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# Pollution Embodied in Norwegian Consumption

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## Abstract

A promising way to reduce environmental impacts of consumer expenditure is through the encouragement of more sustainable consumption patterns. This requires a consistent and accurate framework to identify the most sustainable lifestyles and consumption patterns. With the increase in international trade, it is becoming increasingly important to accurately determine environmental impacts resulting from imports. Many previous studies have unrealistically assumed that imports are produced using domestic production technology. For countries with diverging technology and energy mixes the likely errors are significant. This study applies a methodology that explicitly includes technology differences to the case of Norway. It is found that the majority of emissions in Norwegian consumption are embodied in imports; signifying the importance of considering regional technology differences. The methodology is then used to determine environmental impacts at three levels; national, aggregated households, and household types.

## Keywords

Input-output analysis; Embodied pollution; CO<sub>2</sub>; SO<sub>2</sub>; NO<sub>x</sub>; Trade; Sustainable consumption; Balance of trade; Household consumption; Environmental impacts; Norway

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# 1 Introduction

For countries with a high proportion of imports an accurate method of determining emissions embodied in imports is essential. This is particularly important when there are significant technology differences between the domestic economy and its trading partners. To date, most studies determining the environmental impacts of consumption have assumed that imports have the same production technology as the domestic economy. For some industrialized countries this approximation is adequate. Although as production technologies start to diverge and energy mixes differ, then this assumption is clearly inadequate. Further, empirical studies in international trade theory have also shown the importance of technology difference in predicting trade patterns (Hakura, 2001). Recently, some studies with more accurate methods of determining pollution embodied in trade have started to appear in the literature (Ahmad and Wyckoff, 2003; Lenzen et al., 2004b; Nijdam et al., 2005).

In earlier work, a rigorous method was developed using input-output analysis (IOA) to determine the pollution embodied in trade (Peters and Hertwich, 2004). The method uses regional specific technologies to determine the pollution embodied in trade. The key advantages of using IOA are the availability of data and the ability to study the intricate web of indirect effects for a given consumer demand. With a consistent methodology for the calculation of embodied pollution, it becomes possible to accurately establish the environmental impacts of different consumption patterns. The theoretical framework is outlined in the following section.

Norway is particularly interesting for studies of energy and pollution embodied in trade due to its high proportion of imports and since most of its domestic electricity is supplied by hydropower. Consequently, relative to domestic production, Norwegian imports are expected to have a high degree of embodied pollution (Hertwich et al., 2002). This has implications when studying the environmental impacts of domestic economic activities, including the study of different consumption patterns.

In this article, the environmental impacts of Norwegian consumption are calculated at three different levels; national, aggregated households, and household types (c.f. Munksgaard et al., 2005; Hertwich, 2004). At the national level, issues such as a “balance of trade” for pollution can be studied. Also, the issue of who is responsible for pollution, consumer or producer, can be addressed (Munksgaard and Pedersen, 2001). Analysis at the aggregated household level allows identification of the most important economic sectors generating pollution and identifies areas where environmental improvement initiatives should be targeted. At the most detailed level, the Norwegian Survey of Consumer Expenditure (SCE) can be used to compare the environmental impacts of different household consumption patterns and broad life-style differences (c.f. Lenzen et al., 2004a). These studies allow explicit analysis of different lifestyle choices and the development of policies that encourage sustainable lifestyles. These three levels of detail are the focus of calculations in this article.

This paper is structured as follows. First, the theoretical framework and notation is briefly stated. Second, the data sources are presented and some of the key data challenges discussed. The bulk of the paper presents different applications of the methodology. Particular focus is given to illustrating the potential of the methods used to address en-

vironmental issues of different consumption patterns. Finally, advantages and limitations of the methodology are discussed and future research areas identified.

## 2 Theoretical framework

The theoretical framework has been presented in detail in Peters and Hertwich (2004) and so only the main equations are shown here. The model is based on input-output analysis (IOA) (Leontief, 1941; Miller and Blair, 1985; United Nations, 1999). In summary, the total output of the economy is given by intermediate consumption and final consumption,

$$x = Ax + y \quad (1)$$

where  $A$  is the interindustry requirements matrix and  $y$  represents various demands on the economy. Solving for the total output,  $x$ , gives

$$x = (I - A)^{-1}y \quad (2)$$

The interindustry requirements matrix  $A$  represents the technology of an economy. It can be broken down into two components representing the interindustry requirements of domestically produced goods and the interindustry requirements of imported goods,  $A = A^d + A^{im}$ .

Name	Description
$x_i$	Output of region $i$
$y_i^d$	Final domestic demand on domestic production
$y_{ij}$	Imports to final demand from region $i$ to region $j$
$y_i^{im} = \sum_{j \neq i} y_{ji}$	Total imports into final demand in region $i$
$A_i^d$	Interindustry requirements on domestic production in region $i$
$A_{ij}$	Interindustry requirements of imports from region $i$ to $j$
$A_i^{im} = \sum_{j \neq i} A_{ji}$	Total interindustry requirements of imports in region $i$
$A_i = A_i^d + A_i^{im}$	Total interindustry requirements in region $i$

Table 1: The notation used for the multi-region formulations.

In this article Norway (NO) is the domestic economy; denoted region 1. For the development of the theoretical framework assume that Norway trades with  $m - 1$  regions. The notation is given in Table 1. The output in each region for the total demand in Norway can be expressed as (Peters and Hertwich, 2004),

$$\begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ \vdots \\ x_m \end{pmatrix} = \begin{pmatrix} A_1^d & A_{12} & A_{13} & \dots & A_{1m} \\ A_{21} & A_2^d & A_{23} & \dots & A_{2m} \\ A_{31} & A_{32} & A_3^d & \dots & A_{3m} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ A_{m1} & A_{m2} & A_{m3} & \dots & A_m^d \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ \vdots \\ x_m \end{pmatrix} + \begin{pmatrix} y_1^d + \sum_{j \neq 1} y_{1j} \\ y_{21} \\ y_{31} \\ \vdots \\ y_{m1} \end{pmatrix} \quad (3)$$

The matrix is a generalization of the interindustry requirements,  $A$ , in standard IOA. The columns in the matrix represent the inputs into production; the off diagonal matrices

are the imports into production from foreign regions. The rows represent the exports to foreign regions. The first element in the demand vector represents final demand on domestic production and the other elements are imports into final demand. The matrix equation, (3), is the same as the multi-regional models developed by Miller and Blair (1985). Lenzen et al. (2004b) developed a similar model using the make-use framework; on collapsing their make-use blocks into symmetric matrices the same model results. Ahmad and Wyckoff (2003) also used a similar model to calculate emissions embodied in trade.

The data requirements for (3) are significant; at this stage we do not know of any countries that collect data of the imports into industry and to consumers by exporting country. However, this data is often available for the total imports into a country,  $A_i^{im}$ . Further, trade statistics often give the trade between given countries at the commodity level. Given this it is possible to approximate  $A_{ij}$  and  $y_{ij}$  using trade shares. Further, in a similar study, Lenzen et al. (2004b) found that direct trade with the domestic economy is dominant, and the resulting induced trade between other regions is negligible<sup>1</sup>. Given these approximations, (3) becomes

$$\begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ \vdots \\ x_m \end{pmatrix} = \begin{pmatrix} A_1^d & 0 & 0 & \dots & 0 \\ \hat{s}_2 A_1^{im} & A_2^d & 0 & \dots & 0 \\ \hat{s}_3 A_1^{im} & 0 & A_3^d & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \hat{s}_m A_1^{im} & 0 & 0 & \dots & A_m^d \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ \vdots \\ x_m \end{pmatrix} + \begin{pmatrix} y_1^d + y_1^{ex} \\ \hat{s}_2 y_1^{im} \\ \hat{s}_3 y_1^{im} \\ \vdots \\ \hat{s}_m y_1^{im} \end{pmatrix} \quad (4)$$

where  $y_1^{ex} = \sum_{j \neq 1} (A_{1j}^{im} x_j + y_{1j})$  is the total exports from Norway to all regions, including both industry and final demand, and the share of imports from each region is estimated using

$$\{s_i\}_j = \frac{\{M_i\}_j}{\{M_{total}\}_j} \quad (5)$$

where  $\{M_i\}_j$  is the total imports of good  $j$  from region  $i$  and  $\{M_{total}\}_j$  is the total imports of good  $j$  into Norway. Calculations discussed later show that it is important to consider the trade shares in individual sectors and not the average of all sectors.

Extracting the individual equations from the matrix, (4), gives the output in Norway,

$$x_{NO} = (I - A_{NO}^d)^{-1} y_{NO}^d \quad (6)$$

and the output in other regions

$$x_i = (I - A_i^d)^{-1} M_i \quad \text{for } i > 1 \quad (7)$$

where

$$M_i = \hat{s}_i (A_{NO}^{im} x_{NO} + y_{NO}^{im}) \quad (8)$$

is the total imports (interindustry plus final demand) into Norway from region  $i$ .

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<sup>1</sup>This approximation can be relaxed slightly by assuming that in the foreign regions, imports are produced with domestic production technology; that is, in the trading regions put  $A_i^d \mapsto A_i$ .

