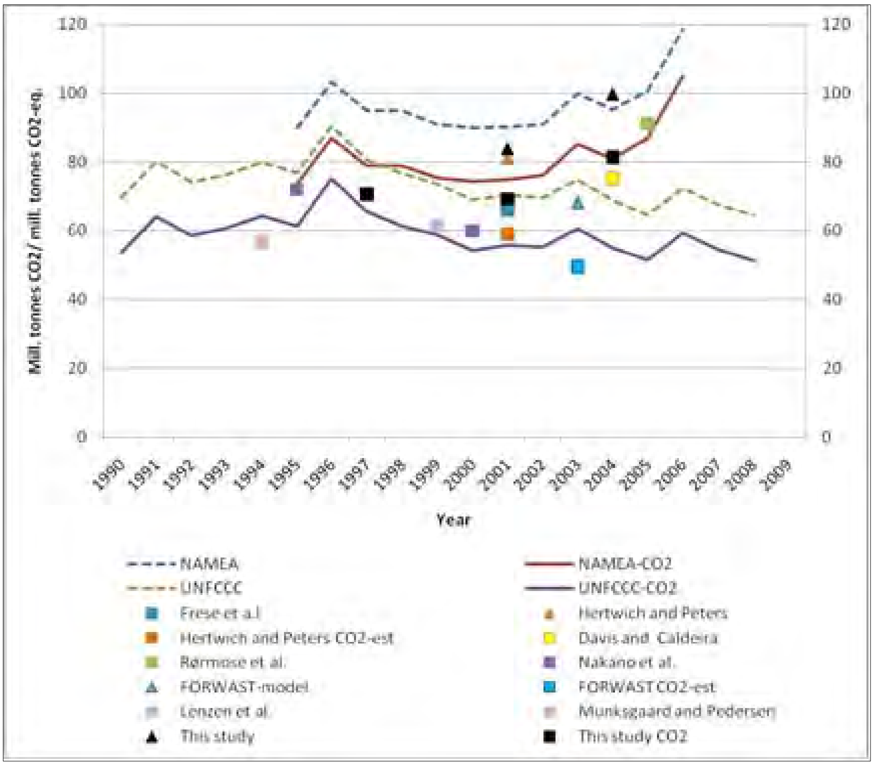

Figure 4: The NAMEA and UNFCCC emissions in Denmark overlaid with various estimates of the carbon footprint.

3.2.2 Finland

Mäenpää and Siikavirta (2007) published one of the first studies with Finnish data for the reference year 1999. They used the DTA for imported products. The results from the study are in line with the OECD study (Nakano et al. 2009) despite the fact that they use very different methods.

Recently the ENVIMAT project (Seppälä et al. 2009) has produced a model of the Finnish economy combining IOA, LCA, MFA and other physical data. This comprehensive model has been made for more uses than just looking at the aggregated emissions embodied in trade on a national level, hence the use of more specific physical data.

One of the explanations why the ENVIMAT model produces lower results than this study and the studies of Hertwich and Peters (2009) and Davis and Caldeira (2010), could be that ENVIMAT to some extent uses bottom-up data for emission calculations. This approach is known to result in cut-offs. Although the model is considered to be of high quality, it receives a lower quality rank in this report, since the criteria is based on applicability to consistently produce results for emissions embodied in trade on a national level.

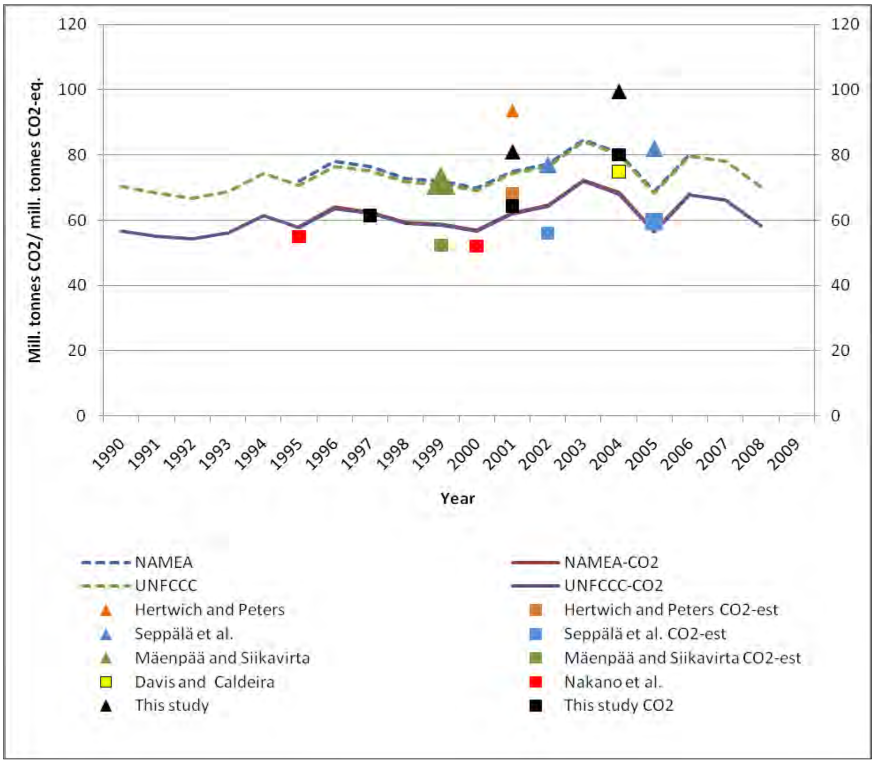

Figure 5: The NAMEA and UNFCCC emissions in Finland overlaid with various estimates of the carbon footprint.

3.2.3 Iceland

No studies on emissions embodied in trade have been identified for Iceland. This may be due to data availability, as statistics like NAMEA's and IOTs are not available for Iceland. Still, like for Norway in 1997 and 2001, we have produced some estimates for Iceland based on the "Rest of EFTA" region in GTAP. We allocate the emissions to Iceland from the "Rest of EFTA" region based on GDP shares. The results for 1997 and 2001 would be based mainly on Norway (Norway was 94% of GDP), while for 2004, it is only Iceland and Liechtenstein included in "Rest of EFTA" and Iceland has 73% of the total GDP. The results for 2004 are probably more reliable, but still uncertain.

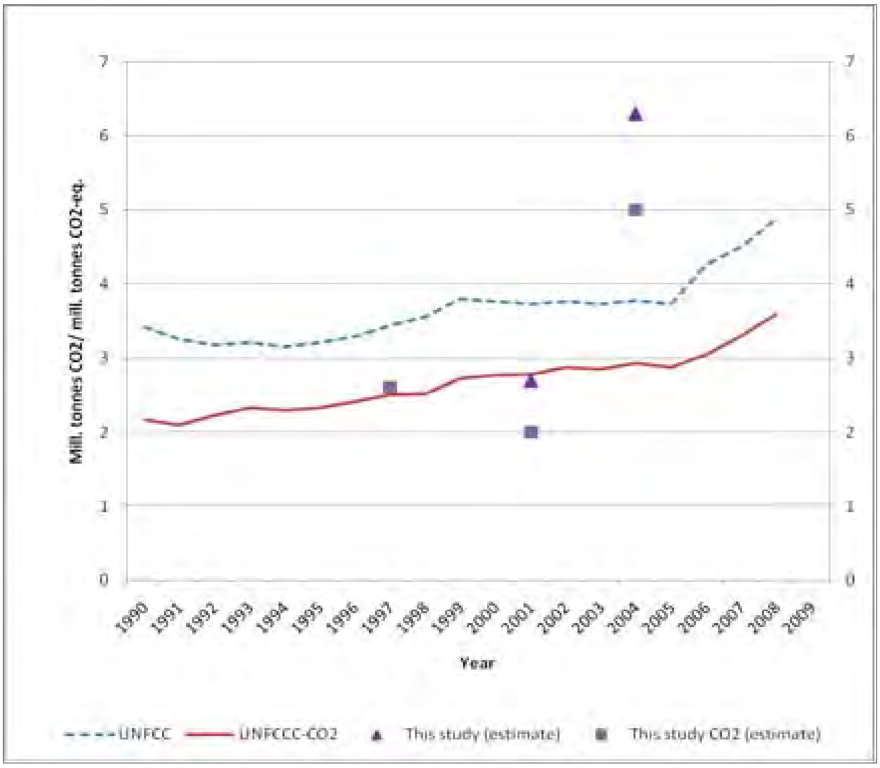

Figure 6: The NAMEA and UNFCCC emissions in Iceland overlaid with various estimates of the carbon footprint.

3.2.4 Norway

In Norway the national statistics office did some early work on a multiregional input-output model called the "world model" (Bjerkholt et al. 1993). Results were not presented at an aggregate level, but emission multipliers including emissions embodied in trade were developed. Straumann (2003) studied emissions in imports and exports, but did not include more than the first production layer of the imports, so large fractions of upstream emissions are missed (see Section 2.4). More recent studies have applied these estimates in computable general equilibrium models (Bruvoll and Fæhn 2004, 2005, 2006; Fæhn and Bruvoll 2009) to obtain emission estimates for several years. We only show the 2000 results here. Due to the limited system boundary and a different research question, these studies are not seen as applicable to investigate emissions embodied in trade on a national level.

Peters and Hertwich (2006c) constructed a multiregional input-output model centred on Norway. To reduce the data requirements in constructing the model, they only assumed uni-directional trade. They only collected input-output data for key trade partners with the remainder of the trading partners given the same technology as the most similar trade partner. The results of this study are lower than the more extensive studies for the same base year, indicating the aforementioned shortcomings of the uni-directional trade assumption (see Section 2.4).

Later a study by Hille et al. (2008) produced estimates of carbon footprint for Norwegian consumption for 1987, 1997 and 2006. Their result is consistently lower than the other studies, suggesting that the bottom-up approach used in the study results in severe cut-offs. Note that we use the numbers where they use the Norwegian electricity mix. They also present figures for emissions if all Norwegian electricity was from the Nordic mix.

Also for Norway there is a WWF funded study (Reinvang and Peters 2008). This gives results more or less in line with the other MRIO studies for the same base year, which is expected due to the similarities in data and method.

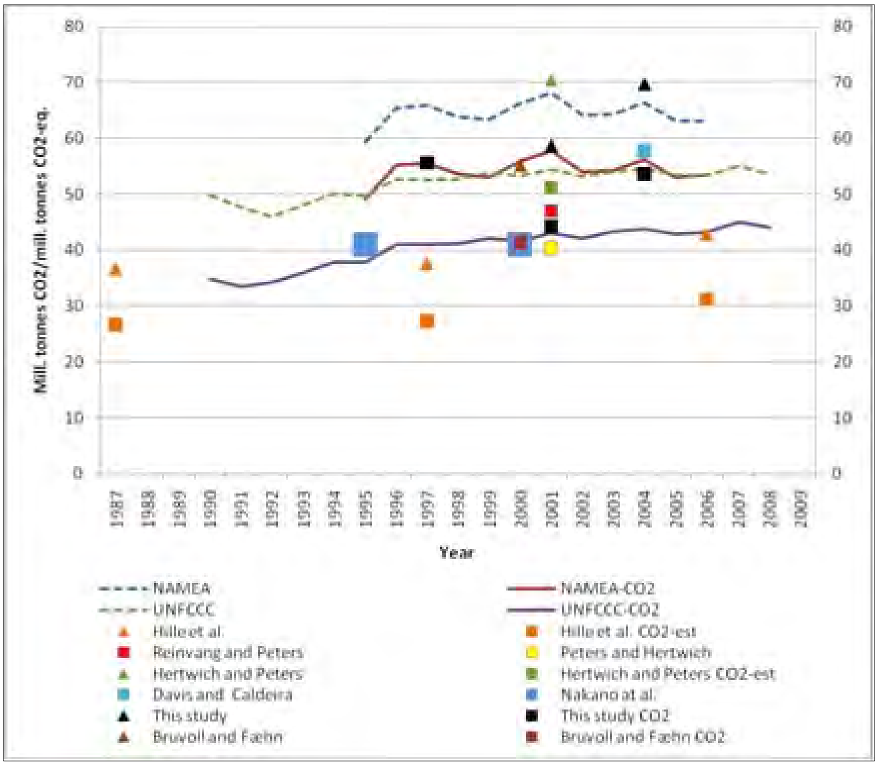

Figure 7: The NAMEA and UNFCCC emissions in Norway overlaid with various estimates of the carbon footprint.

3.2.5 Sweden

An early Swedish study considered emissions embodied in Swedish trade in 1991 (Östblom 1998), but did not include imports and only presented emission intensities. Statistics Sweden has done several studies examining the issue and provides informative statistics on the internet (Statistics Sweden 2010). Some of the work has been published in reports (Westin et al. 2000; Westin and Wadeskog 2002; Carlsson et al. 2006), but the most up-to-date results are on the website (Anders Wadeskog, personal communication). The Statistics Sweden results here are also easier to interpret than many other studies. In most of this work imports are treated as if they were produced with Swedish technology (DTA), although emission coefficients are modified for imports according to the emission intensity of the trade partners. An implication of this is less accurate estimates of emissions occurring in countries that Sweden imports from. The presentation of time series data gives an opportunity to analyze trends in the Swedish carbon footprint, which is a valuable asset of the SCB data.

Carlsson-Kanyama et al. (2007) included a more advanced import model resulting in much higher estimates for the Swedish carbon footprint. The emission intensities used in that study are based on Hertwich and Peters (2009), but Carlsson-Kanyama used Swedish trade data which probably leads to the inconsistencies with Hertwich and Peters (2009). A WWF funded report (Minx et al. 2008b) was also based on Hertwich and Peters (2009). This comes out more in line with the Hertwich and Peters study which is one of the three comprehensive multiregional models presented here. The others being the study of Davis and Caldeira (2010) and this study.

Generally we notice the large variation in reported results. For instance we see the more than factor two difference between the Carlsson et al. (2006) study for 2002 and the Carlsson-Kanyama (2007) study for 2003. The difference can probably mostly be explained by the latter including more realistic emission intensities for foreign countries. Between those extremes we observe that the studies employing a full MRIO with good country coverage produce results more in line with each other. This is not surprising as they use similar datasets. Differences between these studies are caused by how various issues regarding allocation of international transport emissions and technical issues, is treated.

Most of the Swedish studies give a carbon footprint estimate, but import and export are not defined in such a way that EEBT-figures can be extracted. This way proper trade balances cannot be found for other studies than this one. An indication is, however, possible by subtracting the NAMEA emissions from the emissions embodied in domestic final demand.

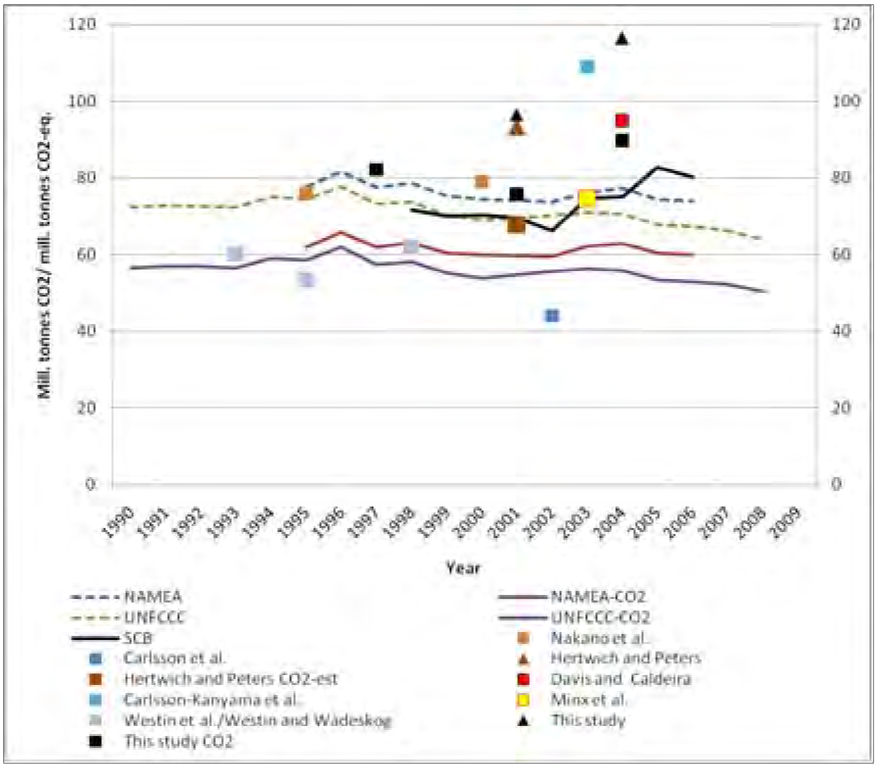

Figure 8: The NAMEA and UNFCCC emissions in Sweden overlaid with various estimates of the carbon footprint.

3.3 Review discussion

Generally we found large variations in the carbon footprint between studies for each country. Some of these differences can be explained by definitions, methods and system boundaries, while other differences are hard to identify without having the background data for each study. Generally the limited system boundaries of bottom-up methods (cut-offs, see Section 2.4) lead to lower estimates than more comprehensive multiregional studies. Studies using the domestic technology assumption for imports (see Section 2.4) also differ from more comprehensive multiregional studies. The true multiregional studies with a top down perspective produce more coherent results. This highlights the importance of using consistent methods to produce robust results to compare countries. For more specific purposes, such as in-depth sectoral analyses, the MRIO can be extended with other data or other methods could be used.

The studies display a general trend of increasing consumption based emissions over time, growing faster than territorial emissions, indicating the increasing importance of emissions embodied in imports. Note that this impression (based on the study review) can be biased by the earlier studies having poorer quality than the more recent. The detailed results from this study (see Chapter 4), however, confirm this trend.

Most of the studies have employed a MRIO-type consumption approach (emissions embodied in domestic final demand) for the carbon footprint, although often the definition is not 100% clear. When it comes to emissions embodied in bilateral imports and exports, often incomplete or inconsistent definitions are applied making it difficult to compare studies. This is the reason why we haven't emphasised the results for imports and exports in the review; they are simply not comparable across studies, since definitions differ or are unclear. Some comparisons are still made and discussed in Section 4.4.

While it is preferable to use an MRIO-type consumption model for the carbon footprint, to estimate the emissions embodied in bilateral imports and exports requires a different way of allocating emissions. The total induced emissions from domestic final demand is useful in a carbon footprint context, but the "import" and "exports" are not consistent with bilateral trade data and, depending on definitions, exports and imports may not balance at the global scale. To consistently investigate the emissions embodied in exports and imports requires both exports and imports to be treated consistently. The EEBT method, discussed earlier, is one way of doing this and can also be used to produce a trade-adjusted carbon footprint (domestic emissions+imports^{EEBT}-exports^{EEBT}). This carbon footprint will be different to the one based on final consumption as in the MRIO method.

Table 6: An overview of all the Nordic studies that were reviewed. (PR=Peer Review, CF= Carbon footprint, 3G=CO2+CH4+N2O, 6G=Kyoto gases)

Country	Authors	PR	Method	System boundary	Base year(s)	Country coverage	GHG Gas coverage	CF	Imports	Exports	QR
DK	(Rørmose et al. 2009)	N	MRIO	world	2005	DK, EU, and proxies	CO2	91,2	24,6	20,4	3
DK	(Lenzen et al. 2004)	Y	MRIO	world	1999	DK, major trade partners, 5 regions	CO2	61,5	41,8	39,6	3
DK	(Munksgaard and Pedersen 2001)	Y	IOA, some adjustments for energy	DTA	1994	DK	CO2	56,5	11,4	18,3	2
DK	(FORWAST 2010)	N	MRIO, hybrid	world	2003	DK, EU27	3G	68,2	83,3	49,8	3
DK	(Frese et al. 2008)	N	MRIO	world	2001	DK, x regions	CO2	66	30	19	2
DK	(Weidema et al. 2005)	N	IOA	DTA, adjusted emissions factors		DK	6G	No aggregate DK result presented in report			2
DK	(Hertwich and Peters 2009)	Y	MRIO	world	2001	87 regions	6G	81,2	40,9	34,2	4
DK	(Davis and Caldeira 2010)	Y	MRIO	world	2004	113 regions	CO2	75,2	40,8	16,4	4
DK	(Nakano et al. 2009)	N	MRIO	world	1995, 2000	41 regions	CO2	72;60	Only CF-NAMEA		3
DK	This study	N	MRIO	world	2004	112 regions	6G	99,8	54,8	49,1	5
DK	This study	N	MRIO	world	2001	87 regions	6G	83,9	47,1	46,6	4
DK	This study	N	MRIO	world	1997	66 regions	CO2	70,6	31,9	37,1	2
FI	(Seppälä et al. 2009)	N	IOA, PIOT, MFA, LCA.	Mix	2002, 2005	FI, some import adjustments	All	77; 82	53; 55	30;27	3
FI	(Mäenpää and Siikavirta 2007)	Y	IOA	DTA	1999	FI	3G	72	43	50	2
FI	(Hertwich and Peters 2009)	Y	MRIO	world	2001	87 regions	6G	93,6	32,1	45,1	4
FI	(Davis and Caldeira 2010)	Y	MRIO	world	2004	113 regions	CO2	74,9	32	24,8	4
FI	(Nakano et al. 2009)	N	MRIO	world	1995, 2000	42 regions	CO2	55;52	Only CF-NAMEA		3
FI	This study	N	MRIO	world	2004	112 regions	6G	99,4	58,5	29,6	5
FI	This study	N	MRIO	world	2001	87 regions	6G	81	45,2	27,4	4
FI	This study	N	MRIO	world	1997	66 regions	CO2	61,4	35,2	26,9	2
IS	This study	N	MRIO, estimate	world	2004	112 regions	6G	6,3	3,5	2,5	2
IS	This study	N	MRIO, estimate	world	2001	87 regions	6G	2,7	1,8	2	1
IS	This study	N	MRIO, estimate	world	1997	66 regions	CO2	2,6	1,7	1	1
NO	(Reinvang and Peters 2008)	N	MRIO	world	2001	87 regions	CO2	47	29	36	2
NO	(Peters and Hertwich 2006c)	Y	MRIO, unidirectional trade	world	2000	Norway and important trade partners, ROW	CO2	40,3	23,6	37,5	3
NO	(Hertwich and Peters 2009)	Y	MRIO	world	2001	87 Regions	6G	70,4	39,6	42,8	4
NO	(Davis and Caldeira 2010)	Y	MRIO	world	2004	113 regions	CO2	57,7	36,5	28,5	4
NO	(Nakano et al. 2009)	N	MRIO	world	1995, 2000	43 regions	CO2	41;41	Only CF-NAMEA		3
NO	This study	N	MRIO	world	2004	112 regions	6G	69,7	42,5	42,3	5
NO	This study	N	MRIO, estimate	world	2001	87 regions	6G	58,7	39,6	44,2	2
NO	This study	N	MRIO, estimate	world	1997	66 regions	CO2	55,6	35,6	21,1	1