The pollution embodied in trade is calculated as,

$$E_i = F_i x_i \quad (9)$$

If it is assumed that each region has the same technology as Norway, then

$$A_i = A_{NO} \quad (10)$$

and

$$F_i = F_{NO} \quad (11)$$

In this article various scenarios are modeled by varying the demands  $y_{NO}^d$  and  $y_{NO}^{im}$ . All other parameters remain fixed. The demands represent either the entire demands on the Norwegian economy, total household demand in Norway, or demands of individual household groups in Norway.

### 3 Data sources and data preparation

To reduce the required data, data was only collected for Norway's seven major importing partners. Even this requires a considerable amount of data collection. The Norwegian IO data is relatively easy to obtain and requires little or no preparation. The data for the foreign regions requires significant preparation. The data came from a variety of sources, different years, and different currencies and this needs to be made equivalent with the Norwegian input-output (IO) data. Further, trade shares need to be determined from each of the aggregated regions. The SCE data requires considerable manipulation. It has a different pricing to the Norwegian IO data which requires removal of margins and taxation from the SCE data. Further, the direct fuel use and the portion of imports for different household types needs to be estimated. This section gives more detail of the data sources and preparation.

#### 3.1 Trade data

Trade data was only collected for Norway's seven major importing partners: Sweden (SE), United Kingdom (UK), United States (US), Germany (DE), Denmark (DK), Japan (JP), and China (CH). These countries represent 61% of the import value of Norway's commodity and services imports. The minor trading partners were then aggregated under one of the seven major importing partners according to energy use per capita, CO<sub>2</sub> emissions per capita, and gross domestic product per capita<sup>2</sup>; see Table 2. Using this method 100% of Norway's imports are captured. The aggregated importing regions are: Sweden (SE), United Kingdom (UK), North America (NA), Germany (DE), Denmark (DK), Japan (JP), and Developing Countries (DC). Most European countries were assumed to have German, Danish, or Swedish technology and most developing countries were assumed to have Chinese technology; this explains the large increase in import shares for those regions.

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<sup>2</sup>From the World Bank data query service; <http://devdata.worldbank.org/data-query/>

Region	Code	Import	$s_i$
Sweden	SE	14%	19%
United Kingdom	UK	13%	14%
North America (US)	NA	10%	12%
Germany	DE	10%	25%
Denmark	DK	7%	14%
Japan	JP	4%	7%
Developing (CH)	DC	4%	10%
Total		61%	~100%

Table 2: The aggregation of Norway’s import trade.

To use the framework described above requires the share of imports directly into industry and final demand categories from each of Norway’s main import partners. This data was unavailable, but Statistics Norway<sup>3</sup> publishes data on the total share of imports from all countries into Norway. Using this trade data, for both commodities and services, the share of imports from each region was estimated using

$$s_i = \frac{M_i}{M_{total}} \quad (12)$$

where  $M_i$  is the total imports from region  $i$  and  $M_{total}$  is the total imports into Norway; the calculated values are shown in Table 2. From this data the share of imports directly into industry,

$$A_{i,NO} = \hat{s}_i A_{NO}^{im} \quad (13)$$

and to final demand,

$$y_{i,NO} = \hat{s}_i y_{NO}^{im} \quad (14)$$

can then be estimated.

An inspection of the Norwegian trade data shows that there is considerable variability between the types of imports from various regions. For instance, around 50% of Norway’s car imports come from countries with German technology and about 1% come from developing countries. However, 50% of wearing apparel comes from developing countries, while about 10% comes from countries with German technology. This heterogenous nature of the import shares is found across all sectors. Given this, it is desirable to have the trade shares at the industry level and not at a national level, as shown in (5).

An unfortunate data inconsistency arises when constructing the shares data at the industry level. The Norwegian IO data contains information on imports at the industry level; further, this information only includes total imports, and not imports from the various countries. However, Statistics Norway also has the imports from various countries in the SITC product classification. Unfortunately, there is not a 1-1 correspondence between the NACE industry classification and the SITC product classification. We constructed a correspondence table which mapped some SITC sectors to multiple NACE sectors. We then compared the mapped SITC data to the total imports in the IO data to validate the correspondence table. These manipulations gave us the imports into Norwegian industries

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<sup>3</sup><http://www.ssb.no/>



Country	Original sectors	Valuation	Energy data	Year
NO	56	Basic	Yes	2000
SE	58	Basic	No	2000
UK	58	Basic	Yes	1995
US	91	Producer	No	1996
DE	58	Basic	Yes	2000
DK	58	Basic	Yes	2000
JP	93	Producer	Yes	1995
CH	124	Producer	No	1997

Table 3: A summary of the data used.

and final demand categories distributed amongst the exporting countries. From this, the share of imports by region and industry sector can be constructed.

A further issue is that industry and final demand categories have a different use of imports; for instance, imports from the “Manufacture of tobacco products” sector only go to final demand categories. Using the IO data, we constructed import shares by region and industry sector for final demand categories and for interindustry transactions.

Once the import shares had been constructed, calculations showed differences in excess of 50% for CO<sub>2</sub> emissions when comparing import shares by sector and total import shares as in Table 2. Developing countries had the greatest improvements and German technology the worst. The differences vary considerable depending on whether the imports go to final demand, or to industry in the production of domestic demand or exports. The calculations show the importance of using the trade shares on a sector level and not the aggregated national level.

### 3.2 Input-output, emissions, and energy data

The input-output (IO), energy and emissions data came from a variety of sources. As a result the data required several manipulations to make the complete data set consistent. First, the data was mapped into a NACE<sup>4</sup> classification with 49 sectors that gave the best overlap of the datasets. Second, the Consumer Price Index (CPI) in each country was used to convert the monetary data from the base year into 2000 values<sup>5</sup>. Finally, the currencies were converted into Norwegian Krone (NOK) for the base year of 2000<sup>6</sup>. Unfortunately, not all the data was available in basic prices. The producer prices include taxes and subsidies and so are higher than the basic prices. Where possible, adjustments were made for Financial Intermediation Services Indirectly Measured (FISIM) (Ahmad, 2002). For this project, it was not possible to obtain energy data for all regions. The data is summarized in Table 3. The main sources of data for each region are now discussed.

<sup>4</sup>See the RAMON database in EUROSTAT; <http://europa.eu.int/comm/eurostat/ramon>

<sup>5</sup>CPI values taken from the OECD’s sourceOECD database; <http://caliban.sourceoecd.org/>

<sup>6</sup><http://www.oanda.com/convert/fxhistory>

### 3.2.1 Norway

All the Norwegian data was provided by Statistics Norway for the year 2000. Domestic production data was provided for the interindustry flows  $Z^d$ , trade margins, household expenditure, government expenditure, changes in stocks, and exports. A flow matrix,  $K^d$ , for gross fixed capital formation was also provided. Capital was internalized into the interindustry coefficients using

$$A_{NO}^d = (Z^d + K^d)\hat{x}_{NO}^{-1} \quad (15)$$

where  $x_{NO}$  is the total output of the economy and the hat  $\hat{\cdot}$  represents diagonalization (c.f. Lenzen, 2001).

In addition, Statistics Norway provided data for the flow of imports into industry,  $Z^{im}$ , and the final demand of imports into household expenditure, government expenditure, investment, changes in stocks, and re-exports. Capital investments were not distributed by industry for imports and so the interindustry coefficient matrix for imports is given by

$$A_{NO}^{im} = Z^{im}\hat{x}_{NO}^{-1} \quad (16)$$

The import data also includes a category for the expenditure of Norwegians abroad; both final demand and interindustry. These expenditures were distributed in proportion to expenditure in each of the purchasing sectors and demand categories.

### 3.2.2 Foreign IO data

The IO data for Denmark, Germany, Sweden, and United Kingdom came from the European Unions' Eurostat database<sup>7</sup>. The data was provided in basic prices for 2000; except for the United Kingdom which was 1995. The energy and emissions data was obtained from each countries central statistical offices.

The data for the United States of America was taken from two sources. The IO data came from the Bureau of Economic Analysis<sup>8</sup> (BEA) and the emissions data from Missing Inventory Estimation Tool (MIET) Version 2 (Suh and Huppes, 2002). The MIET uses 1996 data and is at the product level. Manipulations were made using the IO data to convert the MIET data into the industry level. Unfortunately, the US data is only available in producer prices and not basic prices. Energy data was not available for this study.

The Japanese data was obtained from the Embodied Energy and Emissions Intensity (3EID) project<sup>9</sup> (Nansai et al., 2003). The data was only available for 1995 and in producer prices.

The Chinese data was constructed at the International Institute for Applied Systems Analysis (IIASA) (Hubacek, 2002). The IO data was taken from 1997 and was only available in producer prices. The emissions data was constructed from 1995 and 2000 data and then interpolated for 1997 to allow combination with the 1997 IO data.

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<sup>7</sup><http://europa.eu.int/comm/eurostat>

<sup>8</sup><http://www.bea.doc.gov/bea/dn2/i-o.htm>

<sup>9</sup><http://www-cger.nies.go.jp/publication/D031/CGER/Web/eng/index-e.htm>

A limitation with the emissions data was a common subset of pollutants. For the calculations here, we only had emissions data overlap for CO<sub>2</sub>, SO<sub>2</sub>, and NO<sub>x</sub>. Some other regions had more detailed emissions data. Future studies should include a broader range of pollutants.

### 3.3 Survey of Consumer Expenditure (SCE)

Statistics Norway conducted a Survey of Consumer Expenditure (SCE) for the years 2000-2002<sup>10</sup>. The SCE provides a detailed description of the expenditure of a sample of private households. The households can be aggregated into various types based on; socio-economic status, income, region, and so on. Consequently, this data is ideal to study the environmental impacts of households with different characteristics.

A primary use of the SCE is to update the weights used for calculating the consumer price index. Consequently, the data is biased heavily towards expenditure. For an environmental analysis it would be ideal to have more detail on direct fuel use, transportation usage, purchase of imports, and so on. This lack of data required several assumptions for the analysis presented here. Further areas of difficulty are in the handling of margins and the mapping of the SCE product data to the IO industry data.

The direct fuel use by households is an important contribution to environmental impacts. This data was not available in physical units for many of the household types we studied. However, estimations can be made based on the expenditure in a given category. For instance, to estimate the direct fuel use for transportation, the expenditure in the category “0722 Fuels and lubricants” was assumed to constitute all automobile fuels. The fuel price was assumed to be 10NOK per liter and it was assumed that the carbon dioxide emissions were 3.13kg CO<sub>2</sub> per kg fuel used. The specific weight of fuel was taken as 0.74kg/l. All data was from Flugsrud et al. (2000) and Statistics Norway (2000).

Data was available on the direct fuel use for house type, household size and net income<sup>11</sup>; although, only the data on household size was used here due to the different aggregations with the SCE data. For the category “Oil and kerosene” it was assumed that all the fuel was oil. It was assumed that 1kWh was  $85 \times 10^{-6}$  tonnes of oil equivalent and that the emissions were 3,150kg CO<sub>2</sub>, 1.2kg SO<sub>2</sub>, and 2.5kg NO<sub>x</sub> per tonne fuel used. For the “Wood, coal, and coke” sector it was assumed that all the fuel was coal; data on wood was not available. It was assumed that 1kWh was  $123 \times 10^{-6}$  tonnes of coal equivalent and that the emissions were 2,420kg CO<sub>2</sub>, 20kg SO<sub>2</sub>, and 17.9kg NO<sub>x</sub> per tonne fuel used. From this data it was possible to estimate the emissions for the direct use of fossil fuels for stationary purposes. All data was from Flugsrud et al. (2000) and Statistics Norway (2000).

The SCE data is tabulated using the Classification of Individual Consumption by Purpose (COICOP) classification; which is a product classification. The industry sectors for the IO tables are in the NACE classification; which is an industry classification. A correspondence table between the two classifications was constructed using the definitions

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<sup>10</sup>Most of the data can be obtained through <http://www.ssb.no/english/subjects/05/02/fbu.en/>. A report on an earlier version of the survey is also available (Lodberg-Holm and Mørk, 2001).

<sup>11</sup><http://www.ssb.no/english/subjects/01/03/10/husenergi.en/tab-2004-06-08-01-en.html>

of each classification<sup>12</sup>. Mapping a product classification to an industry classification requires many approximations since the correspondence is not 1-1. For instance, “0431 Materials for the maintenance and repair of the dwelling” could have been purchased from numerous industry sectors; and this is likely to vary with different household types. To ensure the correspondence between NACE and COICOP was approximately correct the COICOP data for the average household was mapped to the NACE classification and then compared to the IO data for household demand. As discussed above, a similar procedure was used for mapping the SITC imported product data into the NACE industry classification.

A further issue is required to determine the taxes and margins on the different products purchased during the SCE. The SCE data is in retail prices, however, the IO data is in basic prices. Information on the taxes and margins was obtained from the IO data at the product level. Statistics Norway uses its own product classification in the IO tables. Our own estimates were used to map this product classification to the COICOP classification. The SCE data was then converted into basic prices.

The portion of imports purchased by consumers in the various categories was also estimated. It was assumed that the ratio of imports for product  $j$ ,  $r_j$ , was constant in all households and given by

$$r_j = \frac{\{y_h^{im}\}_j}{\{y_h^d\}_j + \{y_h^{im}\}_j} \quad (17)$$

where  $y_h^d$  is the household consumption of domestic produced goods from the IO tables and  $y_h^{im}$  is the household consumption of imported goods from the IO tables.

## 4 The importance of technology differences

The importance of technology differences between different regions can be illustrated through a comparison of the total emission intensities,

$$F_{i,total} = F_i(I - A_i^d)^{-1} \quad (18)$$

Each row in  $F_{i,total}$  represents a different pollutant. The elements in each row represent the total emissions, including indirect emissions, for one NOK of output. The emission intensity multiplier is defined as the sum of the row elements,

$$F_{i,multiplier} = \sum_j \{F_{i,total}\}_j \quad (19)$$

and gives an indication of the overall emission intensity in a given region.

Table 4 shows the multiplier of the emissions intensity for each of the regions. Norway has considerably lower emissions per NOK for both CO<sub>2</sub> and SO<sub>2</sub>. Although, the differences are not so prominent for NO<sub>x</sub>; this is due to the high NO<sub>x</sub> emissions from Norway’s off-shore industries. Norway’s generally lower emission intensities is due to Norway’s high use of hydropower to generate electricity; see Table 5. Despite this, Norway does not

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<sup>12</sup>The classification schemes are shown in Appendix A.1 and A.2. For more information see <http://europa.eu.int/comm/eurostat/ramon/geninfo/geninfo.en.html>

Country	Total multiplier		
	CO <sub>2</sub>	SO <sub>2</sub>	NO <sub>x</sub>
NO*	1.54 kg/NOK	2.07 g/NOK	11.24 g/NOK
NO	1.00	1.00	1.00
SE	1.11	1.00	1.44
UK	2.00	8.21	0.90
US	3.68	7.77	1.05
DE	2.04	1.52	0.28
DK	1.74	3.11	1.36
JP	1.50	3.00	0.94
CH	16.16	85.96	6.98

Table 4: The total normalized multiplier of emission intensity in each region. NO\* gives the actual values in Norway.

Country	Electricity, hot water		
	CO <sub>2</sub>	SO <sub>2</sub>	NO <sub>x</sub>
NO*	0.01 kg/NOK	0.02 g/NOK	0.06 g/NOK
NO	1.0	1.0	1.0
SE	8.4	9.8	4.4
UK	40.4	206.4	18.7
US	77.8	265.9	50.8
DE	65.3	36.0	14.3
DK	58.5	14.8	21.7
JP	20.4	8.3	4.2
CH	258.5	1171.4	134.9

Table 5: The normalized emission intensities in each region for NACE sector 40: Production and distribution of electricity, steam and hot water supply. NO\* gives the actual value in Norway.

Country	Food products and beverages		
	CO <sub>2</sub>	SO <sub>2</sub>	NO <sub>x</sub>
NO*	0.03 g/NOK	0.03 g/NOK	0.30 g/NOK
NO	1.00	1.00	1.00
SE	1.06	0.88	0.85
UK	1.48	7.67	0.42
US	1.24	2.56	0.16
DE	1.67	1.81	0.15
DK	2.02	2.86	1.06
JP	1.10	3.34	0.41
CH	10.24	78.87	2.60

Table 6: The normalized emission intensities in each region for NACE sector 15: Manufacture of food products and beverages. NO\* gives the actual value in Norway.

always have the lowest emission intensity in a given sector. Table 6 shows the emission intensities for the “manufacture of food products and beverages”. This sector is a particularly important sector in terms of total Norwegian expenditure and consumer needs. In this sector, Norway generally has a lower emissions intensity, although the differences are considerably smaller. For NOx emissions in particular, Norway is one of the worst performers. This reflect that a wide range of fuels are used directly and indirectly in this sector. Similar variations are found in other sectors, highlighting the different production technologies and industry structures in the different countries.

The differences demonstrated in Table 4, 5, and 6 show that it is crucial to incorporate the different technology of different regions when determining emissions embodied in trade. The differences are particularly prominent for developing countries and can be as large as three orders of magnitude. Even for small to moderate amounts of trade with developing countries it is likely that the emissions embodied in trade with foreign regions will be significant.

## 5 Pollution embodied in Norwegian consumption

In this section the above model is applied at three different scales using the case of Norway as an example. First, the emissions from total Norwegian production and consumption are calculated and the balance of trade for pollutants discussed. Second, the emissions resulting from Norwegian total household consumption is calculated. Finally, the emissions from several different household types is calculated. Particular attention is given to the accurate determination of emissions embodied in imports.