Country	Authors	PR	Method	System boundary	Base year(s)	Country coverage	GHG Gas coverage	CF	Imports	Exports	QR
NO	(Bruvoll and Fæhn 2004, 2005, 2006; Fæhn and Bruvoll 2009)	Y	CGE	Severe cut-offs	1980; 2000	Major trade partners, ROW	3G	41,6; 55,2	6,3; 10,6	7,5; 19,7	1
NO	(Straumann 2003)	N	N/A	Severe cut-offs	1995	NO, major trade partners, ROW	3G	Only trade" balance"			1
NO	(Hille et al. 2008)	N	Mix	Unclear	1987, 1997, 2006	NO, Unclear	All	36,7; 37,6; 42,9	Partially	NO	2
SE	(Minx et al. 2008b)	N	MRIO	world	2003	87 regions	CO2	74,6	36,4	26,6	2
SE	(Östblom 1998)	Y	IOA	Imports cut off	1991	Sweden	CO2	Presents multipliers (intensities) only			1
SE	(Carlsson-Kanyama et al. 2007)	N	IOA	Variations, GTAP based most advanced	2003	87 regions?	CO2	109	74	27	2
SE	(Carlsson et al. 2006)	N	IOA	DTA, only private and public consumption	2002	Sweden only	CO2	44	NO	NO	1
SE	(Westin et al. 2000)	N	IOA	DTA	1993	SE, adjusted emission factors	CO2	60,2	36,3	21,5	2
SE	(Westin and Wadeskog 2002)	N	IOA	DTA	1995, 1998	SE, adjusted emission factors	CO2	53,3; 61,9	30,3; 39,0	24,7; 26,0	2
SE	(Statistics Sweden 2010)	N	IOA	DTA, simple EF adjustment for imports	1998	SE, adjusted emission factors	CO2	71,7	61	23,6	3
SE	(Statistics Sweden 2010)	N	IOA	“	1999	SE	CO2	70,1	60,2	22,5	3
SE	(Statistics Sweden 2010)	N	IOA	“	2000	SE	CO2	70,4	64,9	22,9	3
SE	(Statistics Sweden 2010)	N	IOA	“	2001	SE	CO2	69,6	66,1	23,8	3
SE	(Statistics Sweden 2010)	N	IOA	“	2002	SE	CO2	66,2	59,5	23,3	3
SE	(Statistics Sweden 2010)	N	IOA	“	2003	SE	CO2	74,6	73,6	25,1	3
SE	(Statistics Sweden 2010)	N	IOA	“	2004	SE	CO2	75	82,1	27,3	3
SE	(Statistics Sweden 2010)	N	IOA	“	2005	SE	CO2	82,7	98,5	26,6	3
SE	(Statistics Sweden 2010)	N	IOA	“	2006	SE	CO2	80,3	98,9	27,3	3
SE	(Hertwich and Peters 2009)	Y	MRIO	world	2001	87 regions	6G	93,3	51,6	25,3	4
SE	(Davis and Caldeira 2010)	Y	MRIO	world	2004	113 regions	CO2	94,9	55,3	14,7	4
SE	(Nakano et al. 2009)	N	MRIO	world	1995, 2000	44 regions	CO2	76;79			3
SE	This study	N	MRIO	world	2004	112 regions	6G	116,5	71,8	31	5
SE	This study	N	MRIO	world	2001	87 regions	6G	96,4	57,2	29,5	4
SE	This study	N	MRIO	world	1997	66 regions	CO2	82,2	53	24	2

4. The Carbon Footprint of the Nordic Countries

4.1 Introduction

In this section we present the carbon footprint of the Nordic countries using two methods. First, we focus on the carbon footprint of consumption which considers global emissions to meet consumption in each Nordic country. Second, we focus on the GHG emissions embodied in international trade between bilateral trade partners. The different sets of results focus on different aspects; either consumption or international trade.

We only show key headline results for each country, due to time and space constraints. The database contains 57 sectors in 112 countries and specifies bi-lateral trade relations. Thus, there are considerably more detailed results than we display here. It is further possible to present normalized results such as results per unit GDP, exports/imports, population, and so on (c.f. Davis and Caldeira 2010).

4.1.1 Method summary

We perform two sets of analyses based on the GTAP database with base years 1997, 2001, and 2004. The emissions embodied in bilateral trade (EEBT) method focuses on international trade flows in bilateral trade links, while the Multi-Regional Input-Output (MRIO) approach focuses on consumption and includes multi-lateral trade links. These methods are discussed in Chapter 2 in addition to other papers (Peters 2008b; Peters et al. 2010b). The EEBT method (Peters and Hertwich 2008a) and MRIO method (Hertwich and Peters 2009) are extensions of previous work to new years and with new data sources. The two models have been used in a variety of peer-reviewed and non peer-reviewed studies (Carlsson-Kanyama et al. 2007; Peters 2007b; Andrew et al. 2008; Frese et al. 2008; John Kornerup Bang et al. 2008; Minx et al. 2008a; Minx et al. 2008b; Peters 2008b; Peters 2008d; Peters 2008e; Peters and Hertwich 2008a; Reinvang and Peters 2008; Andrew et al. 2009; Hertwich and Peters 2009; Peters and Hertwich 2009).

4.1.2 Country Coverage

Our analysis covers the main Nordic countries (Denmark, Finland, Iceland, Norway, and Sweden), but the accuracy of the footprint varies for each year of analysis depending on whether it is included in the GTAP database explicitly or is estimated from the composite regions in the GTAP database, see Table 7. In all years for Iceland and in 1997 and 2001 for Norway, the emissions are estimated using GDP shares and the results should be considered as crude estimates. We only performed these estimates to include them in the Nordic totals. We show detailed country specific results for Denmark, Finland, and Sweden. For Norway we only show results for 2004 where the data is most reliable. Iceland is based on proxy data and we do not give country specific results.

In terms of emissions coverage, we have 1997 in CO_2 only and 2001 and 2004 include all GHGs (CO_2, CH_4, N_2O, and the synthetic gases). As a consequence we only compare 1997 with 2001 and 2004 in normalized form which assumes the distribution of GHG is the same as the distribution of CO_2 by sector in 1997. We focus our analysis on changes between 2001 and 2004, as this is where the data is most reliable and consistent.

Table 7: The country and emission coverage used in the analysis.

	1997	2001	2004
Denmark	CO_2	GHG	GHG
Finland	CO_2	GHG	GHG
Iceland	Estimated	Estimated	Estimated
Norway	Estimated	Estimated	GHG
Sweden	CO_2	GHG	GHG

4.1.3 Data summary

Our estimates for the carbon footprint of the five Nordic countries use the GTAP database and thus have global coverage of imports. When country specific data is poor, the GTAP database uses proxy information. Further details can be found on the GTAP website or documentation (Narayanan and Walmsley 2008). The database is disaggregated into 66 regions in 1997, 87 regions in 2001, and 112 regions in 2004. Each year of the analysis includes 57 economic sectors in each region. Denmark, Finland, and Sweden are represented explicitly in GTAP in every year, while Iceland is not represented explicitly in any year and Norway only in 2004. The GTAP database is based on contributions from interested data users and this lead to the inclusion, via CICERO, of Norway in GTAP in 2004. Iceland could be included in the future if an interested data contributor can be identified.

The GTAP database is undergoing continual renewal, and thus the accuracy of the estimates is expected to increase as the time progresses. The GTAP database had a major update of EU countries in 2004 and this should improve the representation of Nordic countries. Overall, the results in 2004 will be most reliable, followed by 2001, and then 1997. In mid-2011 GTAP will release version 8 of the database covering the world economy in 2007 and this will allow an update of all the estimates to 2007.

We include the emissions of CO_2 in 1997, 2001, and 2004 and CH_4, N_2O, and the fluorinated gases in 2001 and 2004. The emissions cover the combustion of fossil-fuels and process emissions, such as cement production, methane from enteric fermentation, and fertilizer use. We do not include the emissions from land-use, land-use change, and forestry (LULUCF). We are currently developing methods to allow the inclusion of LULUCF in future studies.

We use the economic system boundary in each country as defined in the system of national accounts (SNA; United Nations 1993). This technical point has significant implications for the Nordic countries. The SNA allocates economic activity to resident institutes in the Nordic countries. Some resident institutes, such as tourists and international transportation, have activities outside of Norway (and likewise non-resident institutes have activities in Norway). Many environmental statistics are based on activities in administered territories (e.g., UNFCCC) which may be inconsistent with the economic definition of a country. Analysts have long recognized this and construct environmental statistics that are consistent with the system of national accounts. In the EU this data is collected by Eurostat under the name National Accounting Matrices with Environmental Accounts (NAMEA; de Haan and Keuning 1996; Keuning et al. 1999; de Haan and Keuning 2001; European 2001; Pedersen and de Haan 2006)

Since our emission statistics are based on NAMEA's, they will in general not match with the emission statistics submitted to the UNFCCC. The most significant difference in the Nordic countries is bunker fuels (Peters et al. 2009). The UNFCCC territorial statistics allocate emissions (as a memo) to country that supplies the bunker fuels while in the NAMEA statistics emissions are allocated to the user of the bunker fuel. Both Denmark and Norway have resident institutes that operate significant international transport operations and the NAMEA and UNFCCC in those countries may differ substantially (statistics offices often publish a "bridge" table which maps between the two). Statistical offices sometimes do not report international transport in the NAMEAs, such as Denmark.

Figure 9 shows a comparison of the UNFCCC and NAMEA emission inventories in each of the Nordic countries that have a NAMEA. The largest differences are in Denmark and then Norway. If international shipping is included emissions in Denmark are increasing and not decreasing as in the UNFCCC inventories.

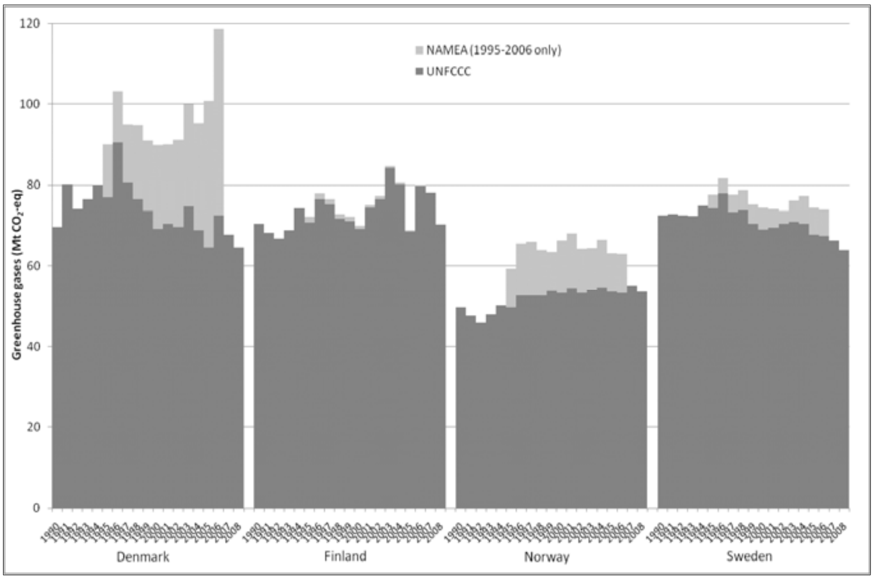

Figure 9: A comparison of the NAMEA and UNFCCC emission inventories in the Nordic countries. The NAMEA data is only from 1995–2006.

In each country there exist many different emissions estimates, both official and estimated by third parties. These estimates often differ due to different input data and different assumptions. For a variety of reasons, analysts sometimes do not use officially submitted statistics (e.g., to ensure consistency across a cross-section of countries). The CO_2 emissions statistics used in the GTAP database are based on energy consumption provided by the International Energy Agency, later modified by GTAP, and then used to estimate emissions. The non-CO_2 GHG's are developed by GTAP based on UNFCCC reports and supplemented by us to include biomass emissions. Thus, the default production-based emission estimates in the model may differ to official data and this should not be a concern to the reader. However, for key countries we have updated the database with country-specific NAMEA's; all of the EU, Australia, Canada, China, Japan, New Zealand, and USA. Thus, for the Nordic countries the database will be close to the NAMEA's officially reported to Eurostat.

4.2 The Nordic countries in perspective

Before moving onto the results it is worth discussing the development of various macro-variables in the Nordic countries over time. We compare Gross Domestic Product (GDP) and exports and imports measured in constant 2000 euros (Eurostat), the UNFCCC emission inventories, and population (Eurostat) all since 1990.

Figure 10 shows the absolute change between the macro variables. This allows the scale of each country to be compared. A good indication of the size of the countries is via population. Sweden has the largest population at around 9 million people, Denmark, Finland, and Norway are all around 5 million people, and Iceland is considerably smaller with only 250,000 people. Apart from Iceland, and to some degree Sweden, the Nordic countries should be very comparable without adjusting for population. In absolute terms, Sweden has the largest GDP, Norway and Denmark are similar, followed by Finland. When normalized with respect to population (GDP/capita), Norway has the highest level that is around 30% higher than the lowest (Finland). The other Nordic countries are very comparable on a per capita basis. The GHG emissions reported to the UNFCCC are remarkably similar in Denmark, Finland, and Sweden with lower values in Norway and of course Iceland. On a per capita level, the higher population in Sweden means that it has somewhat lower emissions per capita than the other Nordic countries. We only compare the trade balance in absolute terms and since around 1993 all the Nordic countries have been net exporters. There are large fluctuations over time with Sweden showing a strong growth in exports compared to imports (steady increase in the trade surplus) with similar changes of smaller magnitude in Finland.

Figure 11 shows the same macro-variables but measured in relative terms. The results are shown in each country to show how the macro variables change with respect to each other over time. This type of analysis can be further generalized to look at emission drivers over time (c.f., Raupach et al. 2007). All the Nordic countries show similar trends. Population growth is only small and, as in other studies, probably has minimal effect on emission levels. Denmark has shown a drop in the GHG emissions reported to the UNFCCC, though the emissions allocated to the system of national accounts have grown (Figure 9). Growth in GDP (constant 2000 prices) has been strong in all the Nordic countries. However, in all the Nordic countries, the strongest growing macro-variable is exports and imports. This would suggest that emissions embodied in trade are growing much faster than territorial emissions linked to GDP (c.f., Le Quéré et al. 2009; Peters et al. 2009).

Based on the change in the macro-variables, one may suspect that exported and imported emissions are growing quickly in the Nordic countries. However, whether exported and imported emissions grow faster or slower than the monetary values will depend on whether there has been a change in trade structure (regions or sectors) or a change in emission intensities in the trading partners. For instance, if imports have shifted from clean to polluting countries or sectors, then it would be expected that imported emissions have grown faster than imports. For exports, one would only expect significantly different growth between exported values and emissions if there has been a change in the mix of exported products. Underlying changes in both exported and imported emissions will depend on how emission intensities have changed over time. These are related issues can be answered and explored further in the results.

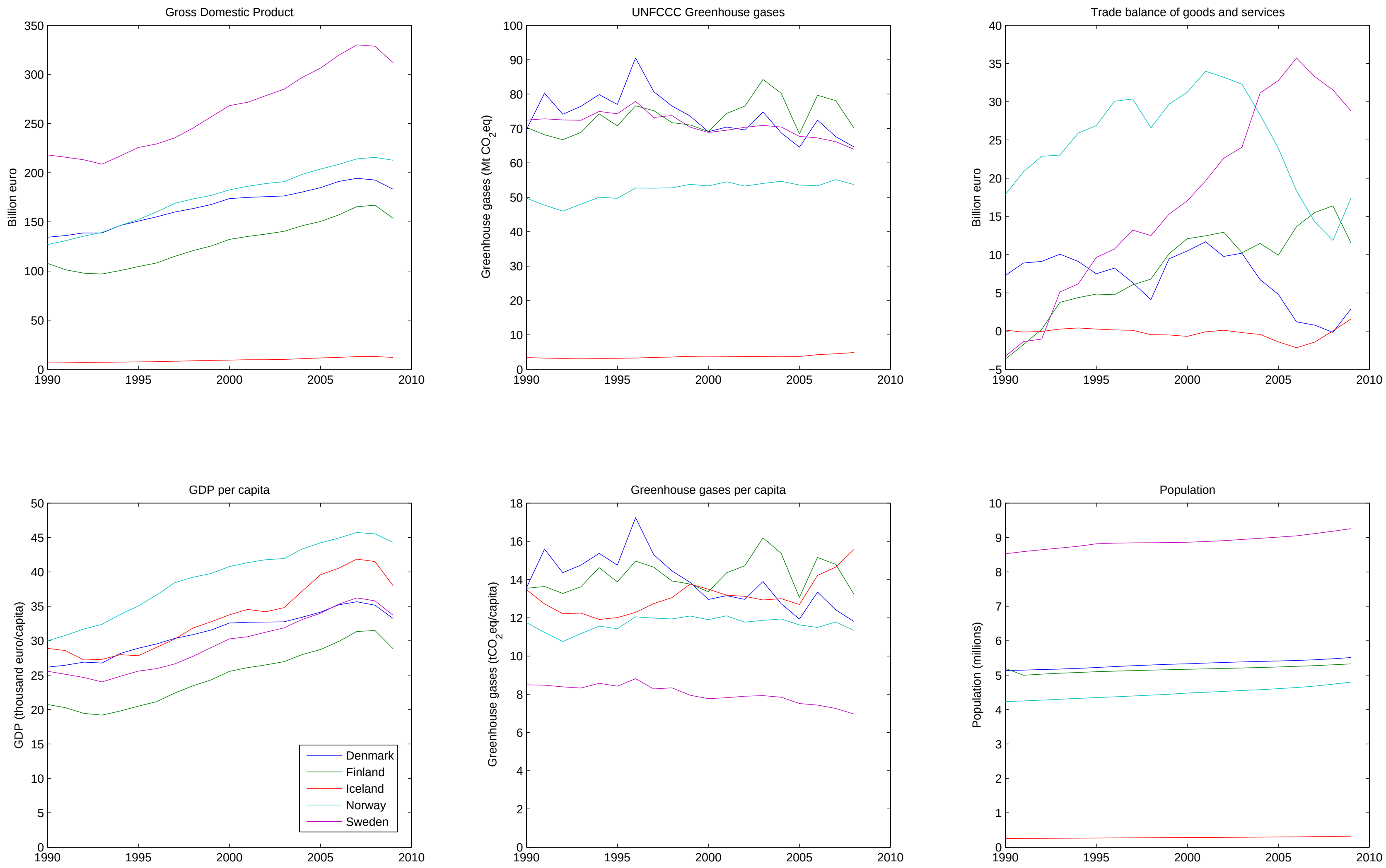

Figure 10: A comparison of the development in various macro variables in the Nordic countries from 1990 to the most recent data.

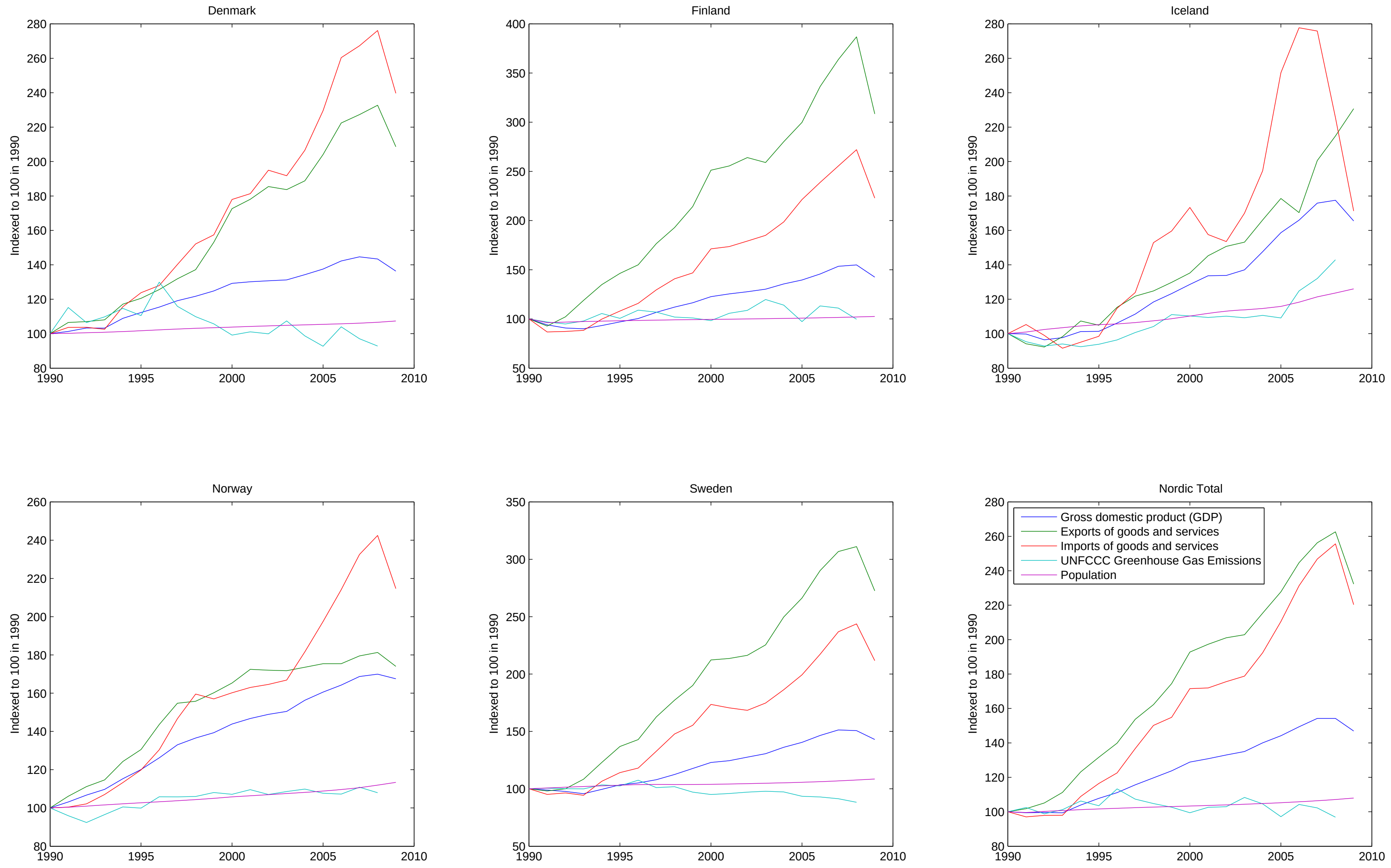

Figure 11: A comparison of the relative changes in various macro variables over time in the Nordic countries.