Before proceeding with this section some definitions are required to avoid confusion. The *direct emissions* are the emissions that result from the fuel used directly by consumers; for instance, the petrol that is used for private transportation or the wood that is used to heat a house. The *indirect emissions* are the emissions resulting from the production of goods and services demanded by the consumer and is given by  $F_{i,total}$ ; for instance, the emissions resulting from the production of a TV purchased by a consumer. Within  $F_{i,total}$  there are also direct and indirect emissions. The direct emissions,  $F_i$ , refer to the direct emissions from the “manufacturer of TV” sector. While,  $F_{i,total}$  also includes all the upstream production processes originating from the “manufacturer of TV”; that is, the emissions resulting from the Leontief inverse in IOA.

### 5.1 Total emissions

Tables 7, 8, and 9 show the CO<sub>2</sub>, SO<sub>2</sub>, and NOx emissions for total Norwegian demand. In each table  $y_{domestic}$  represents the emissions resulting from Norwegian domestic demand on domestic production,  $y_{export}$  represents the emissions resulting from export demand, and  $y_{import}$  represents the emissions resulting from imports into final demand categories. Each row shows the embodied emissions from the different regions.

The emissions in Norway are the emissions resulting from the demand  $y_{domestic}$  or  $y_{export}$ ,

$$F_{NO}(I - A_{NO}^d)^{-1}y \quad (20)$$

Carbon Dioxide	$y_{domestic}$ 10 <sup>9</sup> kg	$y_{export}$ 10 <sup>9</sup> kg	$y_{import}$ 10 <sup>9</sup> kg
<b>NO</b>	14.0	35.8	0.0
SE	0.8	0.9	0.6
UK	0.9	1.4	0.8
NA	2.5	1.5	1.2
DE	1.9	3.0	1.9
DK	0.5	0.5	0.6
JP	0.2	0.3	0.7
DC	4.1	5.1	7.5
<b>Foreign</b>	10.8	12.7	13.3
<b>Total</b>	<b>24.8</b>	<b>48.6</b>	<b>13.3</b>

Table 7: The CO<sub>2</sub> emissions in all regions from total Norwegian final demand.

Sulfur Dioxide	$y_{domestic}$ 10 <sup>6</sup> kg	$y_{export}$ 10 <sup>6</sup> kg	$y_{import}$ 10 <sup>6</sup> kg
<b>NO</b>	15.3	67.1	0.0
SE	1.2	1.4	0.9
UK	4.0	6.2	4.1
NA	6.2	3.6	2.6
DE	1.9	3.0	1.9
DK	0.6	0.6	0.6
JP	0.3	0.4	1.0
DC	29.7	37.0	54.2
<b>Foreign</b>	43.9	52.2	65.4
<b>Total</b>	<b>59.2</b>	<b>119.3</b>	<b>65.4</b>

Table 8: The SO<sub>2</sub> emissions in all regions from total Norwegian final demand.

where  $y$  represents  $y_{domestic}$  or  $y_{export}$ . *Indirect imports* are required in the production of the demands  $y_{domestic}$  and  $y_{export}$  and the resulting embodied emissions are tabulated in the rows for each region. The magnitude of the emissions due to indirect imports is given by

$$F_i(I - A_i)^{-1} \underbrace{s_i A_{NO}^{im} x_{NO}}_{\text{imports } i} \quad (21)$$

where “imports  $i$ ” are the imports into industry from each region  $i$  required to produce the demand,  $y$ , and

$$x_{NO} = (I - A_{NO}^d)^{-1} y \quad (22)$$

is the output in Norway for the given demand,  $y$ .

The column  $y_{import}$  represents the *direct imports* to consumers. The emissions from each foreign region in this column is due to production of the imports in the foreign region. In this column the entry for Norway is zero; however, any Norwegian exports used in production in the foreign region would be calculated in the  $y_{export}$  column. Note that all these calculations only consider interindustry trade into Norway, and not interindustry

Nitrogen Oxides	$y_{domestic}$ 10 <sup>6</sup> kg	$y_{export}$ 10 <sup>6</sup> kg	$y_{import}$ 10 <sup>6</sup> kg
<b>NO</b>	110.0	384.2	0.0
SE	4.0	3.0	2.9
UK	2.0	3.2	1.9
NA	4.7	3.0	2.1
DE	1.9	3.0	1.9
DK	2.2	1.8	2.5
JP	0.5	0.6	1.6
DC	11.4	14.6	20.7
<b>Foreign</b>	26.7	29.3	33.5
<b>Total</b>	<b>136.7</b>	<b>413.6</b>	<b>33.5</b>

Table 9: The NOx emissions in all regions from total Norwegian final demand.

trade between foreign regions which is assumed to be negligible; that is, “second-order” trade is not included.

Tables 7, 8, and 9 show that a large portion of emissions occur in foreign regions as a consequence of Norwegian production. For instance, to produce the domestic consumer demand in Norway,  $y_{domestic}$  emits  $14.0 \times 10^9$  kg of CO<sub>2</sub> in Norway, but  $10.8 \times 10^9$  kg of CO<sub>2</sub> are emitted in foreign regions due to indirect imports. Of the foreign emissions the contribution from developing countries (DC) is dominant; this is despite DCs representing only 10% of Norway’s imports; see Table 2. This occurs due to the poor emission intensities in the DCs, see Table 4.

Tables 10, 11, and 12 show the emissions when imports are assumed to be produced with Norwegian technology. By comparing with Tables 7, 8, and 9 it is evident that assuming imports are produced with Norwegian technology leads to large differences in emissions. These differences highlight the importance of including technology differences when determining pollution embodied in trade.

Several results and generalizations can be drawn from these tables. First, of the Norwegian domestic emissions, 72% of the emissions result from exports; however, only 38% of Norway’s domestic output is from exports. This signifies that production of Norwegian exports are more CO<sub>2</sub> intensive than production of domestic demand. Second, about 50% of the impacts from Norwegian consumption activities occur in other regions. About half of these impacts occur in developing countries which represent only 10% of Norwegian imports. This occurs since Norway has a unique energy supply where almost 100% of electricity is produced by hydropower. Third, assuming other regions have Norwegian technology, greatly underestimates the impacts of Norwegian imports.

## 5.2 Balance of Trade

The results from the previous section highlight an important issue resulting from climate change policies such as the Kyoto Protocol; namely, “carbon leakage” (Wyckoff and Roop, 1994). A country that is a part of the Kyoto Protocol may reduce its emissions by importing from a foreign region. If the foreign country has a worse emissions profile than



Carbon Dioxide	$y_{domestic}$ 10 <sup>9</sup> kg	$y_{export}$ 10 <sup>9</sup> kg	$y_{import}$ 10 <sup>9</sup> kg
<b>NO</b>	14.0	35.8	0.0
<b>Foreign</b>	3.8	5.4	3.3
<b>Total</b>	<b>17.8</b>	<b>41.2</b>	<b>3.3</b>

Table 10: The CO<sub>2</sub> emissions when it is assumed that the foreign regions have the same technology as Norway.

Sulfur Dioxide	$y_{domestic}$ 10 <sup>6</sup> kg	$y_{export}$ 10 <sup>6</sup> kg	$y_{import}$ 10 <sup>6</sup> kg
<b>NO</b>	15.3	67.1	0.0
<b>Foreign</b>	5.3	7.6	5.0
<b>Total</b>	<b>20.6</b>	<b>74.7</b>	<b>5.0</b>

Table 11: The SO<sub>2</sub> emissions when it is assumed that the foreign regions have the same technology as Norway.

Nitrogen Oxides	$y_{domestic}$ 10 <sup>6</sup> kg	$y_{export}$ 10 <sup>6</sup> kg	$y_{import}$ 10 <sup>6</sup> kg
<b>NO</b>	110.0	384.2	0.0
<b>Foreign</b>	16.2	20.3	15.9
<b>Total</b>	<b>126.2</b>	<b>404.5</b>	<b>15.9</b>

Table 12: The NO<sub>x</sub> emissions when it is assumed that the foreign regions have the same technology as Norway.

the domestic economy, then total global emissions will increase due to trade. This problem can be lessened by including all countries in the Kyoto Protocol. An alternative approach is to make the consumer, and not the producer, responsible for emissions (Munksgaard and Pedersen, 2001).

Currently, the producer is responsible for emissions. Total emissions in a country are determined from all producing industries; whether for domestic production or export. If the consumer is responsible, then the total emissions for a given country are the emissions emitted producing goods for domestic consumption, including the emissions emitted in the production of imports for domestic consumption. If emissions are taken from a consumer perspective, then the consumer must seek the countries with the most efficient production processes. The net difference between producer responsibility and consumer responsibility is the balance of trade for emissions.

Tables 13, 14, and 15 show different methods of expressing the environmental impact for Norway (Munksgaard and Pedersen, 2001). The “producer” column shows the total emissions embodied in Norwegian production. The “consumer” column shows the total emissions embodied in Norwegian final demand (consumption). The “net” column is the difference between producer and consumer; equivalently, it is a trade balance of exports minus imports. The rows represent the emissions occurring directly in Norway, emissions occurring in foreign regions, and the total emissions. These values can be derived from Tables 7, 8, and 9. The figures with an asterisks, \*, in each figure is the official figure

Carbon Dioxide	Producer $y_{dom} + y_{ex}$	Consumer $y_{dom} + y_{im}$	Net $y_{ex} - y_{im}$
<b>NO</b>	49.8*	14.0	35.8
<b>Foreign</b>	23.6	24.1	-0.6
<b>Total</b>	<b>73.4</b>	<b>38.1</b>	<b>35.3</b>

\* This is the official emissions figure for Norway.