4.3 Territorial-based emissions in the Nordic Countries

Figure 12 shows the territorial-based emissions allocated to economic sectors for the Nordic countries. These are the territorial emissions but include emissions allocated to international transport according to the resident principle in the System of National Accounts; National Accounting Matrix with Environmental Extensions (NAMEA). Figure 9 compares the NAMEA and UNFCCC estimates. The Nordic countries have had a general increase in territorial emissions from 2001 through to 2004. The 1997 numbers only include CO_2 and are thus not directly comparable with 2001 and 2004.

The development over time of the NAMEA emissions in the Nordic countries is best assessed using Figure 9, but Figure 12 allows a comparison of the key source of emissions in each country. The largest difference between emission sources in the Nordic countries is related to electricity production and international transport. In terms of electricity, the outlier is Norway which has virtually zero direct emissions from electricity production due to the extensive use of hydro-power in electricity generation. Denmark and Finland have a higher share of coal, and hence emissions, in electricity production. Sweden sits between the other Nordic countries with diverse sources of electricity generation. Despite the high levels of renewable and nuclear power, Sweden still does use non-renewable fuels in electricity generation and heating. The weather conditions in the Nordic countries can have a large influence on the annual emissions from the electricity sector due to the large share of hydropower. This is shown in Table 18 where Finnish emissions changed by around 10Mt CO_2 between 2004 and 2005 due to a good year for hydropower. In terms of electricity emissions, it is best to take an average of several years due to these annual variations.

Another important sector explaining the different emissions between the Nordic countries is international transportation. For Norway and Denmark in particular international shipping is a large sector. While emissions from international transportation are reported as a memo in UNFCCC emission inventories, they should be recorded in the NAMEA estimates as they contribute to economic activity (Figure 9). All our data includes emissions from international transportation due to resident institutes to be consistent with the System of National Accounts. Other significant sources of emissions in the Nordic countries include energy-intensive manufacturing (e.g., primary metals, concrete). The mining sector has large emissions in Norway due to the oil and gas sector (which is included in mining). The Household Direct emissions cover direct emissions from household activities such as personal transportation and direct fuel use in the household for heating and cooking. The remainder of the sectors are relatively small as they are generally processing sectors.

The Nordic Statistical Offices published a report on the consistency of definitions and reporting of NAMEA's in the Nordic countries (Hass 2000). They found several challenges in key sectors. A significant issue is the treatment of international transportation. Issues arose in how to estimate the emissions, how to allocated them, and particularly in the case of air transportation, how to distribute the emissions between countries when companies have joint ownership. Another sector with consistency issues was the pulp and paper industry where secondary production was reported differently in Finland. These sorts of issues need to be considered when comparing the Nordic countries, and for that matter, any other country (Peters et al. 2008).

The disadvantage of analyzing source-based emissions is that they reveal very little information on the underlying cause of the emissions. Primary metals, for example, are usually transferred from industry to industry and not from industry to final consumers such as households. By transferring emissions from producing (source) sectors to consuming sectors, and adjusting for imports, leads to the carbon footprint and gives a quite different perspective on emission drivers.

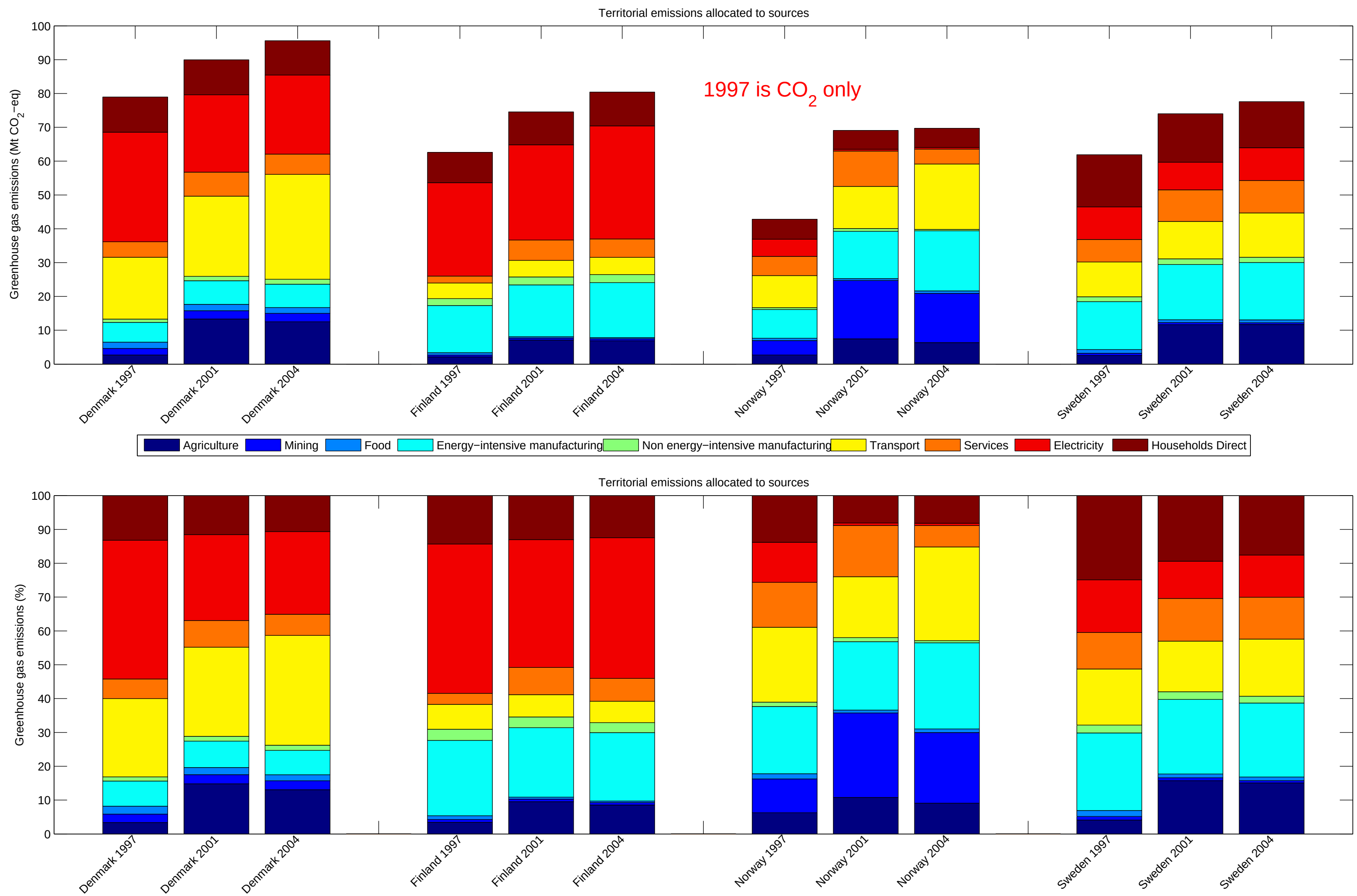

Figure 12: Territorial-based NAMEA emissions allocated to economic sectors; absolute emissions (top) and sector distribution (bottom).

4.4 Carbon Footprint in the Nordic countries

In this section, we present the consumption-based emissions (or carbon footprint) of the Nordic countries. We present two sets of results related to consumption: one in terms of consumption (this section) and one in terms of international trade (following section). While these issues are connected, it is often easier to separate them to focus on the individual components (see Chapter 2).

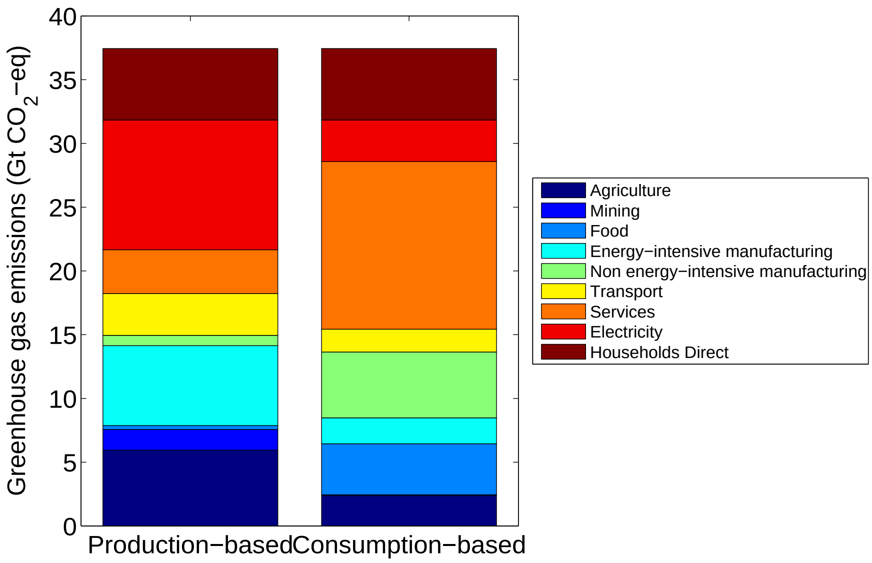

Figure 13: A comparison of global emissions allocated to the sectors emitting GHG's and to the consumed products which lead to production. Data is for 2004 covering all GHG's.

The first set of results focus on consumption in the Nordic countries. Consumption can have a wide range of definitions, and here we focus on final consumption of households, governments, and capital investments as used in the System of National Accounts. Figure shows a comparison of production- and consumption-based emissions at the global level. For the production-based estimates, the emissions are allocated to the sector that actually emits the pollution (territorial responsibility). This identifies the energy-intensive sectors such as electricity production, energy-intensive manufacturing, and agriculture. However, these sectors are often not purchased directly by consumers. The consumption-based estimate shows the emission allocated to the products of final consumption which gives a substantially different view of emissions. These sectors include all the emissions in the supply chain and thus, generally, the energy-intensive sectors become smaller as they are not purchased directly by consumers but are rather embedded in products that consumers do purchase (e.g., steel versus a car).

Starting from the bottom of Figure 13, agriculture is much smaller from a consumption perspective and food is larger as consumers generally purchase processed food and not primary agriculture (e.g., they purchase meat and not a cow). Mining becomes negligible in a consumption perspective as this is used as an input into other sectors and not used in final consumption. Energy-intensive manufacturing becomes much smaller while non energy-intensive manufacturing becomes larger as these products are used in final consumption (e.g., steel versus a car). Transport services become smaller as a share of these are used for freight and not directly to transport consumers (whether privately or publically). Services become significantly larger as this is often for final consumption and has low direct emissions. Since a substantial share of electricity production goes to industry and not final consumption, it becomes smaller in a consumption-based viewpoint. The direct emissions are the same as they occur directly in the household. With this as background, we now show the equivalent results for the Nordic countries.

Figure 14 shows the consumption by aggregated sector in addition to the consumption shares. The final consumption of households, government, and capital investments are included and imports appear embedded in the calculations. In all countries, the carbon footprint is growing rapidly, and faster than changes in territorial emissions (Figure 12). To compare the countries it is easiest to focus on the distribution of emissions. The lower part of the figure shows the sectors which contribute to increased consumption. For final consumption, primary sectors like agriculture and mining and secondary sectors like heavy manufacturing are not important in terms of final consumption. The emissions from these sectors appear embedded within the final consumption of other products, for example, consumers rarely purchase steel but often buy a car containing steel. Of more importance in terms of consumption are more processed and manufactured products such as food, light manufacturing and services. The emissions for private transportation (own car) appear in the household direct emissions.

A comparison across the Nordic countries shows a similar distribution of emissions. Food and agriculture is similar in each of the Nordic countries as would be expected for countries of similar income levels. The purchase of manufactured products is also similar. A more significant difference is transportation, driven particularly by international transportation. Even though the consumption figure has reallocated emissions from production to consumption the emissions for international transportation still remain high. This may be an artefact of the international transportation data, which is known to be bad in GTAP (Peters et al. 2010b). The electricity emissions vary significantly between the Nordic countries due to a different electricity system in each of the Nordic countries. Even though the Nordic countries are connected by a grid, the estimates here show domestic production adjusted for exports and imports, as has been done for consumption of products. The direct household emissions vary a little, and a share of this relates to different energy distribution; Norway, for example, uses a lot of electricity for heating and this is allocated in electricity consumption.

Since we have included all final consumption in Figure 14, services are significant as most government expenditure is for services and construction activities from capital investments are included in services. Figure 15 focuses only on household final consumption. The emissions consequently drop as government consumption and capital investments are not included. However, this figure gives a better description of household consumption in the Nordic countries.

Household consumption is growing in all the Nordic countries (Figure 15), and the distribution of emissions across sectors is broadly consistent across Nordic countries. This is expected for countries with similar income levels (Hertwich 2005; Hertwich and Peters 2009). Since food and agriculture becomes more important for the household consumption, relative to total consumption, the values in 1997 become less reliable due to the importance of CH_4 and N_2O in agriculture. Focusing on 2001 and 2004, food and agriculture consumption is roughly constant across the Nordic countries with a slightly decreasing share. There seems to be a slight increase in the consumption of manufactured products and services, which is consistent with increasing incomes (Hertwich and Peters 2009). Electricity based emissions, which are adjusted for imports, could be expected to vary rapidly from year to year due to variations in weather patterns. Thus, it is not possible to draw any conclusions on changes. Interestingly, the share of household direct emissions (which covers mainly fuel use for private transportation and energy used directly in the home) has a diminishing share over time in all the Nordic countries despite remaining constant in absolute terms. This suggests that this sector has stabilised while other sectors are growing, most notably manufacturing and services.

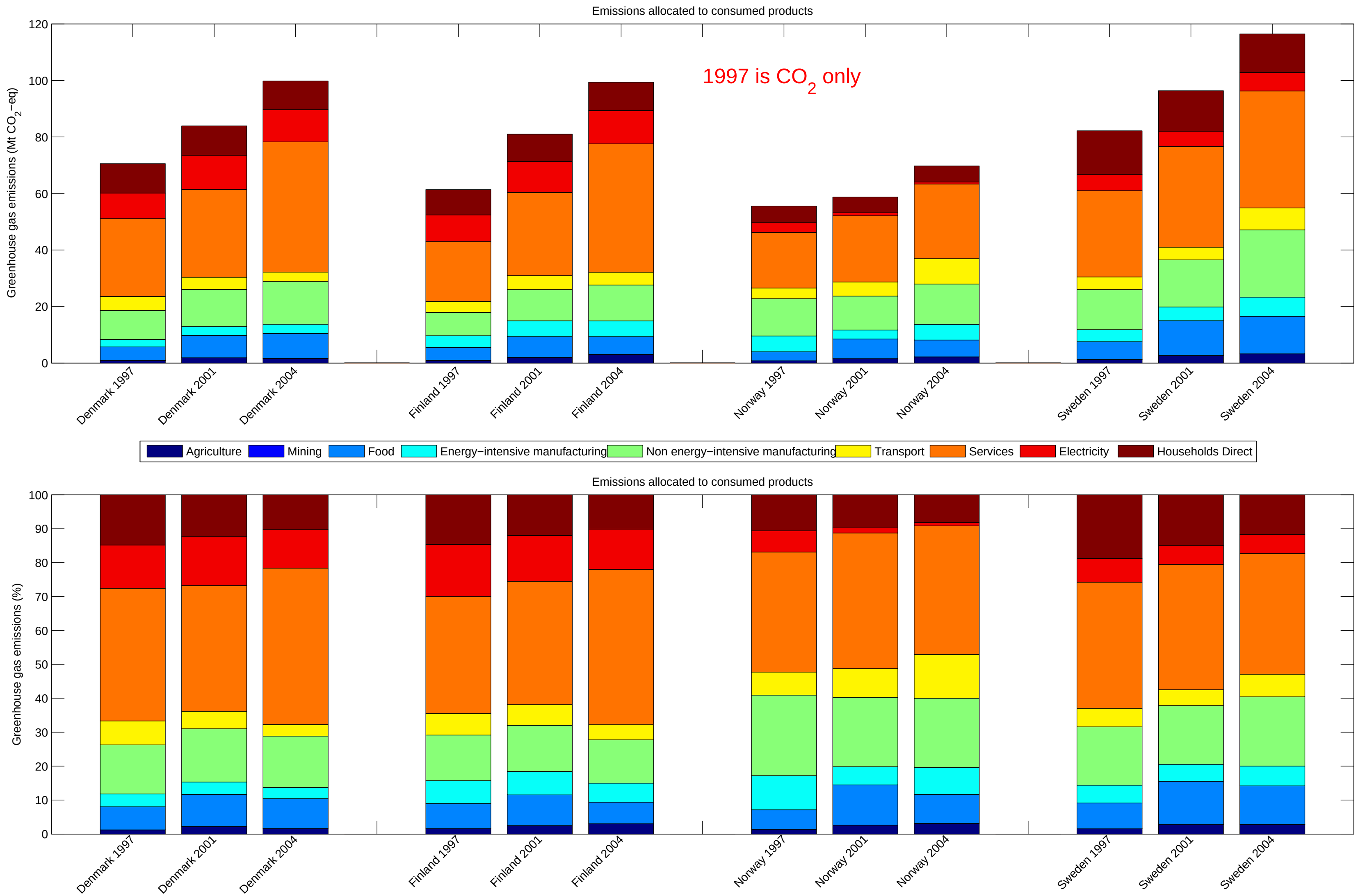

Figure 14: Total consumption in the Nordic countries, covering households, governments, and capital investments. Imported emissions are included in these totals.

A comparison between the territorial source-based emissions (Figure 13) and the carbon footprint (Figure 14) clearly demonstrates the different emphasis in terms of allocation (c.f. for the global comparison Figure 12). While the territorial-based source of emissions reveals where the emissions occur, the consumption-based emissions (carbon footprint) give an indication of why the emissions occur (Peters et al. 2009). An understanding of both perspectives is beneficial for policy. By focusing upstream on what is being consumed and ultimately driving production, the policy maker can focus on mechanisms that lead to consumption. By focusing downstream on where the emissions occur, the policy maker can focus on mechanisms that address the direct source of emissions. There are several useful techniques which can be used to identify the linkages between the consumer and producer in the supply chain and thus may be useful for some policy applications (Lenzen 2003; Peters and Hertwich 2006d). Studies at the global level can provide further understanding in the regional differences in consumption which may differentiate abilities for mitigation (Hertwich and Peters 2009).

So far we have only focused on the final consumption of products, and another perspective is to isolate where the actual emissions occur. Figure 16 considers total final consumption (c.f., Figure 14, but allocated to the region emitting the GHGs. The first striking point is that most of the emissions occur domestically or in the other Nordic countries. This highlights the importance of domestic mitigation policies; a carbon footprint analysis does not negate the need for domestic action. The next most significant source of emissions is in other European countries and, particularly for Finland, the former Soviet countries. Since the carbon footprint is dominated by domestic or EU emissions, it implies that uncertainty due to poor data in developing countries will only impact on a small part of the footprint.

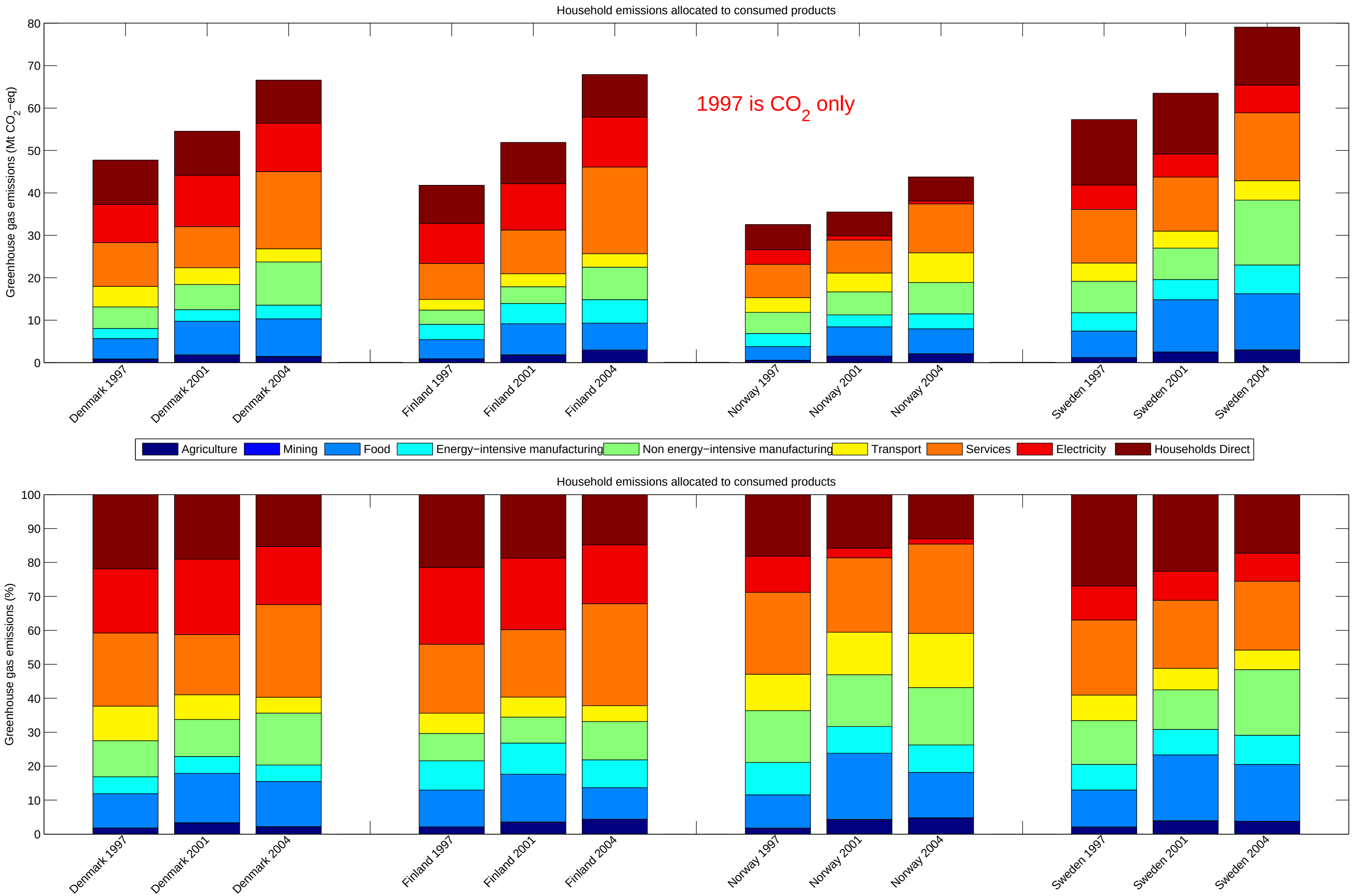

Figure 15: Final household consumption in the Nordic countries. Imported emissions are included in these totals.

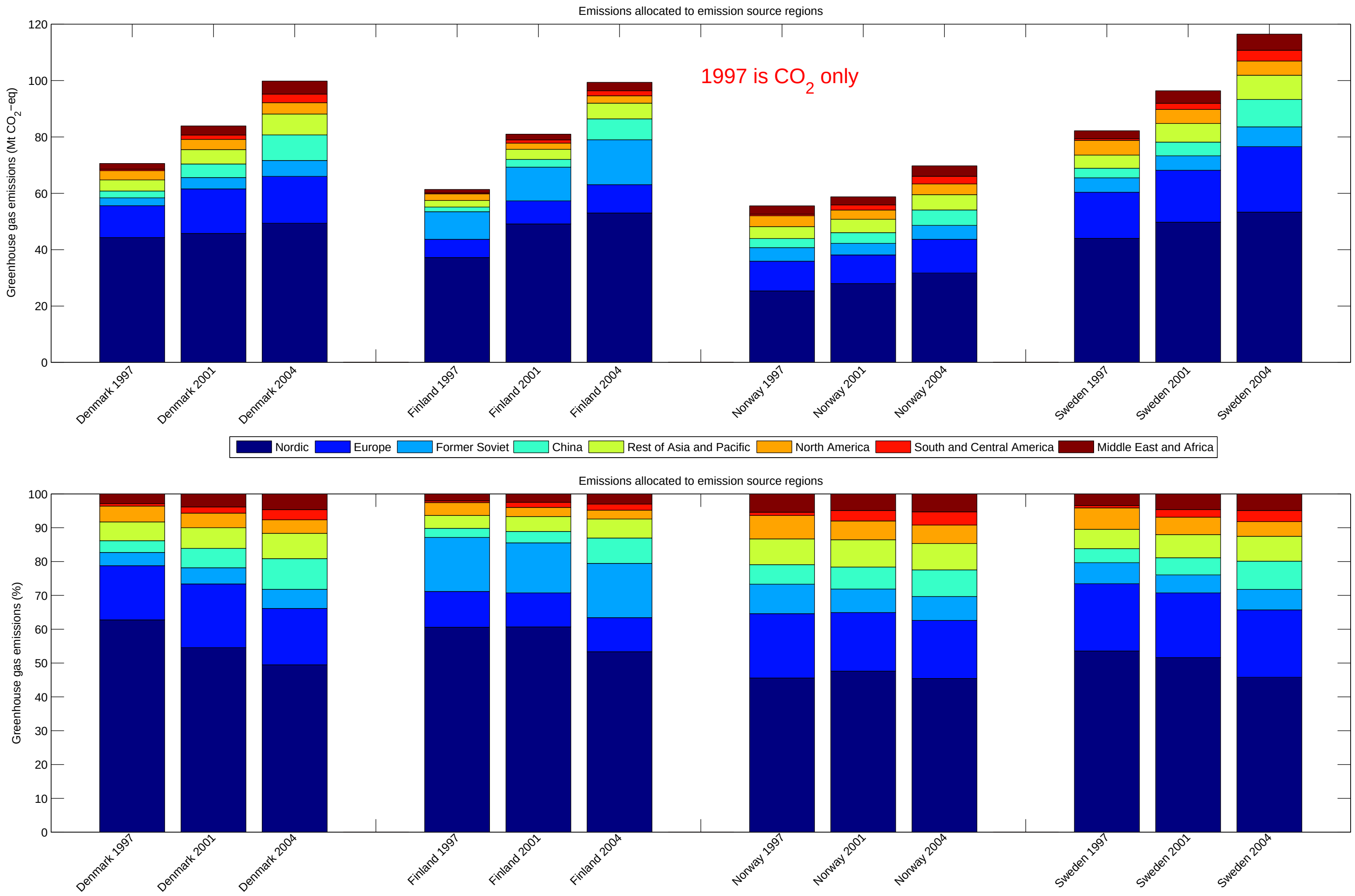

Figure 16: The region emitting the emissions for total final consumption in the Nordic countries. Imported emissions are included in these totals.

Up to now we have he focused on a graphical presentation of the carbon footprint. Table 8 compares the published territorial emissions, estimates carbon footprint, and the difference between the two in absolute values. This is not a trade balance due to differences in definitions of each column (Peters 2008b). Nevertheless, the comparison does show that the Nordic countries as a whole have a higher carbon footprint than territorial emissions and this has increased considerably from 2001 to 2004. Denmark and Norway both had larger territorial emissions than the carbon footprint in 2001, but this has reversed in 2004. Denmark and Norway are both heavily influenced by the large emissions from international transportation which is primarily due for export making the territorial emissions higher than expected compared to the other Nordic countries. Sweden and Finland both have a much larger carbon footprint then territorial emissions and this is growing over time.

Table 8: Summary of the territorial emissions and carbon footprint for the Nordic countries, also with the difference between the two.

	Territorial (Mt CO_2-eq)		Carbon Footprint (Mt CO_2-eq)		Difference (Mt CO_2-eq)	
	2001	2004	2001	2004	2001	2004
Denmark	90	96	84	100	6	-4
Finland	75	80	81	99	-6	-19
Iceland	3	5	3	6	0	-1
Norway	69	70	59	70	10	0
Sweden	74	78	96	116	-22	-39
Total	311	329	323	392	-12	-63

The results show that the Nordic countries increasingly have emissions occurring outside of the Nordic countries to meet consumption within the Nordic countries. This would suggest that the imports into the Nordic countries are growing much faster than exports out. However, as discussed in Chapter 2, the carbon footprint does not reveal directly how bilateral trade flows have changed in the Nordic countries. The growth in the carbon footprint may be due to trade between third countries, for example, trade between Japan and China. We now turn to a more direct focus on the bilateral trade links between the Nordic countries and their trading partners.

4.5 International Trade and the Nordic Countries

For a closer analysis of the change in emissions related to international trade we now move away from the focus on consumption and focus directly on the international trade flows through bilateral linkages. There are several reasons to make the analysis of consumption and international trade distinct, particularly in a policy context. There is a close linkage between the consumption and international trade flows, but also significant differences (Chapter 2). A policy on consumption may affect trade flows, and likewise a change in trade policy may affect consumption patterns. When focussing on consumption policy, e.g. comparing a car purchased from different countries or meat versus vegetables, it is important to include global supply chains. When it comes to trade policy, however, the direct bilateral linkages are more important than linkages between third countries; e.g., the Nordic countries may not have much policy jurisdiction to effect the trade linkages between New Zealand and Australia, but they do between the Nordic countries and China. Today, policy makers deal routinely with bilateral trade linkages (as in the trade balance) and not multi-lateral linkages as in the global supply chain. Due to policy relevance, this section focuses on direct trade linkages and how they have changed over time. Those changes can translate into changes in consumption discussed in the previous section.

Figure 17 shows the total territorial emissions (NAMEA) in the Nordic countries, the emissions occurring in the Nordic countries to produce exported goods and services, the emissions occurring outside of the Nordic countries to produce imported goods and services (i.e. emissions occurring *domestically* in trade partners to produce export to Nordic countries), and the net exports minus imports (Balance of Emissions Embodied in Trade, BEET) for each Nordic country. Table 9 additionally shows Figure 17 in terms of absolute values and Table 10 as percentage of total territorial emissions in each country. The BEET shown in these tables differs from the difference between consumption and territorial emissions in Table 8 as the consumption results cover global emissions in global supply chains, while the trade results cover domestic emissions in bilateral trade links. More thorough discussions on the definitions are in Chapter 1 and Chapter 2. In 1997 only data for CO_2 was available, and all Icelandic data is estimated based on neighbouring regions. Norway is estimated in 1997 and 2001. The results in Denmark, Finland, and Sweden are the most reliable, and the most recent years are more reliable.

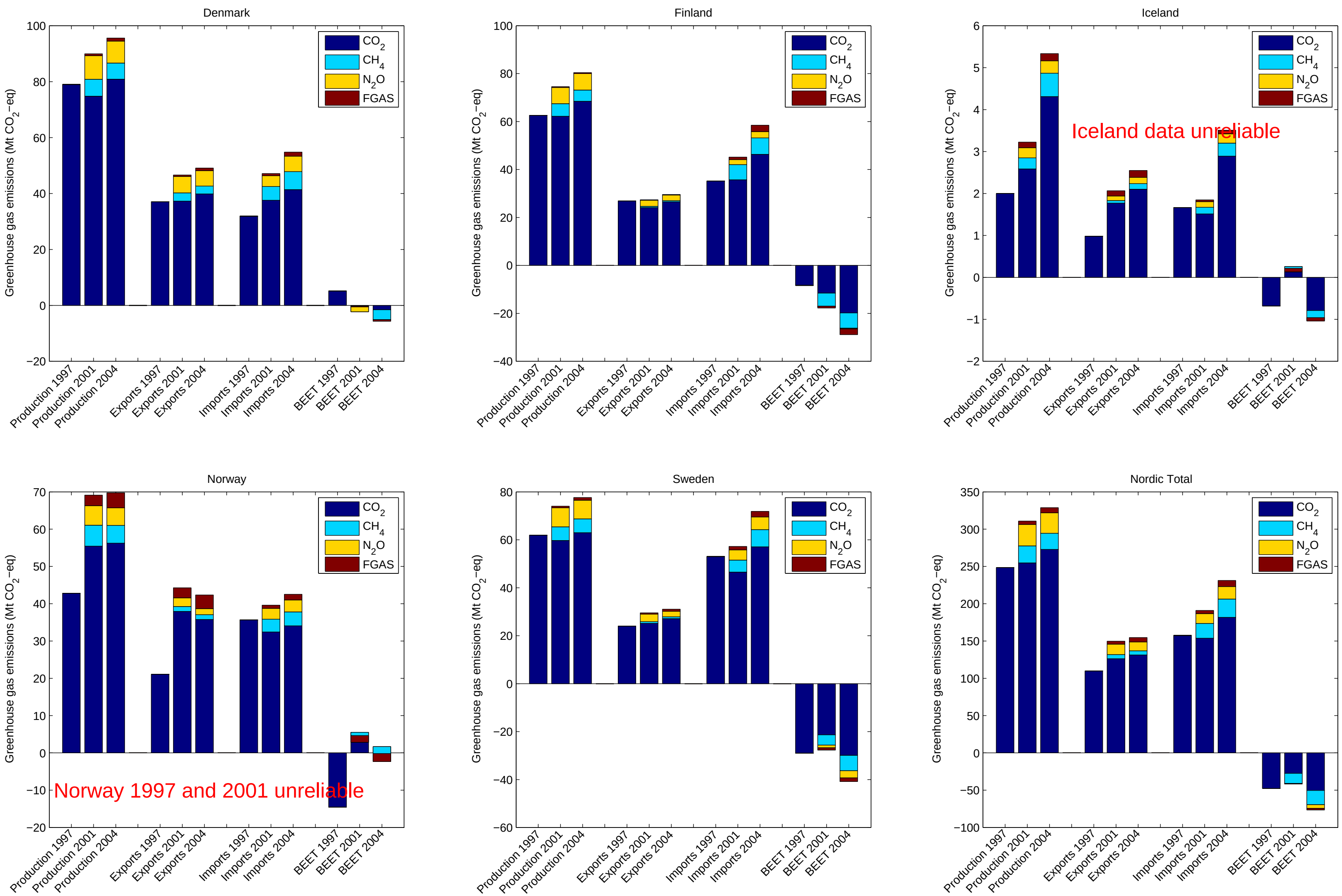

Figure 17: The territorial emissions, exported emissions, imported emissions, and trade balance for the Nordic countries. Not that the scale is different in each region.

Table 9: The emissions embodied in exports, imports, and the balance of emissions embodied in trade (BEET).

	Exports (Mt CO_2-eq)		Imports (Mt CO_2-eq)		BEET (Mt CO_2-eq)	
	2001	2004	2001	2004	2001	2004
Denmark	47	49	47	55	-1	-6
Finland	27	30	45	58	-18	-29
Iceland	*2*	*3*	*2*	*4*	*0*	*-1*
Norway	*44*	42	*40*	43	*5*	0
Sweden	30	31	57	72	-28	-41
Total	150	155	191	231	-41	-77

Values in italics for Norway and Iceland are unreliable.

Table 10: The emissions embodied in exports, imports, and the balance of emissions embodied in trade (BEET) as a share of territorial emissions.

	Exports (%)			Imports (%)			BEET (%)		
	1997	2001	2004	1997	2001	2004	1997	2001	2004
Denmark	47	52	51	40	52	57	7	-1	-6
Finland	43	37	37	56	61	73	-13	-24	-36
Iceland	*49*	*64*	*48*	*83*	*57*	*66*	*-34*	*7*	*-18*
Norway	*49*	*64*	61	*83*	*57*	61	*-34*	*7*	0
Sweden	39	40	40	86	77	93	-47	-37	-53
Total	44	48	47	63	61	70	-19	-13	-23

Values in italics for Norway and Iceland are unreliable.

Figure 17 shows that generally the imported emissions are increasing faster than the exported emission (giving a growing trade deficit in terms of emissions). This is despite significant monetary trade surplus in the Nordic countries (Figure 10). This indicates that there is a structural change in traded products, an issue which is explored further below. As a share of total emissions the exported emissions are roughly constant (Table 10), which indicates that the exported emissions are changing in roughly the same rate as total emissions. For relatively stable economies this result is probably not surprising as the economic structure will only change gradually (that is, the export mix will change only gradually). In addition, many policies on production efficiency will likely affect both domestic and export orientated industries. Compared to other countries, the Nordic countries have a higher share of emissions embodied in exports than the average, though this is expected for small and open economies (Peters and Hertwich 2008a).

The share of imports in total emissions in the Nordic countries shows a general increasing trend, most notably from 2001 to 2004 (Table 10). At the aggregate, the Nordic countries are importing 40Mt CO_2-eq more in 2004 than in 2001 (Table 9). The largest changes were in Finland and Sweden. In the case of Sweden, an equivalent of almost 90% of the domestic territorial emissions are imported, and if current trends continue than Sweden will soon import more emissions than it produces domestically. Generally speaking, the Nordic countries are net importers of GHG emissions (exports minus imports) and this net import is increasing over time.

The fact that there are emissions flows between countries is not surprising, particularly in a globalized world. What is of more concern is how and why those imported emissions change over time. In the case of the Nordic countries, the imported emissions are increasing and arguably Nordic territorial emissions would have increased faster if it was not for the increase in imported emissions. However, to determine the implications these changes have on global emissions requires an analysis of how the imported emissions have changed over time, particularly in terms of source regions and type of product. The following country specific results focus on this issue.

4.5.1 Denmark

Figure 18 shows the relative changes in Danish exported and imported emissions in 1997, 2001, and 2004 at the aggregated level. In terms of exports (left) we see that Danish exports are dominated by the export of international transport services and closely followed by the export of various types of manufacturing. At the aggregated level the shares have remained relatively static over time, although there has been modest growth in sea transport. Within the aggregated sectors, there has been growth in processed meat products and chemical products, and a large drop in the export of business services (Table 11). There was large variation in the export of energy products, but these may vary from year to year depending on weather patterns. The change in energy trade between 2001 and 2004 offset some of the increases in other sectors. In terms of regions, the Nordic countries and Europe are by far the most important destination of Danish exports and this is expected due to geographic proximity and open markets. There has been large growth in Danish exports towards Asian countries, most notable China.

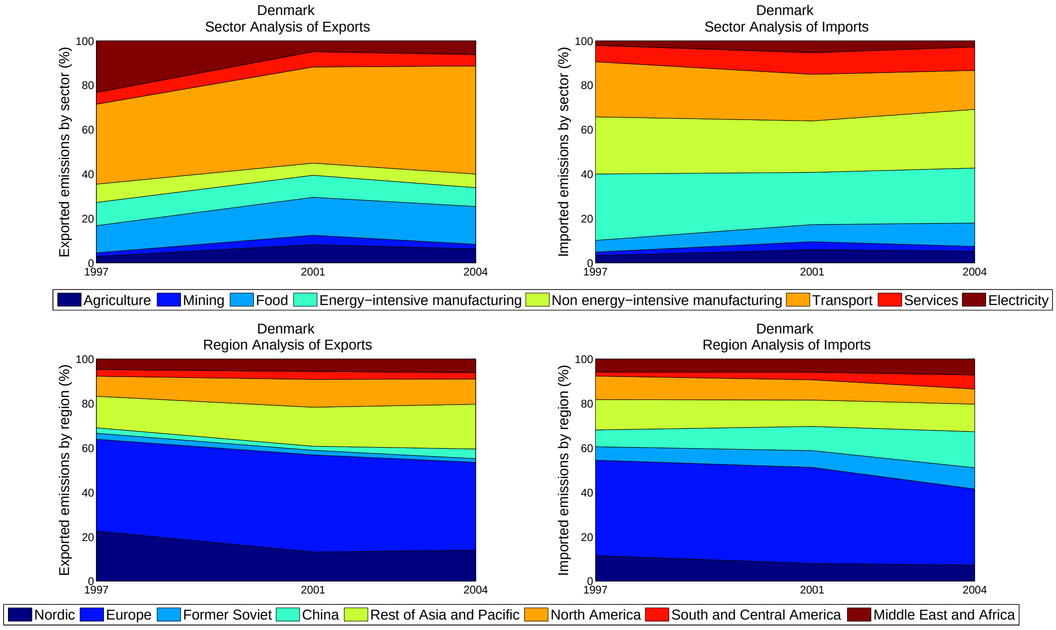

Figure 18: The distribution of exported and imported emissions in Denmark in terms of sectors and regions. Care needs to be taken comparing 1997 with 2001 and 2004 since 1997 only includes CO2 emissions and 2001 and 2004 all GHG (which assumes that in 1997 GHG had the same distribution as CO2).

The right side of Figure 18 shows the change in imports over time, with the changes between 2001 and 2004 in Table 12 Imported emissions have grown at a faster rate than exports (Figure 17). There has been large growth in the import of energy intensive manufacturing (such as chemicals and metals), but the largest increases have occurred in non-energy intensive manufactured products such as electric equipment, motor vehicles and parts, and business services. There has also been a significant shift in the origin of imports with strong growth in Asia and Central and South America. In terms of countries, strong growth has occurred in China, Russian Federation, India, Argentina, and Brazil with drops in the US and some European countries.

Table 11: The growth of Danish exported emissions from 2001 to 2004 for the top 20 regions and sectors.

Export Growth from 2001 to 2004 (GHG)	2001	2004	Annualized growth (%/year)	Export Growth from 2001 to 2004 (GHG)	2001	2004	Annualized growth (%/year)
Germany	5.9	6	0.7	Sea transport	16.7	20	6.3
United States	4.9	4.6	-2.1	Meat products, other	3.3	3.8	4.2
Japan	3.6	3.7	1.3	Electricity	2.3	3.1	10
United Kingdom	3.3	3.1	-2.5	Chemical, rubber, plastic products	2.3	2.6	3.3
Sweden	2.9	3.4	5	Air transport	2.1	2.2	1.2
Rest of EFTA	2.3	2.8	5.7	Dairy products	1.9	1.6	-4.7
France	2.1	1.6	-9.4	Food products, other	1.6	1.5	-1.6
Italy	1.9	1.7	-3.2	Land Transport	1.4	1.7	6.2
Rest of Middle East	1.4	1.6	3.2	Machinery and equipment, other	1	1.2	6.9
China	0.9	2.1	35.5	Animal products, other	0.9	1.4	15
Netherlands	1.2	1.5	8	Crops, other	1.4	0.8	-17.6
Spain	1.1	1	-1.1	Meat: cattle, sheep, goats, horse	1	1	2.9
Korea	0.9	1.1	4.2	Oil	1.6	0.3	-44.7
Hong Kong	0.8	1	8.5	Business services, other	1.3	0.5	-28.1
Greece	0.9	0.8	-5.3	Mineral products, other	0.9	0.7	-7.4
Belgium	0.8	0.7	-4.4	Petroleum and coal products	0.8	0.4	-20.1
Finland	0.8	0.7	-6.4	Trade	0.3	0.8	46
Russian Federation	0.8	0.6	-6.7	Electronic equipment	0.4	0.5	10.5
Canada	0.6	0.6	-0.8	Gas manufacture and distribution	0.6	0.2	-29.4
India	0.4	0.8	31.2	Fishing	0.3	0.4	10.9
Others	9.2	9.9	2.3	Others	4.6	4.4	-1.7
Total	**46.6**	**49.1**	**1.7**	**Total**	**46.6**	**49.1**	**1.7**

Table 12: The growth of Danish imported emissions from 2001 to 2004 for the top 20 regions and sectors.