Table 13: The balance of trade for CO<sub>2</sub> emissions (millions of tonnes).

Sulfur Dioxide	Producer $y_{dom} + y_{ex}$	Consumer $y_{dom} + y_{im}$	Net $y_{ex} - y_{im}$
<b>NO</b>	82.4*	15.3	67.1
<b>Foreign</b>	96.1	109.3	-13.2
<b>Total</b>	<b>178.5</b>	<b>124.6</b>	<b>53.9</b>

\* This is the official emissions figure for Norway.

Table 14: The balance of trade for SO<sub>2</sub> emissions (1000 tonnes).

Nitrogen Oxides	Producer $y_{dom} + y_{ex}$	Consumer $y_{dom} + y_{im}$	Net $y_{ex} - y_{im}$
<b>NO</b>	494.2*	110.0	384.2
<b>Foreign</b>	56.1	60.2	-4.2
<b>Total</b>	<b>550.3</b>	<b>170.2</b>	<b>380.1</b>

\* This is the official emissions figure for Norway.

Table 15: The balance of trade for NO<sub>x</sub> emissions (1000 tonnes).

reported by Statistics Norway. When this figure is compared to the emissions occurring in foreign regions it can be argued that the figure is a poor representation of Norwegian environmental impacts, particularly for pollutants with global impacts.

For the arguments here, it is assumed that the indirect imports are embodied in the produced good. This implies that all the upstream emissions from production processes, in both the domestic economy and foreign regions, are allocated to the produced good that is sold to a final demand category. For instance, the emissions from producing the imports required in Norwegian production are allocated to the the producer of the final good in Norway, not the region that produced that import. This is perhaps a strong definition of embodied emissions, but this definition is consistent with the concept of life-cycle emissions and ignores political and geographical boundaries.

Munksgaard and Pedersen (2001) raise the argument of who should be responsible for the pollution; the producer or the consumer. The current approach is the producer. If the producer is responsible then the total Norwegian impacts are higher than if the consumer is responsible. This reflects that a large fraction of the Norwegian economy (38%) is based pollution intensive exports (72% of CO<sub>2</sub> emissions). When total imports are included, Norway is a net exporter of pollution; see the last column in Tables 13, 14, and 15.

In terms of international global climate change policies, should Norway be punished for being an exporter of pollution? Given the Norwegian energy mix is high in the use

of hydropower, the emission intensities of Norway in the exporting sectors is relatively low compared to other regions. This would suggest that Norway should be encouraged to export energy intensive goods due to its low greenhouse gas emissions. This argument would favor making the consumer responsible for Norwegian pollution, not the producer. If the consumer is responsible, then they need to purchase goods from the country with the lowest embodied emissions intensity.

Ultimately, all pollution is the result of consumer demand somewhere in the world. Encouraging consumers to demand less pollution intensive goods is a favored means of reducing global pollution. For this, a method is required to determine the emissions resulting from consumer consumption patterns. This can be approached at the economy scale or the household scale. These two approaches are considered in the following sections.

### 5.3 Household consumption

If the consumer is to be held responsible for environmental impacts, then a method is needed to determine the pollution from household consumption. In this section the environmental impacts of total Norwegian household consumption is calculated. These calculations show which industry sectors cause the greatest environmental impacts for household purchases. An analysis of these industry sectors shows where the greatest reductions in environmental impacts can be made.

Tables 16, 17, and 18 show the total emissions resulting from Norwegian household demand. Again, the proportion of the emissions coming from foreign regions is large. The column for domestic demands has been broken into three sections. The first column is the emissions in various regions due to household consumption without margins. The second column represents trade and transport margins. The last column is the total. In the Norwegian IO tables, trade and transport margins are treated as a final demand category (also in the value added). In the calculations performed here, a proportion of these margins are allocated to household consumers. The new domestic household consumption vector is given by

$$y_h^d \mapsto y_h^d + y_{Margins} \frac{y_h^d + y_h^{im}}{y_t^d + y_t^{im}} \quad (23)$$

where the calculations are performed on a sector by sector basis. That is, in each sector, the proportion of margins in household consumption are assumed to be in the same proportion of household consumption in total demand. Since all of the margins are produced in the domestic economy, only the domestic household demand is increased. Whilst this is not the most ideal way to deal with margins, it gives a suitable estimate. Equivalent data was not available for the foreign regions and so it is implicitly assumed that there are no emissions due to trade or transport margins in the foreign regions.

The emissions from the direct import of goods is greater than Norwegian domestic emissions for CO<sub>2</sub> and SO<sub>2</sub>. Approximately 16% of Norwegian household consumption comes from imports, but approximately 65% of emissions occur in Foreign regions when compared to the total emissions. The differences are particularly apparent when it is assumed that Norwegian imports are produced with domestic technology; see Tables 19, 20, and 21. The emissions assuming Norwegian technology are up to 6 times lower.

Carbon Dioxide	Domestic			Imports	Total
	Household	Margins	Total		
<b>NO</b>	5.6	0.8	6.4	0.0	6.4
<b>Foreign</b>	4.5	0.4	4.9	7.1	12.0
<b>Total</b>	<b>10.1</b>	<b>1.2</b>	<b>11.3</b>	<b>7.1</b>	<b>18.4</b>

Table 16: The CO<sub>2</sub> emissions from total Norwegian household consumption (million tonnes).

Sulfur Dioxide	Domestic			Imports	Total
	Household	Margins	Total		
<b>NO</b>	5.9	0.7	6.6	0.0	6.6
<b>Foreign</b>	18.3	1.6	19.9	36.3	56.2
<b>Total</b>	<b>24.2</b>	<b>2.3</b>	<b>26.5</b>	<b>36.3</b>	<b>62.8</b>

Table 17: The SO<sub>2</sub> emissions from total Norwegian household consumption (1000 tonnes).

Nitrogen Oxides	Domestic			Imports	Total
	Household	Margins	Total		
<b>NO</b>	46.0	6.2	52.2	0.0	52.2
<b>Foreign</b>	11.5	1.0	12.5	19.2	31.7
<b>Total</b>	<b>57.5</b>	<b>7.2</b>	<b>64.7</b>	<b>19.2</b>	<b>83.9</b>

Table 18: The NO<sub>x</sub> emissions from total Norwegian household consumption (1000 tonnes).

Carbon Dioxide	Domestic			Imports	Total
	Household	Margins	Total		
<b>NO</b>	5.6	0.8	6.4	0.0	6.4
<b>Foreign</b>	1.7	0.2	1.9	2.1	4.0
<b>Total</b>	<b>7.4</b>	<b>1.0</b>	<b>8.3</b>	<b>2.1</b>	<b>10.5</b>

Table 19: The CO<sub>2</sub> emissions from total Norwegian household consumption when it is assumed that imports are produced with Norwegian technology (million of tonnes).

Sulfur Dioxide	Domestic			Imports	Total
	Household	Margins	Total		
<b>NO</b>	5.9	0.7	6.6	0.0	6.6
<b>Foreign</b>	2.3	0.2	2.4	2.8	5.2
<b>Total</b>	<b>8.2</b>	<b>0.9</b>	<b>9.0</b>	<b>2.8</b>	<b>11.8</b>

Table 20: The SO<sub>2</sub> emissions from total Norwegian household consumption when it is assumed that imports are produced with Norwegian technology (1000 tonnes).

Note that these calculations do not include direct fuel use in households; such as the fuel used in a car, wood used in an oven, and so on. Data provided from Statistics Norway shows that the emissions from direct use of fuel is  $4.9 \times 10^9$  kg for CO<sub>2</sub>,  $908 \times 10^3$  kg for SO<sub>2</sub>, and  $19.0 \times 10^6$  kg for NO<sub>x</sub>. These values should be added to the domestic totals in Tables 16, 17, and 18 to get the total direct and indirect emissions resulting from Norwegian household consumption.

Nitrogen Oxides	Domestic			Imports	Total
	Household	Margins	Total		
<b>NO</b>	46.0	6.2	52.2	0.0	52.2
<b>Foreign</b>	7.7	0.6	8.4	10.2	18.5
<b>Total</b>	<b>53.8</b>	<b>6.8</b>	<b>60.6</b>	<b>10.2</b>	<b>70.7</b>

Table 21: The NO<sub>x</sub> emissions from total Norwegian household consumption when it is assumed that imports are produced with Norwegian technology (1000 tonnes).

Of more interest is a study of the pollution coming from production in different sectors instigated by Norwegian household demand. Table 22 shows the top ranking total domestic and foreign emissions for total Norwegian household demand. Also shown is the percentage of total household expenditure for those sectors. The top 25 ranking sectors represent 90% of emissions and 75% of household expenditure. Many of the high ranking expenditure sectors not listed are service related and have low emissions. Care needs to be taken with the aggregated sectors “Real estate and business activities” and “Wholesale and retail trade” as they represent a disproportionately large expenditure and emissions due to aggregation.