Import Growth from 2001 to 2004 (GHG)	2001	2004	Annual-ized growth (%/year)	Import Growth from 2001 to 2004 (GHG)	2001	2004	Annual-ized growth (%/year)
China	5.1	8.9	20.1	Chemical, rubber, plastic products	4	5.2	8.8
Germany	6.9	6.5	-1.9	Air transport	4	3.4	-5.4
United States	3.6	2.9	-6.5	Land Transport	3.4	3.8	3.4
Russian Federation	2.4	4	17.6	Ferrous metals	3.1	3.9	7.3
United Kingdom	2.2	2.1	-0.6	Machinery and equipment, other	2.4	2.8	5.6
Poland	2.4	1.8	-9	Sea transport	2.5	2.5	-0.2
Sweden	1.8	2	4.8	Electricity	2.5	1.5	-15.7
Netherlands	1.4	1.6	5.4	Mineral products, other	1.7	1.8	1.1
Rest of Former Soviet Union	1.1	1.4	6.2	Food products, other	1.9	1.5	-6.5
Rest of Middle East	0.8	1.6	23.6	Electronic equipment	1.2	2.1	19.1
Rest of EFTA	1.2	1.2	-0.9	Motor vehicles and parts	0.6	2.2	56.1
Italy	1.3	1.1	-6	Business services, other	1.1	1.5	12.4
France	1.2	1	-5.2	Wearing apparel	1.2	1.4	3.4
India	0.8	1.2	15	Wood products	1.2	1.3	0.8
Argentina	0.4	1.3	54.7	Textiles	1.1	1.4	7.4
Spain	0.8	0.8	0.6	Coal	1.4	1	-10.4
Belgium	0.8	0.7	-3.7	PubAdmin/Defence/ Health/Education	1	1.2	8
Turkey	0.8	0.7	-5.3	Transport equipment, other	1.1	1	-0.6
Korea	0.7	0.8	5.4	Petroleum, coal products	0.8	1.2	13.7
Brazil	0.5	1	27.1	Metal products	0.9	1.1	4.7
Others	10.9	12.1	3.5	Others	9.9	13.1	9.8
Total	**47.1**	**54.8**	**5.1**	**Total**	**47.1**	**54.8**	**5.1**

Directly related to the Kyoto Protocol is the share of imports from Annex B versus non-Annex B countries. In 2001 and 2004, 31 Mt CO_2-eq of the imported emissions originated in Annex B countries, but the share of imported from non-Annex B countries has grown at 15% a year between 2001 and 2004. The share of emissions from non-Annex B countries has increased from 32% in 2001 to 42% in 2004. The non-Annex B countries do not have an emission cap and the large increase in imported emissions from these countries suggests that Danish consumption has increased with the subsequent emissions occurring outside of Denmark and particularly in countries without emission caps.

Table 13: The growth of Danish imported emissions from 2001 to 2004 for Annex B and non-Annex B countries.

	Import Growth from 2001 to 2004 (GHG)		
	2001	**2004**	**Annualized growth (%/year)**
Annex B	32.1	32	-0.2
non-Annex B	15	22.8	15
Total	**47.1**	**54.8**	**5.1**

Comparison with Statistics Denmark study

Statistics Denmark has recently completed a report on embodied emissions for 2005 using a similar methodology as we have used here (Rørmose et al. 2009). Table 14 shows the difference between the Statistics Denmark estimates and the estimates in this report. Statistics Denmark removed the emissions from international transport from their estimates, which was 26 Mt CO_2 in 2004 (our base year) and 35 Mt CO_2 in 2005 (their base year). When excluding international transport we get a similar estimate to Statistics Denmark, well within the uncertainty bounds of the data and methods. When including international transport our results differ, though this is most likely due to the higher emissions from international transport in 2005 compared to 2004. Thus, our studies are consistent in terms of exports when consistent definitions are used.

In terms of imports we get considerably different estimate to Statistics Denmark, though this relates to a different definition of imports. Statistic Denmark did not include the imported emissions to produce exported products. We do not believe this is a consistent method. If the Statistics Denmark method is followed by all countries, then the emissions from the production of global exports will be higher than the emissions from the production of global imports, the difference due to imports to produce exports. For consistency, if this method is adopted the imports for export should be transferred to the export column. Our analysis includes all imports to allow consistency with global exports.

Another difference with the Statistics Denmark approach is that for imported emissions they include the imported emissions to produce imports, but using the domestic technology assumption. This would make their import estimate higher than ours, all else being equal. This is supposedly to capture the global emission to produce imports. This approach is inconsistent with how they have dealt with exports (which did not include the imports to produce the exports and hence global emissions to produce exports would differ to that of imports). As we discussed earlier (Chapter 2) it is possible to consistently deal with imports and exports to get agreement at the global level. Although, if desired, it is possible to use the Statistics Denmark method of re-allocated imports as long as both imports and exports are treated consistently.

Overall, on the export side the Statistics Denmark and our estimates are reassuringly close. On the import side, the import values are not really comparable due to different definitions and methods.

Table 14: A comparison of the estimates used in this report and those from Statistics Denmark.

CO_2 only	This study (2004)	DK study (2005)
Total Territorial emissions	80,871	86,955
…which includes shipping	25,996	34,698
Exports		
…no shipping	20,195	20,368
…with shipping	39,835	52,935
Imports		
…all imports	41,389	
…exclude imports to exports		24,577

4.5.2 Finland

Figure 19 shows the relative changes in Finnish exported and imported emissions for aggregated sectors in 1997, 2001, and 2004. In terms of exports (left) we see that Finnish exports are dominated by energy-intensive manufacturing, particularly pulp and paper, primary metals, and chemicals (Table 15). The aggregated shares have remained relatively stable over time, as have the total exported emissions (Table 10). However, within the aggregated sectors there have been large changes. Pulp and paper has remained relatively static, while there has been large growth in primary metals and chemicals (Table 15). There has been a drop in the export of light manufacturing, particularly electronic equipment. There has been a large change in the service sectors, including transportation, although these are often poorly represented in global datasets (Peters et al. 2010b). In terms of regions, the Nordic countries and Europe are important for Finnish exports. Distinct from the other Nordic countries are the Finnish exports towards the former Soviet countries. There has been strong growth in exports towards the former Soviet countries, China, and Sweden, with large declines in exports to the US.

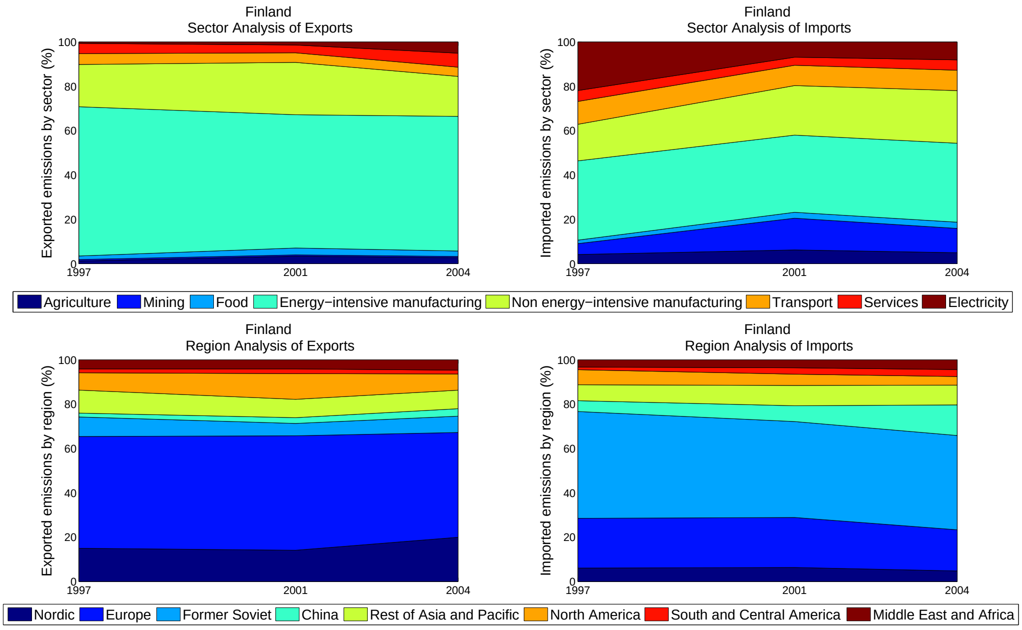

Figure 19: The distribution of exported and imported emissions in Finland in terms of sectors and regions. Care needs to be taken comparing 1997 with 2001 and 2004 since 1997 only includes CO_2 emissions and 2001 and 2004 all GHG (which assumes that in 1997 GHG had the same distribution as CO_2).

The right side of Figure 19 shows the relative change in imports over time. Finnish imported emissions have grown from 43 to 56 Mt CO_2 from 2001 to 2004. In terms of sectors, the large change in electricity and energy trade from 1997 to 2001 dominates the changes, with relatively small changes in distribution from 2001 to 2004. At the detailed level, there has been a rapid increase in the imported emissions of chemical products, metals products, electronic equipment, and motor vehicles (Table 16). The imported emissions from Asia have grown substantially; in particular imported emissions from China have grown at 36% per year from 2001 to 2004 almost tripling in size. There has also been strong growth from the Russian Federation, although a drop from other former Soviet countries.

Table 15 The growth of Finnish exported emissions from 2001 to 2004 for the top 20 regions and sectors.

Export Growth from 2001 to 2004 (GHG)				Export Growth from 2001 to 2004 (GHG)			
	2001	2004	Annualized growth (%/year)		2001	2004	Annualized growth (%/year)
Germany	3.6	3.5	-0.1	Paper products, publishing	7.8	7.5	-1.4
Sweden	2.4	4.5	22.6	Ferrous metals	3.8	5	9.3
United States	2.7	1.8	-12.7	Chemical, rubber, plastic products	3	3.5	5.9
United Kingdom	2.2	1.9	-4.2	Machinery and equipment, other	2.3	2.1	-2.5
Russian Federation	1.3	1.9	12.9	Electronic equipment	1.5	1.1	-8.7
Netherlands	1.2	1.4	7.3	Non-ferrous metals	0.9	1.1	5.3
France	1.3	1.1	-5.3	Electricity	0.4	1.5	58.3
Italy	1	0.9	-3.7	Wood products	0.7	0.8	1
Belgium	0.9	1	4.8	Business services, other	0.5	0.9	18.2
China	0.7	1	12.1	Sea transport	0.6	0.7	7.3
Spain	0.8	0.9	4.9	Non-metallic minerals	0.6	0.5	-7.5
Denmark	0.7	0.7	-1.9	Transport equipment, other	0.5	0.3	-19.8
Rest of EFTA	0.7	0.7	1.6	Trade	0.1	0.7	73
Japan	0.6	0.6	0.3	Metal products	0.4	0.4	-2.2
Rest of Middle East	0.6	0.6	3.9	Animal products, other	0.3	0.5	22
Estonia	0.6	0.6	-1.3	Petroleum and coal products	0.3	0.4	6.5
Poland	0.6	0.5	-2.1	Cereal grains, other	0.6	0.2	-29.8
Switzerland	0.4	0.3	-7.3	Dairy products	0.4	0.3	-2.6
Austria	0.3	0.3	-2.3	Land Transport	0.3	0.3	-7.2
Korea	0.3	0.3	-2.5	Motor vehicles and parts	0.3	0.2	-9.3
Others	4.4	4.8	2.8	Others	2	1.6	-6.4
Total	**27.4**	**29.6**	**2.6**	**Total**	**27.4**	**29.6**	**2.6**

Table 16: The growth of Finnish imported emissions from 2001 to 2004 for the top 20 regions and sectors.

Import Growth from 2001 to 2004 (GHG)				Import Growth from 2001 to 2004 (GHG)			
	2001	2004	Annualized growth (%/year)		2001	2004	Annualized growth (%/year)
Russian Federation	17.9	24	10.2	Chemical, rubber, plastic products	6.4	9	11.7
China	3.2	8.1	36	Ferrous metals	3.2	5.3	18.6
Germany	2.4	2.7	3.7	Electricity	3.1	4.7	15.2
United States	1.9	1.9	0	Electronic equipment	2.6	4.9	23
Sweden	1.4	1.5	2.2	Machinery and equipment, other	3.6	3.6	0.1
Rest of Former Soviet Union	1.6	0.9	-17.6	Oil	3.1	2.9	-1.6
United Kingdom	1.3	1.2	-2.9	Non-ferrous metals	1.8	3.6	26.6
Poland	0.9	1.3	12.1	Sea transport	2.2	2.6	5.8
Australia	1.1	0.9	-3.9	Petroleum and coal products	2	1.5	-9.3
Netherlands	0.8	1.2	14.2	Coal	1.3	1.9	13
Brazil	0.7	0.9	11	Non-metallic minerals	2	1.1	-17.5
Denmark	0.8	0.7	-6.4	Land transport	0.9	1.8	24.7
Rest of Middle East	0.6	0.9	17.7	Forestry	1.1	1.5	8.6
Estonia	0.9	0.6	-10.5	Air transport	1	1	-1.1
Japan	0.7	0.8	2.7	Minerals mining	0.9	1.1	5.2
Italy	0.7	0.7	0.5	Wood products	0.9	1	3.1
Rest of EFTA	0.7	0.7	-1.3	Business services, other	0.6	1	15.4
France	0.6	0.6	-0.8	Gas	1.1	0.5	-25.2
Korea	0.5	0.7	15.7	Motor vehicles and parts	0.5	1	24
Rest of Sub-Saharan Africa	0.2	0.9	68.4	Metal products	0.6	0.8	7
Others	6.5	7.4	4.8	Others	6.1	7.8	8.9
Total	**45.2**	**58.5**	**9**	**Total**	**45.2**	**58.5**	**9**

Directly related to the Kyoto Protocol, is the split in imported emissions between Annex B and non-Annex B countries. Finland had an increase in imported emissions, though most of the growth has been from non-Annex countries. In 2001, 21% of Finland's imports originated in non-Annex B countries and this has grown to 28% in 2004. Imported emissions from non-Annex B countries have grown at a rate of 21% per year from 2001 to 2004. Thus, the emissions from Finnish consumption have grown with most of the growth occurring outside of Finland in countries without emission commitments.

Table 17: The growth of Finnish imported emissions from 2001 to 2004 for Annex B and non-Annex B countries.

	Import Growth from 2001 to 2004 (GHG)		
	2001	**2004**	**Annualized growth (%/year)**
Annex B	35.7	41.9	5.4
non-Annex B	9.4	16.6	20.7
Total	**45.2**	**58.5**	**9**

Comparison with a Finnish study

Under the research project ENVIMAT (www.ymparisto.fi/syke/envimat) estimates have been made on Finnish exported and imported emissions. Table 18 compares our estimates. Our final estimates should be comparable, despite large methodological differences. The most notable difference is the territorial emission estimates between 2004 and 2005. About 11 Mt CO_2 difference occurs in the electricity sector, due to a good year for hydropower and low output in coal fire electricity generation. There was also a strike in the pulp and paper industry which affected emissions.

The estimated exported emissions between the two studies are within expected error bounds. Our estimated imported emissions in 2004–2005 are within expected error bounds, but ENVIMAT has a much larger estimate in 2002. It is not clear why the 2001–2002 estimates are so different. However, based on the underlying changes in international trade and the global economy, other studies suggest a growth in imported emissions from developing countries. Further comparisons between the ENVIMAT and our estimates would be required to determine the reason for the differences. Despite this one key difference, the remainder of the estimates are within expected error bounds.

Table 18: A comparison of the estimates used in this report and those from the Finnish ENVIMAT project.

	This study (2001)	**ENVIMAT (2002)**	**This study (2004)**	**ENVIMAT (2005)**
Total Territorial emissions	74.5	77.0	80.4	69.0
Exports	26.9	30.0	29.0	27.0
Imports	43.4	53.0	56.3	55.0

4.5.3 Iceland

Iceland is not in included in the GTAP database and consequently we do not have explicit estimates for Iceland. In Figure 17 we did a crude estimate of Iceland as a share of Icelandic GDP in the GTAP region “Rest of EFTA”. We did this crude estimate so that we could get a Nordic total. The “Rest of EFTA” region includes all the EFTA countries not represented explicitly in the database, most notably Norway in 1997 and 2001. Since Norway dominates “Rest of EFTA” in 1997 and 2001, the Iceland results would be skewed heavily towards Norwegian trade patterns and average European input structures. In 2004, “Rest of EFTA” includes Iceland and Liechtenstein. To fully represent Iceland in future analysis would require an Icelandic IOT to be submitted to GTAP.

4.5.4 Norway

Norway is only represented explicitly in the database in 2004, and this section focuses on 2004 results only. In 1997 and 2001, Norway is represented in the region “Rest of EFTA” together with other EFTA countries that are not explicitly represented in the database. Our 1997 and 2001 estimates of Norway (Figure 17) are based on GDP shares in the “Rest of EFTA” region. A 2001 estimates was made for Norway using the GTAP database for a WWF report (Reinvang and Peters 2008), but these have not been repeated here. Thus, for Norway, we only do an analysis of the emission distribution in 2004, and do not look at changes from 1997 and 2001 through to 2004. Figure 20: The 2004 Norwegian exported and imported emissions in terms of sectors. and Table 19 show the Norwegian exported and imported emissions in terms of products. Oil and gas together, represent the largest share of exported emissions at around one-third of the total, closely followed by the emissions from international transportation. The distribution between oil and gas in the Norwegian results is probably an artefact of the GTAP data as the split oil/gas is not available in the information submitted to GTAP (Peters 2008c). Energy intensive heavy metals and chemicals production are other key sectors in the profile of Norwegian exports. Together, the oil and gas, shipping, metals, and chemicals account for almost 90% of the exported emissions from Norway. In terms of imported products, sea transportation surprisingly ranks number one and this may be an artefact of the GTAP data due to Norway’s high share of international transport (the same was found in Denmark). The data quality for trade in international transport services is known to be a weakness of the GTAP database (Peters et al. 2010b). Following this, the most important sectors in terms of imports are import of metals and chemicals, with a variety of manufactured products following. The imports are distributed over a wider range of sectors which is expected in most countries.

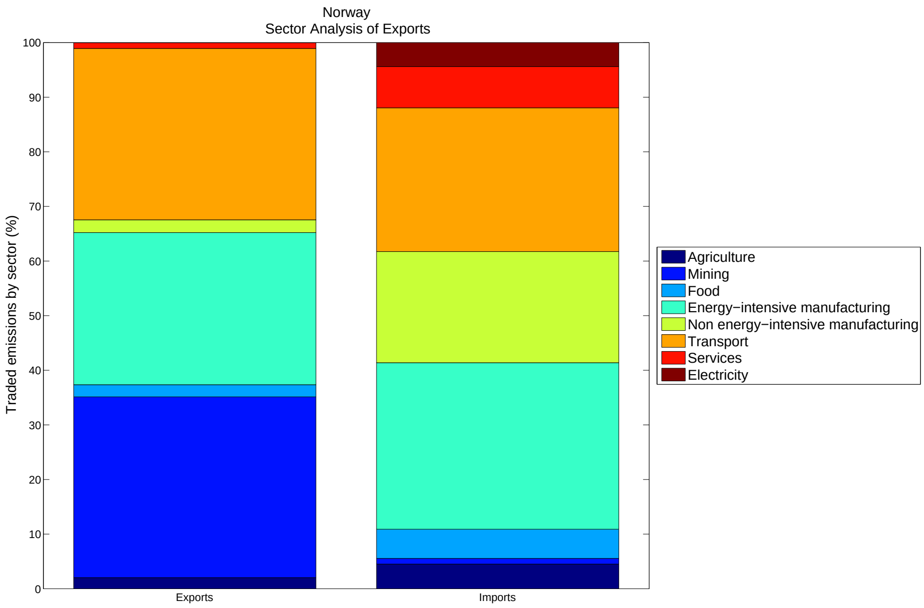

Figure 20: The 2004 Norwegian exported and imported emissions in terms of sectors.

Table 19: The top 20 list of Norwegian exported and imported emissions in terms of products.

	Exports (2004)	Exports (%)		Imports (2004)	Imports (%)
Gas	12	28.2	Sea transport	6.3	14.9
Sea transport	11.7	27.5	Non-ferrous metals	5.1	12.1
Non-ferrous metals	4.2	9.9	Land transport	3.4	8.0
Ferrous metals	2.7	6.4	Chemical, rubber, plastic products	3.1	7.3
Chemical, rubber, plastic products	2.6	6.1	Ferrous metals	2.5	5.9
Petroleum and coal products	1.9	4.5	Electricity	1.9	4.5
Oil	1.7	4.0	Machinery and equipment, other	1.8	4.3
Land transport	1.3	3.1	Air transport	1.5	3.5
Fishing	0.8	1.9	Non-metallic minerals	1.2	2.8
Food products, other	0.8	1.9	Business services, other	1.1	2.6
Machinery and equipment, other	0.4	0.9	Wearing apparel	1.1	2.6
Air transport	0.3	0.7	Transport equipment, other	1	2.4
Paper products, publishing	0.2	0.5	Textiles	0.9	2.1
Business services, other	0.2	0.5	Electronic equipment	0.9	2.1
Minerals mining	0.2	0.5	Food products, other	0.8	1.9
Non-metallic minerals	0.2	0.5	Motor vehicles and parts	0.8	1.9
Transport equipment nec	0.2	0.5	Metal products	0.7	1.7
Motor vehicles and parts	0.1	0.2	PubAdmin/Defence/Health/Educat	0.7	1.7
Wood products	0.1	0.2	Meat: cattle, sheep, goats, horse	0.7	1.7
Metal products	0.1	0.2	Trade	0.6	1.4
Others	0.7	1.6	Others	6.3	14.9
Total	**42.3**	**99.5**	**Total**	**42.5**	**100.5**

Figure 21 and Table 20 show the Norwegian exported and imported emissions in terms of regions. In terms of the destination of Norwegian exports, the European Union is very important followed by the USA. Imports are most concentrated in China and the Russian Federation; however, the European Union is most important at the aggregated level. Other important non-EU countries in terms of imports are Canada, the USA, and Brazil. As for products, trade is more concentrated between a few regions for exports, while imports come from a more diverse range of countries. Table 21 shows the distribution of Norwegian imports between Annex B and non-Annex B countries, with around 60% of the emissions originating in Annex B countries.

Comparison with Norwegian studies

There have been several Norwegian studies in the past (Chapter 3), but Statistics Norway has not performed a historic attribute of trade flows as we have done here. Several studies from Statistic Norway have focussed on related issues (Bruvoll and Fæhn 2006, Fæhn and Bruvoll 2009), but have had a different research question making the studies not comparable to the results in this report.

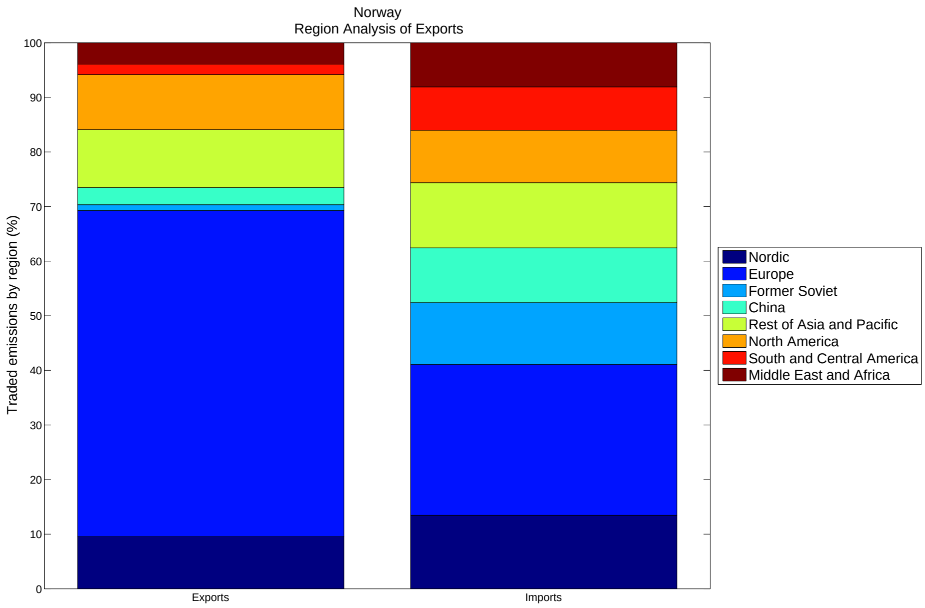

Figure 21: The 2004 exported and imported emissions in terms of regions.

Table 20: The top 20 list of Norwegian exported and imported emissions in terms of regions.

	Exports (2004)	Exports (%)		Imports (2004)	Imports (%)
Germany	10.3	24.3	China	4.3	10.2
United Kingdom	4	9.5	Russian Federation	2.9	6.9
United States	3.7	8.7	Denmark	2.6	6.1
Italy	2.4	5.7	Canada	2.3	5.4
Sweden	2.2	5.2	Germany	2.3	5.4
France	1.9	4.5	Sweden	2.3	5.4
Netherlands	1.8	4.3	Rest of Former Soviet Union	2	4.7
Japan	1.8	4.3	Brazil	1.9	4.5
Belgium	1.4	3.3	United States	1.7	4.0
China	1.3	3.1	United Kingdom	1.6	3.8
Denmark	1.1	2.6	Poland	1.5	3.5
Spain	1	2.4	Rest of Middle East	1.3	3.1
Rest of Middle East	0.7	1.7	Greece	1.1	2.6
Finland	0.7	1.7	Netherlands	1	2.4
Korea	0.5	1.2	Japan	0.9	2.1
Greece	0.5	1.2	Finland	0.7	1.7
Canada	0.5	1.2	Spain	0.7	1.7
Ireland	0.4	0.9	India	0.7	1.7
India	0.4	0.9	Italy	0.7	1.7
Poland	0.4	0.9	South Africa	0.6	1.4
Others	5.4	12.8	Others	9.5	22.5
Total	**42.3**	**100**	**Total**	**42.5**	**100.5**

Table 21: The 2004 distribution of Norwegian imports between Annex B and non-Annex B countries.

Imports (2004)	
Annex B	26.1
non-Annex B	16.4
Total	**42.5**

4.5.5 Sweden

Figure 22 shows the relative changes in Swedish exported and imported emissions at the aggregated level for 1997, 2001, and 2004. Swedish exports (left) are dominated by energy-intensive manufacturing and sea transportation. Within the aggregated sectors there have been large changes (Table 22). International shipping has grown substantially, as has the export of chemicals and manufactured products. There was a drop in the export of business services and food products. In terms of regions, the Nordic countries and Europe are important for Swedish exports. There has been strong growth in exports to China, and a decline in exports to the EU and US.

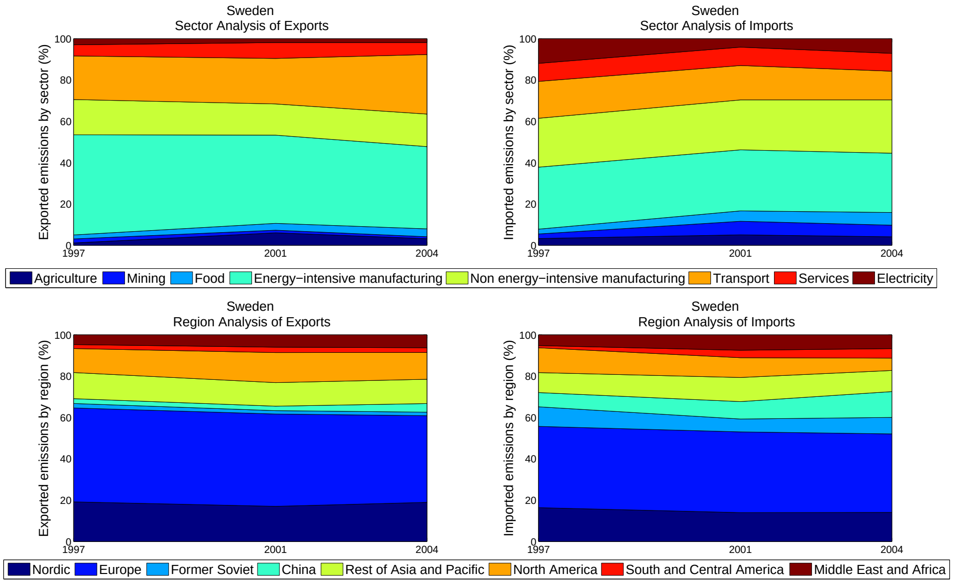

Figure 22: The distribution of exported and imported emissions in Sweden in terms of sectors and regions. Care needs to be taken comparing 1997 with 2001 and 2004 since 1997 only includes CO_2 emissions and 2001 and 2004 all GHG (which assumes that in 1997 GHG had the same distribution as CO_2).

Table 22: The growth of Swedish exported emissions from 2001 to 2004 for the top 20 regions and sectors.

Export Growth from 2001 to 2004 (GHG)				Export Growth from 2001 to 2004 (GHG)			
	2001	2004	Annualized growth (%/year)		2001	2004	Annualized growth (%/year)
United States	3.7	3.5	-1.7	Sea transport	4.6	6.9	14.4
Germany	3.3	2.9	-4.3	Ferrous metals	4.4	4.2	-1.8
United Kingdom	2	2.3	4.8	Chemical, rubber, plastic products	2.2	3.1	12.4
Rest of EFTA	1.9	2.4	7.7	Paper products, publishing	2.6	2.5	-1.4
Denmark	1.8	2	4.8	Machinery and equipment, other	1.2	1.4	5.5
Finland	1.4	1.5	2.2	Non-metallic minerals	1.5	1.1	-11
France	1.4	1.3	-3.8	Air transport	1.1	1.2	2.4
Italy	1.3	1.2	-0.9	Business services, other	1.6	0.6	-28.3
Japan	1.2	1.1	-5.2	Motor vehicles and parts	0.9	1.1	7.2
China	0.6	1.3	26.8	Petroleum and coal products	1.1	0.6	-15.3
Netherlands	1	0.8	-5.1	Non-ferrous metals	0.8	0.8	0.9
Rest of Middle East	0.9	0.9	0	Land transport	0.7	0.8	2.7
Belgium	0.8	1	4.7	Electronic equipment	0.7	0.9	8.6
Spain	0.8	0.8	-0.6	Wood products	0.8	0.7	-2.9
Poland	0.5	0.4	-4.3	Trade	0.4	0.9	33.8
Canada	0.4	0.4	-5.3	Electricity	0.6	0.6	0.7
Russian Federation	0.3	0.4	5.9	Cereal grains, other	0.8	0.1	-43.4
Austria	0.4	0.3	-4.2	Metal products	0.4	0.4	0.7
Korea	0.3	0.4	3.4	Food products, other	0.4	0.4	0.2
Switzerland	0.3	0.3	-6.9	Minerals mining	0.4	0.3	-7.9
Others	5.2	6	5.4	Others	2.5	2.4	-0.5
Total	**29.5**	**31**	**1.7**	**Total**	**29.5**	**31**	**1.7**

The right side of Figure 22 shows the relative change in Swedish imported emissions over time. Swedish imported emissions have grown from 57 to 72 Mt CO_2 from 2001 to 2004. Apart from electricity trade, the relative contribution of the aggregated sectors in Swedish imports has remained relatively static. At the detailed level, there has been a rapid increase in the imported emissions of chemical products, metals products, electronic equipment, and motor vehicles. The imported emissions from Asia have grown substantially; in particular imported emissions from China have grown at 23% per year from 2001 to 2004. There has also been very strong growth in imported emissions from the Russian Federation, Poland, and Brazil.

Table 23: The growth of Swedish imported emissions from 2001 to 2004 for the top 20 regions and sectors.

Import Growth from 2001 to 2004 (GHG)				Import Growth from 2001 to 2004 (GHG)			
	2001	2004	Annualized growth (%/year)		2001	2004	Annualized growth (%/year)
China	4.8	9	23.1	Chemical, rubber, plastic products	6.2	7.8	8
Germany	6.3	6.8	2.7	Ferrous metals	4.3	6.1	12
United States	4.7	3.7	-8	Machinery and equipment, other	4.2	4.7	4.1
Russian Federation	2.7	4.8	22.1	Land transport	3.7	4.3	4.8
Finland	2.4	4.5	22.6	Electricity	2.3	5.1	29.6
United Kingdom	3	3.8	7.8	Sea transport	3.3	3.9	5.2
Poland	1.7	4.9	41.5	Electronic equipment	2.3	3.9	20
Denmark	2.9	3.4	5	Business services, other	2.5	3	5.5
Rest of EFTA	2.6	2.2	-6	Oil	2.8	2.6	-1.5
Rest of Middle East	2	2.2	3.8	Non-metallic minerals	2.4	2.3	-1.9
Netherlands	1.8	2	4.2	Non-ferrous metals	2	2.4	7.2
France	1.7	1.5	-5.1	Air transport	2.4	1.8	-9.7
Italy	1.4	1.4	-1.3	Motor vehicles and parts	1.6	2.1	10.5
Brazil	0.8	1.7	30.9	Metal products	1.2	1.4	5.3
Spain	1.1	1.3	7.9	Textiles	1	1.4	10.7
India	1	1.3	8.7	Petroleum and coal products	1.3	1.2	-1.3
Belgium	1.1	1	-2.2	Meat: cattle, sheep, goats, horse	0.7	1.5	28.3
Japan	1.1	0.9	-7.3	Food products, other	1	1.3	10.1
Rest of Former Soviet Union	0.9	1.1	5.8	Wood products	1.1	1.2	4.2
Thailand	0.7	0.9	6.3	Wearing apparel	0.8	1.2	13.8
Others	12.5	13.6	2.8	Others	10.1	12.6	7.6
Total	**57.2**	**71.8**	**7.9**	**Total**	**57.2**	**71.8**	**7.9**

Again directly related to the Kyoto Protocol, is the split in imported emissions between Annex B and non-Annex B countries. Sweden had an increase in imported emissions, though most of the growth has been from non-Annex countries. In 2001, 30% of Sweden's imports originated in non-Annex B countries and this has grown to 33% in 2004. Imported emissions from non-Annex B countries have grown at a rate of 12% per year from 2001 to 2004, which is lower than for the other Nordic countries.

Table 24: The growth of Swedish imported emissions from 2001 to 2004 for Annex B and non-Annex B countries.

	Import Growth from 2001 to 2004 (GHG)		
	2001	2004	Annualized growth (%/year)
Annex B	40.3	48	6
non-Annex B	16.9	23.8	12.1
Total	**57.2**	**71.8**	**7.9**

Comparison with Statistics Sweden

Statistics Sweden has performed similar estimates to those reported here. Table 25 compares our estimates with those of Statistics Sweden. The Swedish estimates are annual and thus we can compare directly with our data. First, we have used the same NAMEA estimates as Sweden so our national totals are the same. This also means that Statistic Sweden has included international transportation in their figures, in contrast to Denmark. The estimates of exported emissions are very similar and well within the expected error bounds. Only the results that have used the same methodologies are shown here. In terms of imports, Statistic Sweden has a much higher estimate though the growth rate between 2001 and 2004 is similar (around 23%). The Statistics Sweden estimate is higher than ours as they have used the domestic technology assumption in each of the importing partners. This means that the imported emissions include any imported emissions required to produce them in each of the importing countries. Our analysis only included domestic emissions to produce imported products. Thus, if the Swedish methodology was applied to all countries, the global imported emissions would be higher than the global exported emissions. Overall, other than for the magnitude of imported emissions, our estimates are consistent given the differences in input data and model detail.

It is worth noting, that there is overlap between the approach taken by Statistics Sweden and that taken by Statistics Denmark. Even though Statistics Denmark removed the imported emissions required to produce exports, the method of calculation was the similar as Statistics Sweden.

Table 25: A comparison of the estimates used in this report and those from Statistics Sweden.

	This study (2001)	SCB (2001)	This study (2004)	SCB (2004)
Total Territorial emissions	59.7	59.7	62.9	62.9
Exports	25.2	23.8	27.1	27.3
Imports	46.5	66	57	82

4.6 Summary of the Carbon Footprint of the Nordic Countries

Although the main Nordic countries have several distinct features, the overall trends in GHG emissions are generally the same. According to the NAMEA's, including international transportation, there is a slight increase in the territorial emissions. However, the carbon footprint of the Nordic countries is growing faster than the territorial emissions. The trends indicate that increased consumption of manufactured products is one growing consumption category, particularly for products produced in China.

A closer inspection of international trade shows that there has been a strong increase in imports of chemicals and both energy-intensive and non-energy intensive products into the Nordic countries. This growth is much higher than the small increase in the emissions to produce exported products. Most of the increase in imported emissions originates in Asia, most notably China, and also the Russian Federation. We have not analyzed the underlying causes for this, but based on evidence it is likely that these changes in trade patterns are due to pre-existing economic conditions and not climate policy (Peters 2010b).

We compared our results with those undertaken by the Statistical Offices in the Nordic countries, where possible. In general, when we had a common system boundary we found that we had good agreement with exported emissions. Our import estimates varied, but we could identify that this was due to different definitions of what to include in the imported emissions. We have used an approach that leads to consistency at the global level in exports and imports. However, the Nordic countries have taken a different definition of imported emissions. Given our estimates of exports are similar, and that exports of one country are another countries imports, we feel confident that if we apply the same definitions, our estimates would converge.

We have only shown key headline results and it is possible with more resources to provide more detailed results. The results shown here are only to give a flavour of what is possible and in no way be comprehensive. More specific country and sector studies can be performed. A deeper analysis will also identify more data issues and inconsistencies between different studies. This information can be further used to improve the international data sets and the accuracy of estimates.

5. Recommendations

Hopefully throughout this report we have shown that an analysis of carbon footprint and emissions embodied in trade provides useful information for policy development. We have shown how the carbon footprint can be used in conjunction with existing territorial emission inventories to provide a different perspective on emission drivers. We do not see the carbon footprint as an alternative to the existing territorial emission inventories, but rather a supplement. It is within this context that the following broad recommendations are made for the future application of the carbon footprint and related methods:

- Retain the standard territorial emission inventories consistent with the system of national accounts (NAMEA's)
- At regular intervals, perhaps in conjunction with other countries, calculate a carbon footprint and estimate the emissions embodied in both exports and imports.
- Use the territorial emission inventories in conjunction with the carbon footprint and embodied emission indicators to track the development of emissions over time and monitor the effect of changed policies, both climate and non-climate, on domestic and global emissions.

It is currently possible to do all these steps with available data and methods. However, by coordinating efforts significant improvements can be made in reducing uncertainty and facilitating comparability of estimates between countries. In this chapter, we recommend strategies to improve current definitions, methods, and data. In many cases, this can lead to win-win situations by avoiding existing duplications and inconsistencies. We also discuss several policy areas that may benefit greatly from the use of carbon footprint analysis.

5.1 Definitions

As we saw in the review section, and in the study comparisons in the results, different analysts have used different definitions. This makes studies not comparable, and gives the user the impression that carbon footprint analysis is extremely inaccurate. To some extent the definitions used by some analysts reflects the methods they applied.

> *Recommendation 1*: Base the theoretical background of the carbon footprint and embodied emissions around input-output analysis, while allowing the analyst to decide what method to use in final estimates.

This recommendation does not mean to imply superiority to IOA, but rather, as has been shown by numerous authors, most methods can be written in the same notation as IOA (Heijungs and Suh 2002; Peters 2007a). Most work in this area has been done on the links between LCA and IOA (Suh et al. 2004). Even though LCA and IOA have quite different data needs and philosophies, it is important to realize that they can be formulated identically mathematically. With a common theoretical backbone, it becomes easier for the analyst to specify the precise definition of the carbon footprint or embodied emissions used. The theoretical background in Section 2.3 conforms to standard IOA and, by using relevant approximations, can be generalized to other methods and hence definitions.

> *Recommendation 2*: Studies should specify clearly the treatment of imports, both to intermediate and final consumers, and specify whether the method applied gives a match between global exports and imports when applied equally to all countries.

Most studies vary in the way they treat imports. The IOA performed by Statistics Denmark and Statistics Sweden, for example, would not give a global balance in exports and imports which means they give more or less weight to exports or imports. Many LCA methods do not explicitly have a treatment of imports, for example, and by applying standard LCA factors to imported produces will have some ambiguity to how imports to intermediate industries are dealt with. If analysts are encouraged to clearly specify the treatment of imports and implications both for the country under analysis and if applied at the global level, it will go a long way to making studies more comparable.

> *Recommendation 3*: A consensus working group or task force process is needed to clearly define a set of definitions that would meet the needs of a wide group of policy makers and interest groups.

It would make sense for such a process to occur via the IPCC, UN Environmental Accounts or similar, which has existing expertise in this area and already has standardized various emission accounting methods. The existing approaches at the product level, such as the ISO process (ISO 2006b, 2010), PAS2050 in the UK (BSI 2008), WRI GHG Protocol (WRI and WBCSD 2004), and similar, are not applicable to the national level. The best existing examples at the nation level are the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006) or linking environmental and economic accounting (SEEA 2003).

5.2 Methods

As discussed in section 2.1 there are numerous methods that to some extent can estimate a national level carbon footprint. Each method has its advantages and disadvantages, but it is reasonable to say that some methods will always struggle to handle national level emission inventories, such as bottom-up process-based LCA methods. The analyst should have some flexibility in choosing a method that can answer a given research question, however, there probably should be a recommend set of methods and minimum requirements to meet a sufficiently robust carbon footprint estimates.

> *Recommendation 4 (see also 3)*: A consensus working group or task force process is needed to clearly define a set of methods and minimum criteria that can meet the needs of a wide group of policy makers and interest groups.

Based on existing reviews the most versatile method for carbon footprint analysis is multi-regional input-output analysis. Several studies have provided recommendations on how to obtain sufficient sector and region coverage detail (Andrew et al. 2009; Su and Ang 2010; Su et al. 2010) and this was discussed in section 2.4.5. Data is becoming increasingly wide-spread and there are several global data sets already available and several new data sets currently being developed, most with an EU focus (see Section 3.1, Peters et al. 2010b). Based on this, it is clear that MRIOA will be the primary method for country level footprint and trade analysis across a wide range of environmental issues. Thus, it would be likely that the consensus group would favour an MRIOA method, but further clarification is needed on the necessary region and sector detail, and on methodological assumptions that can be justified. A combination of Recommendations 3 and 4 would lead to a highly valued and relevant set of guidelines to make the foundation of future footprint and embodied emission studies.

5.3 Data improvements

An undisputed weakness of previous studies, even global MRIO studies, is the quality of the underlying data. This does not reflect a lack of data, but rather, a lack of coordination between statistical offices and data repositories. In addition, statistical offices have remained surprisingly distanced from global data base development which means researchers without the necessary expertise in national accounting are compiling the statistics from a variety of ad-hoc sources. Most recommendations for improving footprint and trade analysis relate to data improvements.

> *Recommendation 5*: Make the submissions of consistent NAMEA's obligatory for all countries reporting to the System of National Accounts.

The officially reported emissions data to UNFCCC is not suitable for economic modelling as it is not consistent with the principles used in the System of National Accounts. Given the importance of economic modelling for understanding climate and other policies, it is currently a great statistical weakness that all countries that report data to the UN Statistical Department are not required to additionally report NAMEAs for criteria pollutants. As a minimum, countries that report to the UNFCCC should also report NAMEA's consistent with the national accounts. Our recommendation also calls for *consistent* NAMEAs, which implies they should be comparable across countries as far as feasible. There are guidelines available for the compilation of NAMEA's (SEEA 2003), but consistency does not always exist (Hass 2000).

> *Recommendation 6*: Set up a single repository for the SNA Main Aggregates, SUT's, IOT's, international trade data, and NAMEA's, most obviously at the UN Statistics Division.

This recommendation should be seen as a considerable time saving measure for National Statistical Offices. Current Statistical Offices report IOT's to a variety of bodies, often in different formats. Energy data is reported to several institutes in different formats (e.g., IEA, OECD, UN). Trade data is reported to different institutions. And emissions data is reported to different institutions, in many cases, with different definitions. Compounding this is a variety of additional institutes that use reported data to estimate their own emissions statistics or other harmonized data sets. A single data repository will greatly reduce duplication and the repository can additionally act as a data distributer. This means that statistical offices have only one reporting channel. The UNSD already houses National Accounts data, receives trade data, and receives energy statistics. The IOT's and SUT's are the foundation of the National Accounts and thus, many countries if not a majority, that report the National Accounts data to UNSD will also compile SUT's or IOT's. Thus, it is not a great step to additionally report consistent IOT's and SUT's. It is not necessary, at least initially, for all countries to report in a consistent sector classification, but the existence of a common repository can act as a platform to converge to a consistent classification (a process already in place in many regions).

> *Recommendation 7*: At a high level strive to obtain consistency of the SNA Main Aggregations, SUT's, IOT's, international trade data, and NAMEA's.

This recommendation is broad reaching and would probably be widely accepted by most statisticians and analysts. While perfect harmony between data sets may be some time off, gradual improvements over time will greatly streamline the operation of statistical offices and allow analysts to focus on analysis and not consistency checking. Complete harmony may be decades away, but the process has to start at some time. The data sets mentioned in the recommendation are widely used and essential for most analyses. Having a single repository for these data will act as a platform to check for consistency. If the data repository is sufficiently well resourced, then this can act as a first consistency check.

Within Recommendation 7 there are several areas that might need priority. A key priority area would be consistency in international trade data. Most analysts employ a variety of assumptions to make the trade data consistent (Narayanan and Walmsley 2008). International trade in services is also a known problem area and some models clearly state they use "heroic assumptions". Consistency between economic and emissions data is probably a bigger problem than assumed, as was discussed in a Nordic study (Hass 2000) and as we have found in our studies (Andrew et al. 2009). Many of these problems are not published, but are simply known by the analysts familiar with the data. Thus, within Recommendation 7 it is probably beneficial to work through some priority areas, some of which may be taken up by different authorities.