Table 22 shows that some of the worst sectors in terms of environmental performance have low household expenditures. Many of the sectors with high household expenditure have low emissions; these are generally service related sectors. This indicates that changed consumption patterns, for instance to service related sectors, would likely reduce environmental impacts.

The table shows which sectors should receive the most attention to reduce pollution. Generally the worst emissions occur in the same categories and this would suggest targeting, for instance, the top ten ranking sectors. However, the values in the table represent total accumulated emissions. Much of the impacts from one sector may occur indirectly in other sectors due to the interindustry linkages. For instance, manufacturing may require large inputs of metals. If the emission intensity of the metal industries is much greater than manufacturing then a large portion of the emissions may occur in the metals industries. This would suggest targeting the efficiencies in the metals industry. To investigate these interindustry linkages requires the use of other techniques, such as structural path analysis, and is beyond the scope of this article; refer to Lenzen (2002).

Of particular interest would be to follow the interindustry linkages through the trade flows. For instance, 97% of the household expenditure on “Manufacture of wearing apparel” is imported. Of the imports to final demand, 52% of wearing apparel comes from developing countries and the CO<sub>2</sub> emission intensity is 35 times worse in developing countries than Norway. From an environmental perspective, the study of these value chains through structural path analysis will give valuable insight into where to direct environmental improvements.

The “Manufacture of food and beverages” sector is important in terms of expenditure and emissions and would suggest an area for improvements. Although, since food is an essential part of household consumption it may not be possible to drastically reduce the expenditure on food; however, it is certainly worthwhile to improve the environmental performance of the agriculture sector. The “Manufacture of chemicals” sector has low

NACE code and abbreviated description		CO <sub>2</sub>		SO <sub>2</sub>		NO <sub>x</sub>		Expenditure	
		10 <sup>9</sup> kg	Rank	10 <sup>6</sup> kg	Rank	<sup>6</sup> kg	Rank	%	Rank
HH	Direct household use	4.90	1	0.91	20	19.00	1	-	-
15	M. of food products	2.38	2	7.50	2	16.12	2	11.5	2
70-74	Business activities	1.64	3	3.85	4	6.16	5	21.0	1
18	M. of wearing apparel	1.63	4	11.21	1	4.61	6	2.4	11
60	Land transport	1.19	5	0.43	28	8.70	4	4.2	6
24	M. of chemicals	1.08	6	4.58	3	2.35	9	1.8	17
23	M. of petroleum products	0.87	7	1.89	10	2.00	11	1.5	19
63	Support transport activities	0.57	8	1.60	13	3.75	7	3.3	9
36	M. of furniture	0.57	9	2.95	7	1.70	13	2.3	12
17	M. of textiles	0.57	10	3.15	5	1.44	16	1.3	22
34	M. of motor vehicles	0.56	11	1.39	15	1.07	20	3.8	7
26	M. of non-metallic products	0.55	12	1.77	11	1.16	18	0.3	38
1	Agriculture and hunting	0.55	13	1.71	12	3.19	8	1.8	16
61	Water transport	0.52	14	2.09	9	10.77	3	0.6	28
62	Air transport	0.50	15	0.25	30	1.54	15	0.9	24
27	M. of basic metals	0.48	16	1.27	17	0.73	24	0.0	44
19	M. of leather products	0.45	17	2.97	6	1.32	17	0.8	26
35	M. of other transport equip.	0.37	18	2.16	8	0.95	22	0.9	25
29	M. of machinery and equip.	0.33	19	0.82	21	0.61	27	1.4	20
32	M. of communication equip.	0.29	20	1.59	14	0.74	23	1.3	21
50-52	Wholesale and retail trade	0.27	21	0.57	26	1.54	14	5.2	5
55	Hotels and restaurants	0.26	22	0.24	31	2.11	10	7.3	3
28	M. of fabricated metal	0.26	23	1.15	19	0.62	26	0.5	32
31	M. of electrical machinery	0.22	24	1.18	18	0.55	31	0.4	34
21	M. of pulp and paper	0.22	25	0.75	23	1.02	21	0.6	31

Table 22: The domestic and imported emissions from the top 25 ranking Norwegian household consumption sectors. Direct fuel use by households is included as a separate sector. The percentage expenditure is relative to the total household expenditure. The NACE descriptions have been abbreviated, see Appendix A.1 for more details. M. stands for Manufacturing.

expenditure and high emissions. It can be targeted through both efficiency improvements and reduced use. Inspection of Table 22 allows the identification of other important sectors worthy of further investigation.

Many household expenditure categories provide essential services and reduced consumption may be difficult. However, many “non-essential” items may appear the top ranking paths. This suggests that consumers will have different expenditure patterns even if they have the same income; these different expenditure patterns could be said to represent the consumers “life-style”. A study of more detailed consumer consumption patterns may identify which life-style choices have smaller environmental impacts. This leads into an analysis of consumption patterns at a more detailed household level.

## 5.4 Survey of Consumer Expenditure

The survey of consumer expenditure (CSE) gives the average consumption for a variety of household types covering socio-economic status, income, region, and so on (Lodberg-Holm and Mørk, 2001). The data is collected primarily to calculate the Consumer Price Index (CPI), but is also suitable for comparing the environmental impacts of different types of consumers. The first of these types of studies was conducted for energy consumption by Herendeen and Tanaka (1976) and Herendeen (1978); ironically the second study was for Norway. Since then, other similar studies have been performed with a focus on energy consumption or environmental impacts; see for example Vringer and Blok (1995), Wier et al. (2001), Lenzen et al. (2004a), Hertwich (2004), and the associated references.

The calculations performed here are illustrative to demonstrate the use of SCE in studying sustainable consumption and to highlight the significant differences introduced from imports. The studies performed by Wier et al. (2001) and Lenzen et al. (2004a) are more complete and detailed, but in general, the same trends are shown here for Norway.

Figure 1 shows the CO<sub>2</sub> emissions for three different categories; age of the highest wage earner, total household consumption, and household size. Only data for CO<sub>2</sub> emissions is shown; the other emissions follow similar trends. Only direct fuel use was available for household size<sup>13</sup>. For household size the direct fuel use comprised approximately 30% of the total household emissions, Table 23. It is expected that direct fuel use would be a similar magnitude in other categories. Other studies show a higher proportion of direct fuel use; about 50% in Wier et al. (2001). The large difference results from the large proportion of impacts coming from imports in this study; see Table 23 for more details.

Figure 1a) shows the CO<sub>2</sub> emissions for the age of the highest wage earner. The emissions peak at 40-49 years and are a minimum at 67 years and over. The structure of the curve introduces the concept of modeling the emissions profile of an individual as they progress through life; similar “life-cycle” studies are performed in economics (Browning and Crossley, 2001). The curve shows that as an individual progresses into married life the household size increases, hence emissions also increase. Eventually the siblings leave home, household size decreases, and as the person ages their impacts decrease. The impacts per Norwegian Kroner decreases slightly throughout the life-cycle.

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<sup>13</sup>Direct fuel use was also available for household consumption, but it was at a different consumption aggregation to the SCE data.