> *Recommendation 8:* Assess the option of having a single global MRIO maintained and regularly updated by one institute (perhaps in collaboration with others).

It is not clear whether a single global MRIO is desirable. Different datasets often have different properties required to fit a given application (Peters et al. 2010b). However, with a concerted effort, maybe the differences between data sets can be reduced and it may be that most MRIO analysts can work with the same base data. If Recommendations 6 and 7 were followed up, then the only option may be to have the same base data as input into an MRIOT. Recommendation 8 can be combined with Recommendations 3 and 4 to have a broad working group focused on the development and application of MRIOA, footprint, and trade analysis.

5.4 Policy applications

In its early days, IOA was a leading methodology in economic analysis. Wassily Leontief, the founder of modern IOA, focussed on strong and robust data sufficient to answer a variety of policy questions. For a variety of reasons, IOA has now dropped out of most economists" language and is rarely taught in the favour of more orthodox economic methods. Ironically, SUTs and IOT's are still the foundation of the System of National Accounts and additionally IOT's are generally the core of most sectoral computable general equilibrium models.

IOA, however, has had resurgence in the last 10–20 years due to its strength in analyzing a variety of environmental problems (Suh and Kagawa 2005; Wiedmann et al. 2007; Wiedmann 2009b, a; Hoekstra

2010). IOA is beginning to be taught in environmentally related courses outside of mainstream economics. A wide range of journals now publish IO related studies and studies are published in the top ranked journals (e.g., Carter 1974; Davis and Caldeira 2010). The resurgence in IOA may come as a surprise to many economists, but it is set to continue with several large projects funded and more likely to follow.

In this section, we discuss some of the key applications of MRIO in the context of climate policy.

> *Application 1 (drivers)*: Use input-output models to reallocate emissions from the producer to consumer to give new insight into the consumption patterns which have the greatest carbon footprint.

This is probably the simplest and most standard application of IOA. IOA enumerates the supply chain to redistribute emissions from producers to consumers. This is often applied in the analysis of household consumption (e.g. Herendeen 1978; Munksgaard et al. 2000; Hertwich 2005; Peters and Hertwich 2006b; Druckman and Jackson 2009; Baiocchi et al. 2010; Lenzen and Peters 2010) and using this more broadly in policy may lead to more efficient climate policy (Peters et al. 2009).

> *Application 2 (monitoring emission transfers or carbon migration)*: The impacts of greenhouse gas emissions are essentially independent of location (global pollutants) and multi-region input-output models can be used to track if policy has unintentionally caused emissions to increase outside of an administered area (system boundary).

This is an extension of Application 1 to the global level and is a key basis for performing a footprint calculation. If a country implements policies which (perhaps unintentionally) causes emissions to increase in another country then this may be inconsistent with their climate objectives. More explicitly, if a country with an emission limitation reduces emissions while consumption within that country causes emissions to increase in other countries without an emissions limitation then this may offset the goals of climate policy.

The change in emissions may be due explicitly to climate policy (strong carbon leakage), but this is a subset of the change in emissions due to pre-existing policies and economic conditions (which has been called weak carbon leakage, demand-driven carbon leakage, emission transfers, or carbon migration). Studies on the UK and US show that weak carbon leakage is important and growing (Weber and Matthews 2007; Druckman and Jackson 2009; Baiocchi and Minx 2010; Wiedmann et al. 2010). By comparing global studies from different research groups but using different base years, we find that more broadly weak carbon leakage is increasing between Annex B and non-Annex B countries (Ahmad and Wyckoff 2003; Peters and Hertwich 2008a; Hertwich and Peters 2009; Nakano et al. 2009; Davis and Caldeira 2010). Strong carbon leakage as defined by the IPCC is a subset of these studies (transfers explicitly due to climate policy). Strong carbon leakage has been small in the past, and models claim it will be small in the future (Barker et al. 2007; Carbon Trust 2008, 2010). Thus, if current trends continue the analysis of weak carbon leakage or carbon migration should be significantly more prevalent. See Section 1.3 for a more detailed discussion of these issues.

> *Application 3 (country and sector comparisons)*: A multi-region input-output model represents the production technologies in numerous countries and sectors in a consistent way and therefore the models allow detailed comparisons of countries and sectors which include the global supply chain consistently.

This is also a classic input-output application that allows the emissions to produce a given quantity of a sector output (e.g., meat) to be compared across countries. This will identify how the production systems vary between countries, and how much of this is due to domestic technologies and how much is due to global linkages in the supply chain.

> *Application 4 (assess risk to carbon pricing)*: A multi-region input-output model represents the production technologies in numerous countries and sectors in a consistent way and therefore by applying a tax rate in various countries and sectors gives a quick assessment of how the tax may change prices in different countries and sectors.

This is a consequence of Application 3 that allows, for example, assessing the price changes within and outside the EU due to a carbon price on energy-intensive sectors within the EU. It can also be used to design policy by determining how much of a sector and region coverage is needed in an emission trading system to cover an adequate share of emissions (Peters 2008a). An extension of Application 4 allows an analysis of which sectors and which countries have the greatest competiveness concerns given a different tax level in different countries in different sectors. For example, if a carbon tax is placed on energy-intensive industries; will it affect the domestic producers and exporters of manufactured products which use energy-intensive products as inputs to production? This type of approach has been used successfully to analyze competitiveness concerns (Stern 2006; Peters 2008a; Weber and Peters 2009)

> *Application 5 (starting point for in-depth studies)*: A multi-region input-output model can act as a starting point for analyzing country specific key sectors and value chains in more detail.

This is also a consequence of Application 3. Generally speaking, IO results provide a consistent and complete analysis, but often have aggregated sectors. Bottom-up studies usually have more details, but often lack coverage. One method of making IO results more detailed is to use the IO model to identify key sectors and value chains and slowly integrate more detailed bottom-up information (Treloar 1997; Treloar et al. 2001). This allows more detail on sectors that are of high importance. The value chains or sectors for in-depth studies may be chosen for strategic importance, their mere size or if the study focuses on a particular production system (e.g., Hawkins et al. 2007; Izard et al. 2010). For instance, Finland may detail the pulp and paper sector, Sweden may detail the car manufacturing sector, Denmark may detail the food processing sector, and Norway may detail the oil and gas sector. Using the MRIO model as a foundation provides global coverage and the inclusion of bottom-up data (such as LCA data, physical flow data, or similar) improves the accuracy of the analysis for the key sectors.

This quick overview of policy applications highlights a few areas where carbon footprint and embodied emission studies can provide relevant results for policy. There is already a large range of methods available for analysts and much of the necessary data is already available. The recent rapid growth in IO studies, particularly focused on environmental policy (Hoekstra 2010), emphasizes the usefulness of the methods in a variety of applications. We hope this short overview gives the reader some feeling for the untapped potential of these and related methods.

6. Conclusion

This report has covered many aspects of carbon footprints and trade adjusted emission inventories. Here we give a brief summary of each chapter and its broad implications.

Chapter 1 gave a background discussion of carbon footprints and trade adjusted emissions inventories. It pointed to the historic background which dates back to the 1970's and possibly earlier. This highlights that the methods have a strong methodological foundation. The chapter went on to discuss some of the main applications and issues to put the report into context. There are many preconceived assumptions on what a carbon footprint is and how it can be used, and hopefully Chapter 1 dispels a few myths.

Chapter 2 gave a methodological review of the key methods used in carbon footprints and trade-adjusted emission inventories. There have been many reviews in the past and we did not attempt to replicate work previously done. The chapter gave an overview of the methods generally used and their main advantages and disadvantages. For national level studies, most reviews suggest the use of multi-region input-output analysis and Chapter 2 gives a more detailed description of this method. This is the foundation of the method used in this report. Various assumptions are then applied to the method to highlight the weaknesses of other methods and identify key aspects that need to be covered in any method.

Chapter 3 gives a literature review of studies performed on the Nordic countries. These studies cover a variety of methods, and within some methods, different definitions and assumptions are included. Thus, a key conclusion is that it is not really possible to compare studies unless they can be identified to be directly comparable. The spread of estimates reflects different definitions more than differences in carbon footprints. Thus, studies need a clear statement of the definitions used.

Chapter 4 gives details on the carbon footprints of the Nordic countries from a consumption perspective and from a trade perspective. A multi-region input-output model was used with a base year in 1997, 2001, and 2004. The results cover only the key headline results and the model can be used to give much more detail in country and sector detail, in additional to changes over time. The broad conclusion is that the carbon footprint is growing faster than territorial emission in the Nordic countries. This is primarily due to increased consumption of products produced in China, and particularly, various manufactured products. The Chapter also compared with some specific Nordic studies to highlight differences in definitions and methods. Most notable differences are the treatment of international transportation (particularly in Denmark) and the methods used to estimate the emissions from the production of imported products.

While methods are important, we found that the different studies used different definitions and methods. Often the definitions used for imports were inconsistent with those used for exports.

Chapter 5 summarised the findings from the various Chapters to give some key recommendations and overview of applications. It is important to ensure consistency in definitions to make studies comparable. We suggest that multi-region input-output analysis should provide the basic theoretical background to make definitions since most methods are a subset of this. There are many data issues, but we believe that a concerted effort to improve this will benefit a variety of research and policy communities, while also reducing the workload of statistical offices. Finally we discussed some key applications to highlight the usefulness of carbon footprints and trade-adjusted emission inventories. The list of applications is by no means exhaustive, but is to give the reader a flavour of the potential of the methods and datasets.

We hope this report dispels some myths of carbon footprints and trade-adjusted emission inventories. For the analyst it should provide motivation to ensure consistency and clearly explain the definitions and assumptions used to make studies comparable. Clarity from analysts will hopefully dispel the myth that carbon footprints are highly uncertain. For the policy maker, we hope the report makes a good case for using carbon footprints and trade-adjusted emission inventories in policy development. To facilitate the future development of the field, core base funding is needed for statistical offices preparing consistent data and data repositories that avoid duplication of work.

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Utvidet sammendrag

Hovedmålsetningen med prosjektet "Globale klimafotavtrykk: Metoder for og resultater av å beregne globale "fotavtrykk" for de nordiske lands utslipp av klimagasser, korrigert for utslipp knyttet til import og eksport" er å presentere sammenliknbare og nøyaktige estimater for klimafotavtrykket av konsum i de Nordiske landene, samt å beskrive implikasjonene av import og eksport. Å gjøre dette krever en gjennomgang av tilgjengelige metoder for beregning av klimafotavtrykk og utslipp fra import og eksport. En gjennomgang av eksisterende studier, spesielt når man sammenlikner med konsistente og oppdaterte analyser, gjør det mulig å lage en uavhengig sammenlikning av metoder, data og definisjoner. Basert på gjennomgangen av eksisterende studier og egne beregninger kommer rapporten med en rekke anbefalinger for fremtidig bruk av klimafotavtrykk og handelsjusterte utslippsinventar.

Definisjoner

I løpet av de siste tre tiårene har flere forskningsfelt brukt konsepter som idag ville blitt kalt "klimafotavtrykk". Den økte bruken av termen er et relativt nytt fenomen og interessenter bør være kar over at det eksisterer en rik forskningslitteratur som dekker fundamentet som dagens "klimafotavtrykk" er basert på.

På tross av den lange historien til klimafotavtrykksberegninger finnes det ingen veldefinert, uniform definisjon for bruk av termen i alle sammenhenger. Flere felt har definert klimafotavtrykk, men definisjonen gjelder ofte ikke utenfor konteksten til metoden det er definert i. For eksempel kalkulerer de fleste livsløpsvurderinger (LCA) et klimafotavtrykk og det finnes en ISO standard på området. Likevel har definisjonen her et produktfokus som gjør den uegnet på nasjonalt nivå. Litteraturen som finnes på kryssløpsanalyse refererer også til definisjoner av klimafotavtrykk, men disse gjelder ikke nødvendigvis for produktorienterte analyser. Mellom disse to ekstremene finnes det et vell av andre metoder som fokuserer på ulike skalaer og beregner klimafotavtrykk for bedrifter, byer, regioner og så videre.

Det har vært flere nylige forsøk på å definere et klimafotavtrykk mer generelt, og i denne rapporten benytter vi følgende definisjon:

> Klimafotavtrykket til en nasjon er de totale globale langlivete drivhusgassene, aggregert ved å benytte 100-år globale oppvarmingspotensial, som trengs for å bruke (direkte) og produsere (indirekte) produkter og tjenester for å tilfredsstille årlig nasjonal konsum.

Denne spesifikke definisjonen gjelder for klimafotavtrykket til en nasjon (ikke et produkt). Definisjonen fokuserer videre spesifikt på en subgruppe komponenter med klimaeffekt (langlivete komponenter), sammenlikner klimautslipp med en spesifikk (og verdibasert) klimaparameter, dekker den globale forsyningskjeden og er spesifikt interessert i totalt nasjonalt konsum for et gitt år.

Innenfor denne definisjonen er det fremdeles rom for misforståelser. For eksempel, hvilken del av forsyningskjeden er dekket av "indirekte utslipp" og hva er "konsum"? Tittelen til prosjektet nevner to spesifikke forskningsspørsmål; klimafotavtrykk og import-/eksportkorrigerte resultat. Dette er tvetydig i forhold til definisjoner for indirekte utslipp og konsum. Å klargjøre betydningen av disse termene krever mer spesifikk kunnskap om hvilke forskningsspørsmål som er interessante.

I denne rapporten fokuserer vi på de to forskningsspørsmålene som tittelen på prosjektet nevner når vi går gjennom metodene, studiene og diskuterer implikasjoner. Et forskningsspørsmål fokuserer på konsum (klimafotavtrykk) og et annet på internasjonal handel (import-/eksportkorrigerte resultat). Disse spørsmålene kan bli spesifisert mer konkret:

> *Forskningsspørsmål 1*: Hva er de globale utslippene av klimagasser for å produsere de produkter og tjenester som konsumeres i de Nordiske landene?
>
> *Forskningsspørsmål 2*: Hva er de handelsjusterte utslippsinventarene for de Nordiske landene?
>
> a) Hva er de territorielle utslippene i de Nordiske landene for å produsere varer og tjenester for eksport?
>
> b) Hva er de territorielle utslippene utenfor de Nordiske landene for å produsere varer og tjenester som importeres inn til de Nordiske landene?

Metoder

Det finnes like mange metoder for å beregne klimafotavtrykk som det finnes definisjoner av termen. I mange tilfeller vil ofte metoden korrespondere til definisjonen. Definisjonen av klimafotavtrykk som brukes i LCA korresponderer direkte med metodene brukt i LCA; det samme gjelder for klimafotavtrykk for bedrifter (GHG protokollen), byer (ICLIE) eller nasjoner (kryssløpsanalyse). Som en nesten direkte konsekvens er metodene tilpasset et spesifikt problem: definisjonen og metodene innen LCA er mest egnet for produktorienterte livsløpsberegninger. Det samme gjelder for de andre metodene.

Dette prosjektet fokuserer på resultater på nasjonalt nivå. Ikke overraskende anbefaler de fleste sammenlikninger og metodegjennomganger at for nasjonale studier er en top-down metode referert til som "multiregional kryssløpsanalyse" (MRIOA), best egnet. Dette fordi metoden er spesifikt konstruert med det for øye å svare på forskningsspørsmålene 1 og 2. MRIOA har også en lang historikk (tilbake til femtitallet eller tidligere) og utvikleren av metoden fikk Nobels minnepris i økonomi (Wassily Leontief, 1973) og den samme prisen for bruken av metoden i nasjonalregnskapssystemet ble tildelt i 1984 (Richard Stone). Metodikken har blitt brukt i mange klimafotavtrykksstudier (dog ofte under annet navn), særlig under energikrisen på 70- og 80-tallet. Feltet har vokst kraftig de siste årene for å forstå globale miljøproblemer.

Tidligere studier har vist at flere av metodene kan bli representert av det samme teoretiske rammeverket. Vi støtter dette og har brukt en detaljert MRIO-modell for å vise styrker og svakheter ved ulike metoder og antakelser. Det er også en oppfatning at MRIO-modeller er for dataintensive og unøyaktige for policyformål, men vi viser at for å svare på forskningsspørsmålene 1 og 2 trengs en MRIO-modell av begrenset størrelse. For studier på nasjonalt nivå i de Nordiske landene kan en modell med ca 10 land hver og rundt 50 sektorer, være tilstrekkelig. Flere pågående prosjekt i EU og globalt konstruerer nå detaljerte globale datasett som vil gjøre det mulig å fokusere i større detalj på minimumskrav for robuste studier.

Gjennomgang av studier

Vi har kompilert en oversikt over nylig publiserte studier for å vurdere den eksisterende kunnskapsbasen for klimafotavtrykk i de Nordiske landene. Det er stor variasjon mellom studiene, selv om en forklaring for disse kan tilskrives inkonsistente definisjoner. Flere av studiene spesifiserer ikke i klartekst om de besvarer forskningsspørsmål 1 eller 2 og definisjonen av klimafotavtrykk er ofte uklar. En enkel endring i definisjonen kan endre utslippsestimatene grovt, for eksempel hvorvidt internasjonal transport er inkludert eller ikke kan endre danske estimat med rundt 40 %.

Et viktig spørsmål er om studier som bruker forskjellige metoder er sammenliknbare. Estimater for klimafotavtrykk basert på prosess-basert LCA kan systematisk underestimere utslippene på grunn av velkjente problemer med systemgrenser (”cut-offs”). Dette gjør en sammenlikning med MRIO-metoder uten cut-offs vanskelig. På samme tid kan klimafotavtrykk for Finland og Danmark være usammenliknbare på grunn av ulike datakilder, selv om begge skulle være basert på LCA.

Siden mange av studiene var land-spesifikke (f.eks Svensk klimafotavtrykk) er det sannsynlig at metoden ikke kan bli skalert opp på et globalt nivå. Hvis noen av de landspesifikke studiene ble brukt globalt, ville det globale klimafotavtrykket bli forskjellig fra de globale utslippene, eller eksportutslipp forsjellig fra importutslipp. Dette betyr at noen av metodene enten dobbelteller noen utslipp, eller utelater noen utslipp (spesielt knyttet til internasjonal handel).

Litteraturgjennomgangen er spesielt nyttig i forhold til å belyse nødvendigheten av konsistente definisjoner og metoder for å oppnå sammenliknbare analyser. En svakhet hos nesten alle studiene er en klar definisjon av forskningsspørsmålet. En svakhet ved mange av studiene var dårlig detalj i metodebeskrivelsen, spesielt når hybride metoder ble benyttet hvor man kombinerer mange tilnærminger. En annen svakhet var at studiene ikke kunne bli brukt på globalt nivå.

Vi anbefaler at fremtidige studier blir benchmarket mot en multiregional kryssløpsmodell. En global MRIO teller alle globale utslipp og sikrer konsistente definisjoner og metoder. Hvis man ønsker større detalj er det mulig å disaggregere MRIO-modellen og lage en hybrid modell. En fordel med de globale studiene som er omtalt her er at man kan være sikrere på at konsistente metoder og definisjoner er brukt for alle land. Det man vinner i konsistens kan komme på bekostning av redusert detalj (og kanskje nøyaktighet) for noen land, men vi mener at det man vinner på konsistens er mer viktig, spesielt tatt i betraktning den relativt enkle MRIO som er nødvendig for gode estimater, som rapportert under Metoder.

Resultater

I prosjektet har vi beregnet klimafotavtrykk (forskningsspørsmål 1) og handelsjusterte utslipp (forskningsspørsmål 2) for de store Nordiske landene (Danmark, Finland, Norge og Sverige). Estimatene ble gjort ved å bruke en global MRIO-modell basert på den velkjente GTAP-databasen. Dette er en top-down modell som dekker alle land i verden. Vi presenterer resultat for 1997 (66 regioner, bare CO_2), 2001 (87 regioner og CO_2, CH_4, N_2O og fluorinerte gasser) og 2004 (112 regioner og CO_2, CH_4, N_2O og fluorinerte gasser). De nyeste estimatene (2004) er mest nøyaktige, etterfulgt av 2001 og 1997. Modellen, metoden og data benyttet har vært gjennom fagfellevurdering mange ganger og blir kontinuerlig oppdatert etter hvert som nye data blir tilgjengelig (tallene her kan derfor avvike noe i forhold til tidligere studier).

Metoden som benyttes her, og i de fleste klimafotavtrykksanalyser på nasjonalt nivå, bruker definisjonene beskrevet i FNs nasjonalregnskapssystem (System of National Accounts, SNA). SNA lager definisjoner for standard økonomiske størrelser som for eksempel brutto nasjonalprodukt. Likevel er de mest vanlige utslippsinventarene brukt i klimapolitikk (UNFCCC) kjent for å være inkonsistente med SNA. Mindre kjent er utslippsstatistikken som er konsistent med SNA; NAMEA (National Accounting Matrix with Environmental Accounts). De Nordiske landene rapporterer utslipp både til UNFCCC og NAMEA og publiserer tabeller som viser sammenhengen mellom de to. For de Nordiske landene er ofte forskjellen mellom NAMEA- og UNFCCC-utslipp stor på grunn av internasjonal transport. Siden UNFCCC ikke allokerer utslipp fra internasjonal transport, fjerner noen disse fra NAMEA-tallene, noe som gjør dem inkonsistente med SNA og for eksempel BNP. Økonomiske studier av klimagasser bør tekniske sett baseres på NAMEA-, og ikke UNFCCC-utslipp, for å opprettholde konsistens med SNA. Estimatene som presenteres her er basert på NAMEA som inkluderer internasjonal transport (Figur ES1).

Når man sammenlikner resultatene for de Nordiske landene må man være ha i bakhodet at vi presentere absolutte tall for land med forskjeller i størrelse, befolkning og økonomi. Sverige har neste dobbelt så stor befolkning som Danmark, Finland og Norge, mens Island bare har rundt 250,000 innbyggere. I absolutte tall er BNP omtrent rangert som befolkningstall, mne på en per person basis har Norge rundt 50 % høyere BNP enn Finland. Utenom Norge og Island har de Nordiske landene ganske like absolutte utslipp. Per person viser samme resultat, med unntak av Sverige med bare rundt halvparten av de andre Nordiske landene. Alle landene er nettoeksportører. Befolkningsveksten er svak, mye lavere enn veksten i BNP. Klimautslippene er relativt stabile, selv om dette avhenger av om man ser på NAMEA eller UNFCCC. De raskest økende variablene i alle de Nordiske landene er internasjonal handel, både eksport og import. Verdien av eksport og import øker raskere enn BNP, vekslende om eksport eller import vokser mest. Denne bakgrunnsinformasjonen er et viktig fundament for å tolke resultatene under.

Forskningsspørsmål 1 (klimafotavtrykk)

Klimafotavtrykket til de Nordiske landene har vokst fortere enn de territorielle utslippene (NAMEA). Årsakene til dette blir diskutert senere, men hovedfokus for en klimafotavtrykksanalyse bør være å identifisere utslippsdrivere og ikke et ansvarsspill mellom i-land og u-land.

En fordel med et klimafotavtrykk er at det allokerer utslipp til konsumerte produkter og ikke de faktiske utslippskildene (Figur ES2). Dette gir et nytt perspektiv på utslipp. I de mer vanlige punktkildeanalysene dominerer utslipp fra elektrisitet, gruvedrift og energiintensiv industri, selv om de ofte ikke er assosiert med konsuminnkjøp (utenom elektrisitet). Disse sektorene produserer som regel innsatsfaktorer til andre sektorer som forbrukere som regel kjøper produkter og tjenester fra. For eksempel kjøper forbrukere som regel prosessert mat og ikke jordbruksvarer. I et klimafotavtrykk blir da prosessert mat den viktige sektoren, siden den inkluderer alle utslippene i forsyningskjeden (jordbruk, gjødsel, maskiner, transport elektrisitet etc.) som trengs for å produsere mat som forbrukerne kjøper i butikken. På samme måte kjøper forbrukere ferdigvarer som biler eller klær etc.; disse sektorene blir da viktige, mens primærproduksjon blir mindre viktig.

Det endrede fokuset til et klimafotavtrykk gir beslutningstakere mulighet til å analysere de forbruksmønstrene som ligger bak produksjonsprosessene og punktutslippene. I et klimafotavtrykk er det også mulig å analysere hvor utslippene skjer, fremdeles med et fotavtrykksperspektiv. Dette understreker at en stor del av utslippene skjer innenlands. Imidlertid er det slik at for de Nordiske landene kan mye av veksten i klimafotavtrykket tilskrives økte utslipp i utlandet, spesielt i Kina og andre utviklingsland. En nøkkelfaktor for økningen i klimafotavtrykk er import (spesielt fra Kina) av forbruksprodukter. Den hurtige økonomiske veksten i flere utviklingsland er velkjent; en klimafotavtrykksanalyse gir beslutningstakere mulighet til å undersøke denne vekstens effekt på konsum og utslipp fra de Nordiske landene.

Forskningsspørsmål 2 (handelsjusterte utslipp)

Når man fokuserer eksplisitt på klimafotavtrykk (globale utslipp for å tilfredsstille innenlands forbruk) er det lett å miste kontrollen på direkte handelsforbindelser. For eksempel, er den økte andelen utslipp som skjer i Kina knyttet til økt direkte handel mellom Kina og de Nordiske landene eller på grunn av økt handel mellom andre land (Nordiske land kjøper en datamaskin fra Japan med komponenter fra Kina)? I denne konteksten er et klimafotavtrykk ikke direkte knyttet til bilateral handel som blir behandlet på politisk nivå. Forskningsspørsmål 2 omformer klimafotavtrykkskonseptet til å fokusere på bilateral handel, og for å gjøre dette uten dobbeltelling av utslipp ser man bare på innenlands forsyningskjeder (dvs. hva er de innenlandske utslipp for å produsere importerte/eksporterte varer og tjenester?).

Som generelt sett små og åpne økonomier har de Nordiske landene en stor andel av de territorielle utslippene knyttet til produksjon for eksport. Omtrent halvparten av de Nordiske utslippene blir eksportert; denne andelen har vært relativt stabil over tid. Andelen er høyest i Danmark (51 % i 2004) og Norge (61 % i 2004) på grunn av internasjonal transport, og i Norges tilfelle olje- og gassektoren. Sammenliknet med de territorielle utslippene importerer de Nordiske landene rundt 70% av innenlandske utslipp, en andel som vokser over tid. Som en konsekvens er de Nordiske landene nettoimportører av utslipp, og denne andelen vokser over tid. Sverige, som har de laveste utslippene per person, har den høyeste andelen utslipp i import (93 % av territorielle utslipp i 2004).

Rapporten gir detaljerte resultater for de individuelle landene, men mange av trendene er de samme (Figur ES3). Endringen i eksporterte utslipp følger mer eller mindre endringen i territorielle utslipp. Dette innebærer bedret effektivitet gjenspeiles relativt uniformt over alle sektorer i økonomien. For import har alle de Nordiske landene hatt en rask økning av utslipp i andre land for å produsere importerte produkter. Spesielt viktig er import av konsumprodukter ("manufactured goods") fra Kina. Veksten i importerte utslipp fra Russland var sterk, mens India og Brasil også er viktige. Det har vært en reduksjon i utslipp i import fra USA, og for EU har utslippene vært relativt stabile, selv om det er stor variasjon mellom individuelle land. Produktgrupper som er stabilt viktige er kjemikalier, primær- og sekundærmetaller, maskiner og elektronikkprodukter. Det er noen særegne effekter for noen av landene som gjenspeiler unike forhold med enkeltland, for eksempel er Russland veldig viktig for Finsk import og Polen for Svensk import.

Implikasjoner for definisjoner, metoder og data

Rapporten belyser flere områder hvor det er behov for bedre definisjoner, metoder og data, samt områder hvor bruk av metoden kan ha størst effekt. Vi har summert disse i en rekke anbefalinger.

De første tre anbefalingene relateres primært til definisjoner og forskningsspørsmål.

> *Anbefaling 1*: Basere den teoretiske bakgrunnen for klimafotavtrykk på kryssløpsanalyse, samtidig som man åpner for å velge andre metoder når man produserer endelige resultat.

> *Anbefaling 2*: Studier bør klart beskrive behandlingen av import, både til sluttkonsumenter og industri, samt angi hvorvidt metoden gir samsvar mellom import og eksport hvis den blir brukt globalt på alle land.

> *Anbefaling 3*: Etablere en arbeidsgruppe for klart å fastsette et sett med definisjoner som kan brukes av beslutningstakere og interessegrupper.

Som diskutert tidligere er definisjonene og metodene ofte knyttet til hverandre. I utgangspunktet bør ikke definisjonen i seg selv diktere hvilken metode som skal brukes, så lenge metodene har tilfredsstillende kvalitet, men det er klart at noen minimumskriterier må være tilstede for konsistent å koble definisjoner og metoder.

> *Anbefaling 4*: Etablere en arbeidsgruppe for klart å definere et sett med metoder og minimumskriterier som kan brukes av beslutningstakere og interessegrupper.

Datatilgang er ofte beskrevet som en svakhet med klimafotavtrykksstudier. Selv om man har konsistente definisjoner og metoder, er det dataproblemer som bør adresseres. Ofte finnes dataene tilgjengelig, de krever bare konsistens og harmonisering. De følgende anbefalingene er omfattende og noen av dem langsiktige, men de vi føre til mange fordeler innen all bruk av økonomisk statistikk.

> *Anbefaling 5*: Gjøre innsending av konsistente NAMEA-tall obligatorisk for alle som rapporterer til SNA.

> *Anbefaling 6*: Etablere en felles database for nasjonalregnskap (SNA)-nøkkeltall, SUT (supply/use)-tabeller, IO-tabeller, internasjonale handelsdata og NAMEA-data, mest logisk hos FN (UNSD).

> *Anbefaling 7*: På høyt nivå etterstrebe å opprettholde konsistens i rapporteringen for SNA, SUT, IOT, internasjonal handel og NAMEA-utslipp.

> *Anbefaling 8*: Undersøke mulighetene for å ha en enkelt global MRIO vedlikeholdt og oppdatert av et institutt (kanskje i samarbeid med andre).

Implikasjoner for policy

Selv om rapporten ikke prøver å gjøre en detaljert policy-analyse, er det mulig å lage koblinger til politikk på bakgrunn av de resultatene som er produsert. Resultatene i denne rapporten kan generelt fokuseres på spesifikke politiske spørsmål. Vi beskriver flere politikkområder og bruksområder hvor vi mener en klimafotavtrykksanalyse kan gi beslutningstakere nyttig informasjon som generelt ikke er tilgjengelig i eksisterende økonomiske studier.

Bruk 1 (drivere): Bruke kryssløpsanalyse for å flytte utslippsansvar fra produsent til konsument for å gi innblikk i hvilke typer konsum som gir mest utslipp.

Bruk 2 (måle flytting/lekkasje av utslipp): Konsekvensene av global oppvarming er stort sett uavhengig av hvor utslippene skjer og multiregionale kryssløpsmodeller kan hjelpe med å forstå om politikk har ført til utilsiktede økninger i utslipp utenfor landegrensene (systemgrensene).

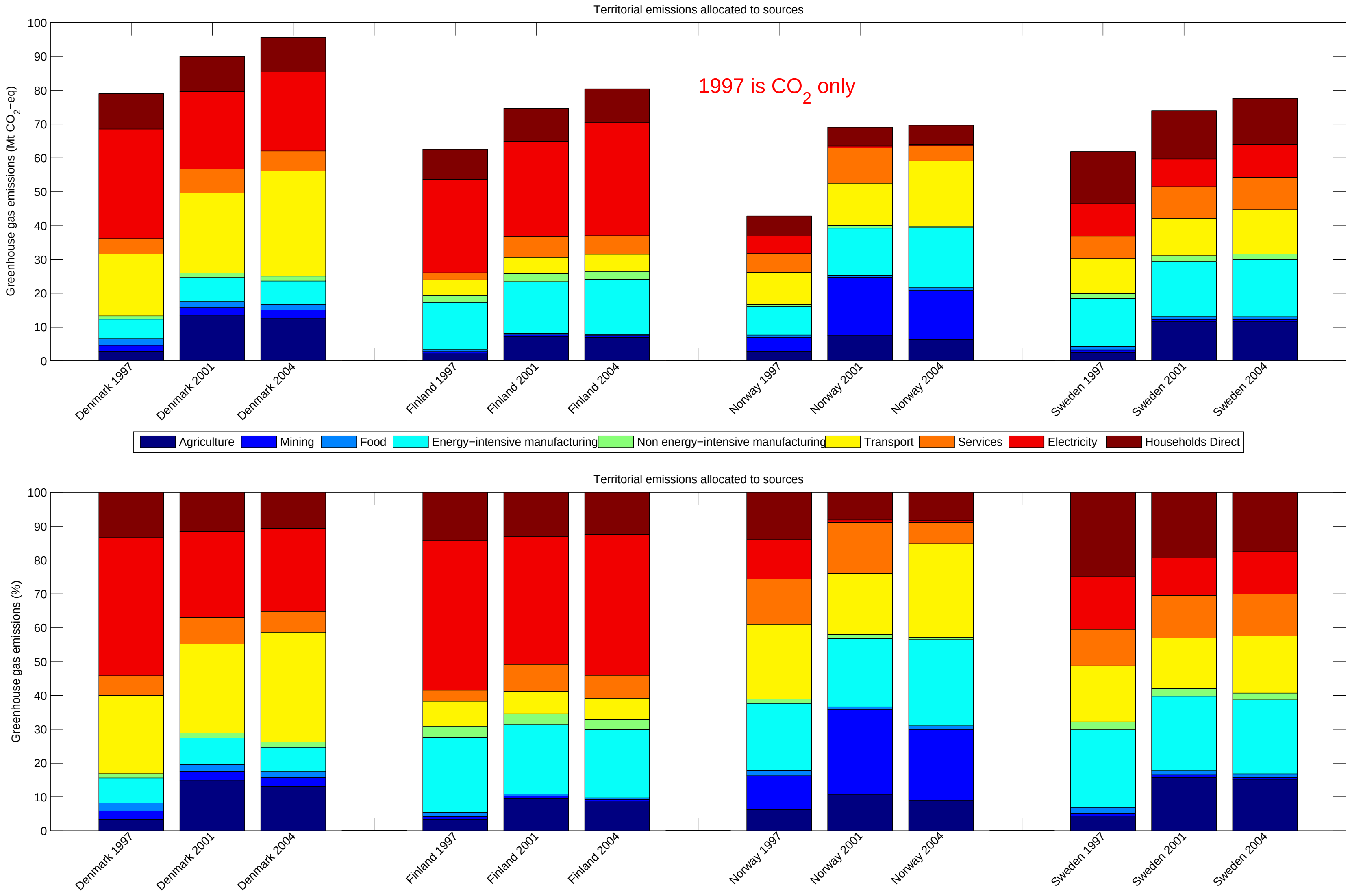
Bruk 3 (land og sektorsammenlikninger): En multiregional kryssløpsmodell beskriver konsistent teknologien i et stort antall land og sektorer. Man kan derfor sammenlikne resultater mellom sektorer og land på en konsekvent måte som inkluderer den globale forsyningskjeden.

Bruk 4 (risiko mtp. Karbonprising): En multiregional kryssløpsmodell beskriver konsistent teknologien i et stort antall land og sektorer. Man kan derfor sammenlikne, gitt visse antakelser, hvordan en økning i karbonskatt ulike steder i verden vil påvirke prisene på produkter et annet sted i verden.

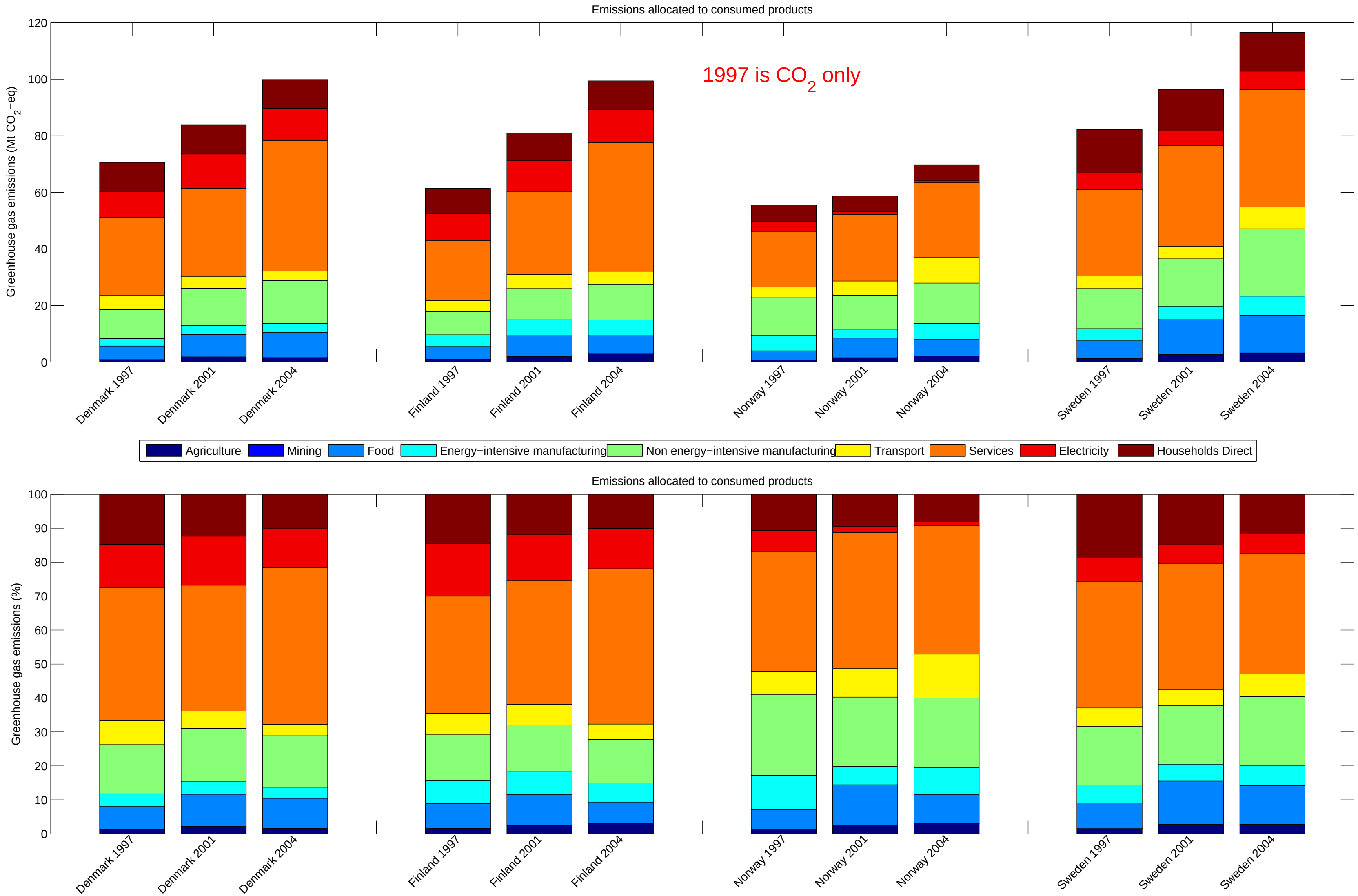
Bruk 5 (grunnlag for detaljerte studier): En multiregional input-output modell kan brukes som utgangspunkt for å studere landspesifikke nøkkelsektorer og verdikjeder i større detalj.

Sammendrag

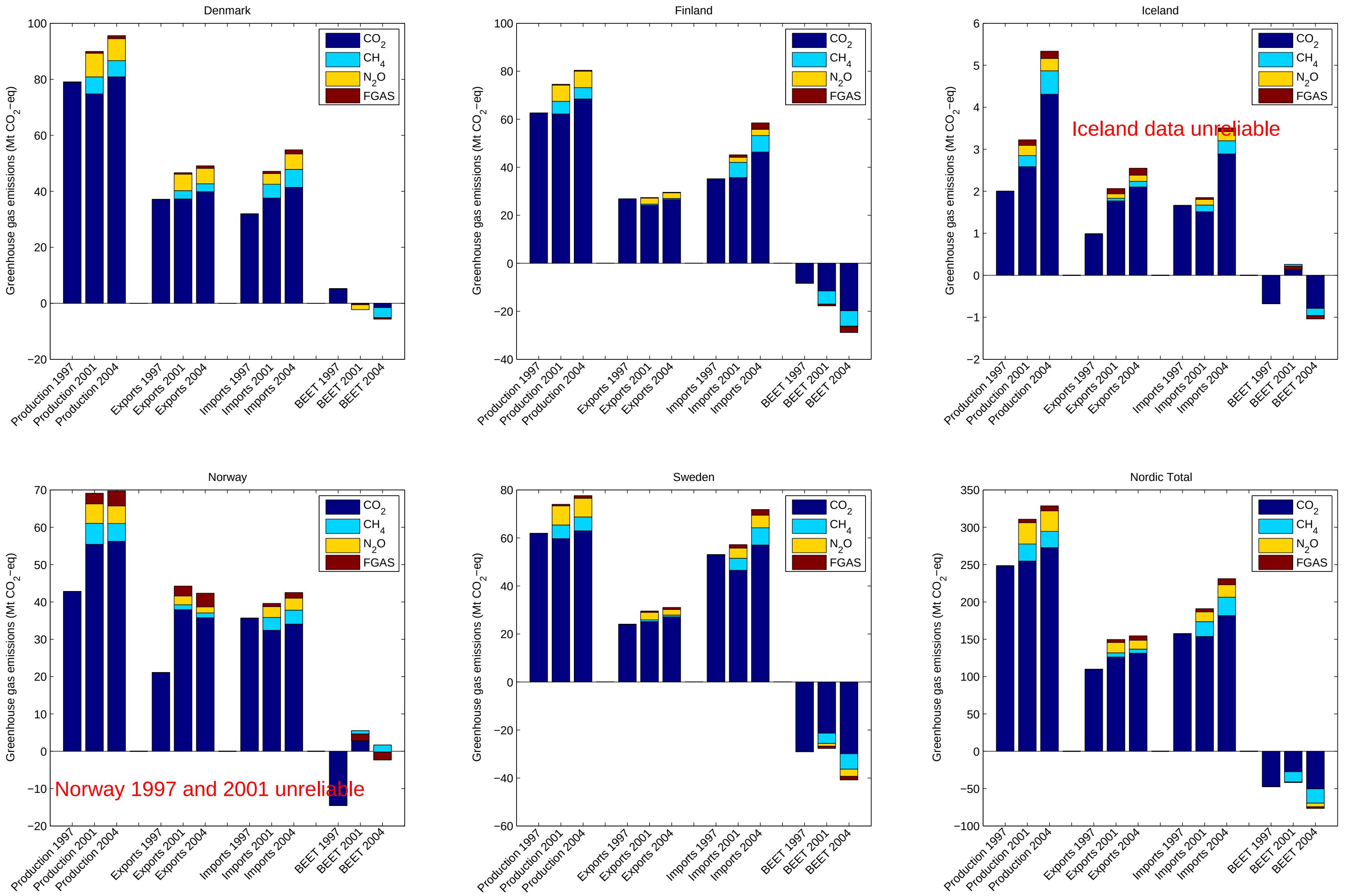
Rapporten dekker en rekke problemstillinger knyttet til klimafotavtrykk og handelsjusterte utslipp. Nasjonale klimafotavtrykk gir verdifull informasjon til en rekke politikkområder, men inkonsistens mellom eksisterende studier gir et inntrykk av dårlig kvalitet eller stor usikkerhet. Vi viser at ved å bruke eksisterende definisjoner, metoder og data, er det mulig i dag å presentere konsistente og robuste estimat for klimafotavtrykk og handelsjusterte utslipp for de Nordiske landene og å benytte disse i en rekke relevante sammenhenger. Imidlertid vil verdien av slike studier bli bedret hvis en samlet innsats settes inn på flere områder. Forskere som estimerer klimafotavtrykk må jobbe sammen for å bli enige om konsistente og robuste definisjoner og metoder å bruke i sine analyser. En rekke prosesser bør settes i gang for å sikre langsiktig utvikling i de underliggende statistikkene, noe som vil være en fordel både for statistikkbyråer, forskere, beslutningstakere og andre interessenter som bruker disse og liknende statistikker.



Figur ES 1: Territorielle utslipp (NAMEA) alloker til økonomiske sektorer; absolutte tall (øverst) og sektorfordeling (nederst).



Figur ES 2: Forbruksrelaterte utslipp i de Nordiske landene, inkludert husholdninger, offentlig forbruk og kapitalinvesteringer. Importerte utslipp er inkludert i talle-ne.



Figur ES 3: Territorielle utslipp, eksporterte utslipp, importerte utslipp og handelsbalanse for de Nordiske landene. Vær oppmerksom på at skalaen er forskjellig for de ulike landene.