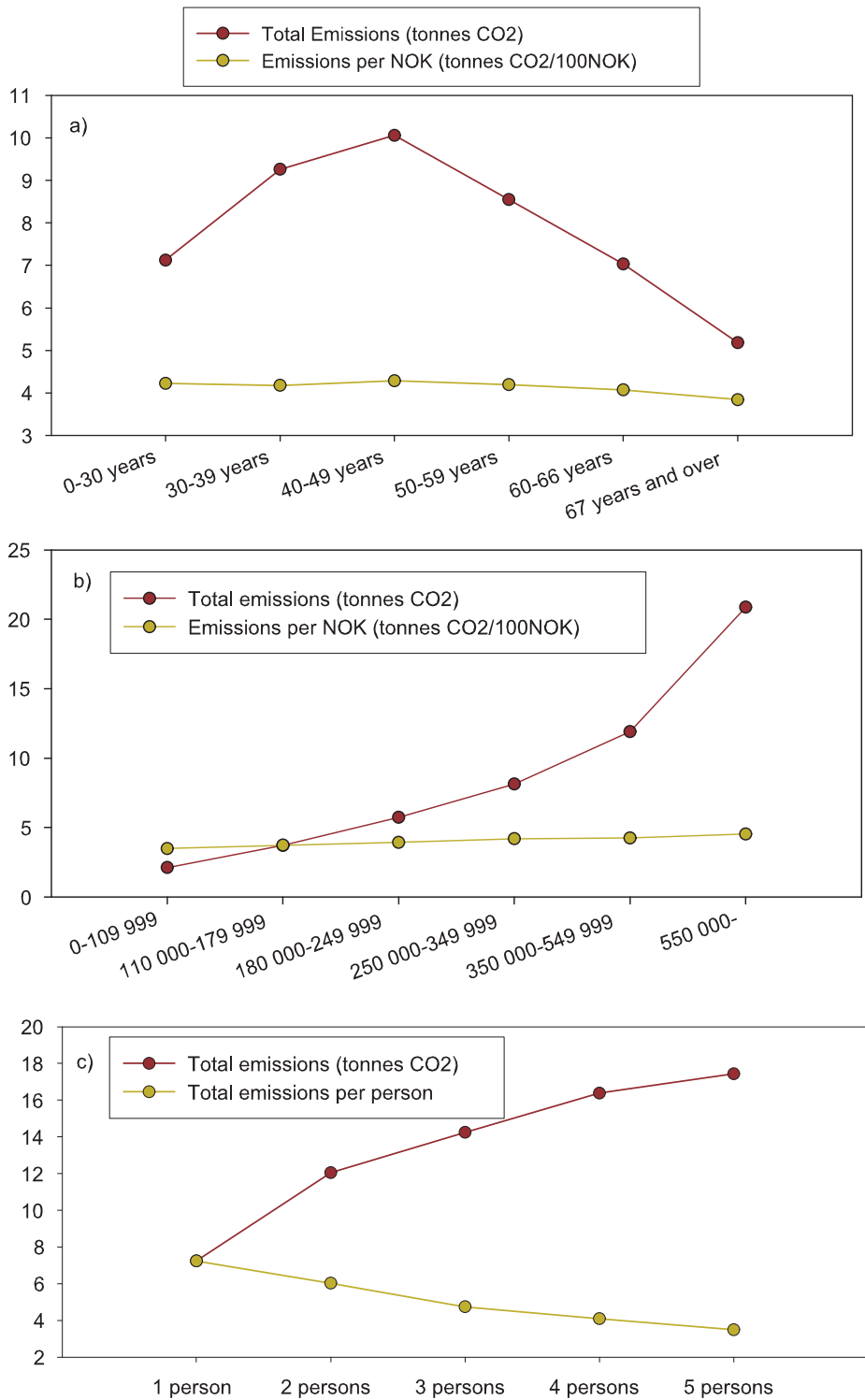


Figure 1: CO<sub>2</sub> emissions and emissions intensities for various household groups: a) Age of highest wage earner, b) Total household consumption, and c) Household size. Only the household size figure includes direct fuel use in the household.



	Average	1 person	2 person	3 person	4 person	5 person
Direct	..	1.9	4.0	4.8	5.3	5.1
Domestic	2.7	2.0	2.7	3.0	3.7	4.0
Indirect import	2.3	1.6	2.3	2.6	3.1	3.3
Direct import	3.0	1.7	3.1	3.8	4.4	5.0
Total	..	7.2	12.1	14.2	16.4	17.4

Table 23: The breakdown of CO<sub>2</sub> emissions for household size. All numbers are tonnes CO<sub>2</sub>. The direct fuel use in the average household was not available. Indirect imports are the imports required for domestic production. Direct imports are the imports purchased by the household.

Figure 1b) shows the CO<sub>2</sub> emissions for total household expenditure. Not surprisingly, impacts increase with income; the emissions intensity increases slightly over the range of incomes. In conjunction with other studies (e.g. Herendeen, 1978) low income households have a high proportion of emissions resulting from essential requirements such as heating and food, whilst high income household purchase more luxury items with a higher value added component. The effect of higher value added is not covered in this study. In the IOA framework, it is assumed that all products within a given product aggregation have the same percentage margin; for instance, it is assumed that a small car at the bottom of the market has the same percentage margin as a luxury car at the top of the market. This work is required to determine an efficient methodology of allowing for different margins within the same product line.

Figure 1c) shows the CO<sub>2</sub> emissions with number of persons in the household, see also Table 23. Consistent with other studies, the emissions increase with household occupants, but the impact per person decreases. In conjunction with Figure 1a) this suggests the impacts of the middle age groups would have a superior per capita performance due to increased household occupants in families; unfortunately data was not available to perform this calculation. The results suggest larger household sizes should be encouraged; for instance, encouraging siblings to live at home longer, the elderly to live with siblings or retirements villages, younger people to live together, communal living arrangements, and so on. There may also be other social benefits for these strategies and so any studies would need to be inherently multidisciplinary.

The three illustrations in Figure 1 identify some of the advantages with using the SCE to study environmental impacts. The data used here had already been aggregated in various household groups, but the use of the raw data in future studies offers greater potential to focus on particular areas of interest; for instance, transportation use or household size. Lenzen et al. (2004a) performed similar studies on energy use and performed multivariate regressions across a variety of variables. Although, to study particular issues may require additional data gathering; for instance, proportion of imports purchased in different households, more detailed transportation usage patterns, and so on.

#### 5.4.1 Issues in using the Survey of Consumer Expenditure

Whilst the SCE offers many possibilities to study sustainable consumption patterns, several issues arise. Importantly, the data is particularly focussed on an economic rational.

Additional data would be beneficial for more environmentally focused studies. Some of the main problem areas include:

- For this study it was assumed that all households have the same proportion of imports. More detail on the purchase of imported items is desirable. This information could easily be collected through the SCE.
- More detail is required on direct fuel use. The use of a large portion of fuel use may be underestimated, particularly for rural areas where undocumented use of wood for heating may be high.
- More detail is required on the usage of different personal transportation modes; such as car usage, type of car, distances traveled, public transportation usage, and so on. This type of information is easily collected during the SCE and could be done in conjunction with transportation studies such as the Norwegian Travel Survey (Denstadli and Hjorthol, 2002).
- The emissions resulting from air transport are not captured. Data on the distances traveled and to which destinations would be required.
- A recurring issue since the initial studies (Herendeen and Tanaka, 1976) is the difficulty with taxes and margins. Data was available for the taxes collected but at a different classification scheme to the SCE data.
- Detail on the different markups on similar products of different branding or quality would be beneficial, but perhaps had to determine. It would be interesting to study any correlation between preferences for brand names or imported goods with socio-economic status, age, and so on.
- The determination of transportation needs better estimation. In particular, the transportation of imported goods is not included; both direct imports and indirect imports to households.

## 6 Limitations and further work

The emissions data here only covered three pollutants. This limitation was due to the emissions data available in the Japanese data we used. The other countries have data available on a wider range of pollutants, but the overlapping subset of pollutants is still limited. Future studies need to use a wider range of impacts; global warming potential, human toxicity, acidification, and so on.

More attention needs to focus on the environmental impacts associated with transportation. This is particularly important for imported goods where transportation may be a significant source of pollution. The degree to which these emissions are captured in the import of transportation services needs to be checked. It may be that separate estimates are required for international transportation given the trade flows. Work is underway in this regard (Strømman and Duchin, 2005).

Companion studies can be used to collect specific data for cases of interest. For instance, studies of the car free housing settlement in Vienna (Hertwich et al., 2004) and car sharing (Briceno et al., 2005) both have a particular focus on car usage. Similar detailed studies can be combined with the SCE data to look at sustainable consumption in particular areas of interest.

Data is available to perform companion studies for energy use. These studies would highlight the differences in energy mix across different countries. For the case of Norway, these studies are likely to show that Norway should export energy intensive products due to the large use of hydropower. However, in other countries the differences may not be so apparent. At the household level, studies of energy usage in a country like Norway may identify areas where energy usage can be improved. Improved energy efficiency may put less pressure on the expansion of the energy sector; for Norway, construction of fossil fuel power stations are being planned to meet growing energy needs.

More detailed information needs to be gathered on the treatment of imports in IO data. Various inconsistencies were noticed in this study. For instance, according to the NACE classification, consumers purchase cars through the “Retail trade” sector; cars are then purchased as an interindustry transaction by the “Retail trade” sector. However, in the IO data for imports, it appears that cars are purchased directly by consumers. There is a potential of missing a large amount of the emissions resulting from margins in this case. When a large portion of emissions result from imports, verification is required to determine if individual countries have a consistent approach to IO data and imports.

The handling of competitive and non-competitive imports may create some difficulties and is an important issue. Norway has a high proportion of non-competitive imports and it is important to ensure that the emissions from non-competitive imports are properly accounted for. Peters and Hertwich (2004) go through a detailed example of some issues with non-competitive imports. Further work is needed to verify the correct handling of non-competitive imports.

Since foreign regions are being compared with the domestic economy then exchange rates between regions must be considered. A problem arises since one unit of a given currency may buy different quantities of a particular good in different countries. As an example of the likely errors it is worth considering the variation in cost of a commonly traded good by region. The export price of unwrought aluminium in 2000 varied considerably across regions<sup>14</sup> (in kg/US\$); Norway 1.73, Sweden 1.70, United Kingdom 1.61, United States 1.44, Germany 1.67, Denmark 1.42, Japan 2.55, and China 1.45. These price differences are considerable and the choice of exchange rate will greatly alter the results. A more thorough analysis may require the use of Purchasing Price Parity across different sectors instead of Market Exchange Rates Peters and Hertwich (2004).

Unfortunately, most of the data required for environmental studies come from a variety of sources; each source has different objectives in their data collection. To alleviate many of the issues in estimating environmental impacts requires more coherence between data sources. While it may be argued that this is underway, there is still a long way to go. The various statistical offices and government organizations need to be encouraged to increase communication and coherence between various data.

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<sup>14</sup>Source: <http://www.unctad.org/>

## 7 Conclusion

The calculations performed here demonstrate the importance of including explicit calculation of the emissions embodied in imports. The emissions for the developing countries were very high. This may be realistic but further investigations are required. Ideally, data should be obtained for other developing countries to see if China is a good representation of the technology and emission intensities in other developing countries.

Calculations were performed at four different scales to show the different applications of the theoretical framework. At the national level it was shown the majority of emissions from Norwegian production and consumption is embodied in imports; particularly from developing countries. This highlights the importance of including regional technology differences in the calculations. Different methods of calculating the total impacts from Norway were considered; producer responsibility or consumer responsibility. Currently, it is assumed that the producer is responsible for pollution, but since Norway is a net exporter of pollution then consumers are made responsible for a larger portion of pollution than they actually consume. It is argued that a better approach would be to have the consumer responsible for emissions, thereby encouraging consumers to purchase from regions with low embodied emission intensities.

The impacts of total households was also calculated. Again a large portion of the emissions came from imports. These calculations were used to show which sectors of the economy produce the biggest portion of pollution and should have policies directed towards. The importance of value chains through both interindustry linkages and trade flows was discussed. Calculations were then performed at the household level. These studies allow more detailed studies of emissions resulting from different consumption patterns. It is hoped that future studies in this direction will allow detailed studies of lifestyles and sustainable consumption patterns.

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## A Classification Schemes

### A.1 Statistical Classification of Economic Activities in the European Community (modified NACE REV.1)

- 01 Agriculture, hunting and related service activities
- 02 Forestry, logging and related service activities
- 05 Fishing, operation of fish hatcheries and fish farms; service activities incidental to fishing
- 10 Mining of coal and lignite; extraction of peat
- 11 Extraction of crude petroleum and natural gas; service activities incidental to oil and gas extraction excluding surveying
- 13 Mining of metal ores
- 14 Other mining and quarrying
- 15 Manufacture of food products and beverages
- 16 Manufacture of tobacco products
- 17 Manufacture of textiles
- 18 Manufacture of wearing apparel; dressing and dyeing of fur
- 19 Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear
- 20 Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
- 21 Manufacture of pulp, paper and paper products
- 22 Publishing, printing and reproduction of recorded media
- 23 Manufacture of refined petroleum products
- 24 Manufacture of chemicals and chemical products
- 25 Manufacture of rubber and plastic products
- 26 Manufacture of non-metallic mineral products
- 27 Manufacture of basic metals
- 28 Manufacture of fabricated metal products, except machinery and equipment
- 29 Manufacture of machinery and equipment n.e.c.
- 30 Manufacture of office machinery and computers
- 31 Manufacture of electrical machinery and apparatus n.e.c.
- 32 Manufacture of radio, television and communication equipment and apparatus
- 33 Manufacture of medical, precision and optical instruments, watches and clocks
- 34 Manufacture of motor vehicles, trailers and semi-trailers
- 35 Manufacture of other transport equipment
- 36 Manufacture of furniture; manufacturing n.e.c.
- 37 Recycling
- 40 Production and distribution of electricity, steam and hot water supply
- 41 Collection, purification and distribution of water

45	Construction
50-52	Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods
55	Hotels and restaurants
60	Land transport
61	Water transport
62	Air transport
63	Supporting and auxiliary transport activities; activities of travel agencies
64	Post and telecommunications
65-67	Financial intermediation
70-74	Real estate, renting and business activities
75	Public administration and defence; compulsory social security
80	Education
85	Health and social work
90	Sewage and refuse disposal, sanitation and similar activities
91	Activities of membership organization n.e.c.
92	Recreational, cultural and sporting activities
93	Other service activities

## **A.2 Classification of Individual Consumption by Purpose (COICOP)**

01	Food and non-alcoholic beverages
011	Food
0111	Bread and cereals
0112	Meat
0113	Fish
0114	Milk, cheese and eggs
0115	Oils and fats
0116	Fruit
0117	Vegetables
0118	Sugar, jam, honey, chocolate and confectionery
0119	Food products
012	Non-alcoholic beverages
0121	Coffee, tea and cocoa
0122	Mineral waters, soft drinks, fruit and vegetable juices
02	Alcoholic beverages and tobacco
021	Alcoholic beverages
0211	Spirits
0212	Wine
0213	Beer
022	Tobacco
03	Clothing and footwear

- 031 Clothing
  - 0311 Clothing materials
  - 0312 Garments
  - 0313 Other articles of clothing and clothing accessories
  - 0314 Cleaning, repair and hire of clothing
- 032 Footwear
  - 0321 Shoes and other footwear
  - 0322 Repair and hire of footwear
- 04 Housing, water, electricity, gas and other fuels
  - 041 Actual rentals for housing
    - 0411 Actual rentals paid by tenants
    - 0412 Other actual rentals
  - 042 Imputed rentals for housing
    - 0421 Imputed rentals of owner-occupiers
    - 0422 Other imputed rentals
  - 043 Maintenance and repair of the dwelling
    - 0431 Materials for the maintenance and repair of the dwelling
    - 0432 Services for the maintenance and repair of the dwelling
  - 044 Water supply and miscellaneous services related to the dwelling
    - 0441 Water supply
    - 0442 Refuse collection
    - 0443 Sewerage collection
    - 0444 Other services relating to the dwelling
  - 045 Electricity, gas and other fuels
    - 0451 Electricity
    - 0452 Gas
    - 0453 Liquid fuels
    - 0454 Solid fuels
- 05 Furnishings, household equipment and routine maintenance of the house
  - 051 Furniture and furnishings, carpets and other floor coverings
    - 0511 Furniture and furnishings
    - 0512 Carpets and other floor coverings
    - 0513 Repair of furniture, furnishings and floor coverings
  - 052 Household textiles
  - 053 Household appliances
    - 0531 Major household appliances whether electric or not
    - 0532 Small electric household appliances
    - 0533 Repair of household appliances
  - 054 Glassware, tableware and household utensils
  - 055 Tools and equipment for house and garden
    - 0551 Major tools and equipment

- 0552 Small tools and miscellaneous accessories
- 056 Goods and services for routine household maintenance
  - 0561 Non-durable household goods
  - 0562 Domestic services and household services
- 06 Health
  - 061 Medical products, appliances and equipment
    - 0611 Pharmaceutical products
    - 0612 Other medical products
    - 0613 Therapeutic appliances and equipment
  - 062 Out-patient services
    - 0621 Medical services
    - 0622 Dental services
    - 0623 Paramedical services
  - 063 Hospital services
- 07 Transport
  - 071 Purchase of vehicles
    - 0711 Motor cars
    - 0712 Motor cycles
    - 0713 Bicycles
  - 072 Operation of personal transport equipment
    - 0721 Spare parts and accessories
    - 0722 Fuels and lubricants
    - 0723 Maintenance and repair of personal transport equipment
    - 0724 Other services in respect of personal transport equipment
  - 073 Transport services
    - 0731 Passenger transport by railway
    - 0732 Passenger transport by road
    - 0733 Passenger transport by air
    - 0734 Passenger transport by sea and inland waterway
    - 0736 Other purchased transport services
- 08 Communication
  - 081 Postal services
  - 082 Telephone and telefax equipment
  - 083 Telephone and telefax services
- 09 Recreation and culture
  - 091 Audio-visual, photographic and information processing equipment
    - 0911 Equipment for the reception, recording and reproduction of sound and pictures
    - 0912 Photographic and cinematographic equipment and optical instruments
    - 0913 Information processing equipment
    - 0914 Recording media
    - 0915 Repair of audio-visual, photographic and information processing equipment



- 092 Other major durables for recreation and culture
  - 0921 Major durables for outdoor recreation
  - 0922 Musical instrument and majors durables for indoor recreation
  - 0923 Maintenance and repair of other major durables for recreation and culture
- 093 Other recreational items and equipment, gardens and pets
  - 0931 Games, toys and hobbies
  - 0932 Equipment for sport, camping and open-air recreation
  - 0933 Gardens, plants and flowers
  - 0934 Pets and related products
- 094 Recreational and cultural services
  - 0941 Recreational and sporting services
  - 0942 Cultural services
  - 0943 Games of chance
- 095 Newspapers, books and stationery
  - 0951 Books
  - 0952 Newspapers and periodicals
  - 0953 Miscellaneous printed matter
  - 0954 Stationery and drawing materials
- 096 Package holiday
- 10 Education
  - 101 Pre-primary and primary education
  - 102 Secondary education
  - 103 Post-secondary non-tertiary education
  - 104 Tertiary education
  - 105 Education not definable by level
- 11 Restaurants and hotels
  - 111 Catering services
    - 1111 Restaurants, cafes and the like
    - 1112 Canteens
  - 112 Accommodation services
- 12 Miscellaneous goods and services
  - 121 Personal care
    - 1211 Hairdressing salons and personal grooming establishments
    - 1212 Electrical appliances for personal care
    - 1213 Other appliances, articles and products for personal care
  - 123 Personal effects
    - 1231 Jewellery, clocks and watches
    - 1232 Other personal effects
  - 124 Social protection
  - 125 Insurance
    - 1252 Insurance connected with the dwelling

- 1253 Insurance connected with health
- 1254 Insurance connected with transport
- 126 Financial services
- 127 Other services

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