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TRADE AND ENVIRONMENT

Emissions intensity of Norway's imports and exports

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Trade and environment - Emissions intensity of Norway's imports and exports

Master thesis

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FOREWORD

The accomplishment of this thesis has required hard work, but it has been a very interesting and exciting period.

I would like to thank the following persons:

My supervisors Edgar G. Hertwich, Glen Peters and Anders H. Strømman, and my colleagues Christian Solli, Håvard Bergsdal and Johan Pettersen for their unvaluable help, support and encouragement.

SUMMARY

An Environmental Input-Output Analysis (EIOA) have been performed in order to assess the importance of including foreign emission and economic data when estimating emissions attached to imports. The CO_2, SO_x and NO_x emissions induced by total imports are calculated using both foreign and domestic inventory. The results show significantly higher emissions when using foreign data, especially for SO_x.

Demand-specific emission intensities are established for both import and domestic production. A comparison of those for emissions of CO_2, SO_x and NO_x indicates much higher values for the imports than for the domestic production.

In addition, analyses are conducted on a more detailed level, defined by the NACE-industry aggregation. Foreign inventory are used on the imports, and domestic inventory are used on the domestic production. The detailed demand-specific emission intensities show similar trends compared with the total results mentioned above. However, there are considerable differences between some of the NACE sectors.

Finally, a brief overview of the assumed emissions related to household consumption is performed. However, the analysis are not on such a detailed level that conclusions can be made.

SAMMENDRAG

En Environmental Input-Output Analysis (EIOA) er blitt utført med det formål å undersøke effektene av å bruke utenlandske utslippsdata og økonomiske data ved beregning av utslipp knytta til import. Tradisjonelt har det blitt brukt innenlands data ved miljømessige vurderinger av import, men med visshet om at det ikke har gitt riktige tall. Import-induserte utslipp av CO_2, SO_x og NO_x er beregnet ved bruk av både innenlands og utenlandske data. Resultatene viser at utslippene er vesentlig høyere når det benyttes utenlandske data, spesielt gjelder dette SO_x.

I resten av oppgaven er det brukt utenlandsk data for importberegninger. Etterspørselsspesifikke utslippsintensiteter for CO_2, SO_x and NO_x er funnet for både import og innenlandsk produksjon. En sammenligning av disse viser tildels store forskjeller, igjen særlig for SO_x.

Liknende analyser er blitt gjennomført på et mer detaljert nivå, i henhold til NACE-rammeverket for næringsaggregering. De detajlerte næringsspesifikke resultatene viser de samme trendene som de foregående undersøkelsene, men likevel tildels store forskjeller NACE-næringene imellom.

Avslutningsvis er det indikert hvilke miljømessige konsekvenser som følger av konsum i husholdningene, ved å se på hvordan de totale utslippene arter seg i utvalgte husholdningsrelaterte næringer.

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1. INTRODUCTION

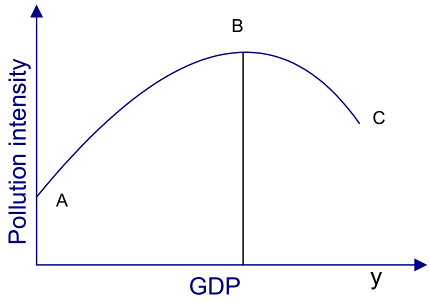
1.1 Motivation

Economic globalization is by many seen as the most important driving force for global economic growth. Yet, the World Trade Organization (WTO) meeting in Seattle in 1999, demonstrated that the opinions about the benefits of this process are split. From an environmental perspective, there are several controversial issues. What are the actual environmental effects of trade? Should the producer or the consumer be held responsible for this environmental stress? The need for an analytical approach to the problems has initiated increasing attention from both trade negotiators and researchers, and various hypotheses have been presented trying to environmentally assess these extremely complex issues.

Relocating large shares of the pollution-intensive industry from developed countries to less developed countries, is a general expected effect of globalization. This shift might be explained by pointing to how industrial development traditionally is expected to occur. The developed countries are currently undergoing the same process as the developed countries did 100 years ago. However, it seems that the shifting of localization can not be explained by this alone. Countries whose environmental legislations are poorly worked out, might appear more attractive for investors since the economic way of thinking traditionally implies that excessive environmental standards leads to a loss of economic activity [1]. The Prebisch-Singer thesis implies that barring major changes in the structure of the world economy, the gains from trade will continue to be distributed unequally between nations exporting mainly primary products and those exporting mainly manufacturers. In addition, inequality of per capita income between these two types of countries will be increased by the growth of trade, rather than reduced [2]. The developing countries specialize in production of resource-intensive products which offers a low value added and are highly sensitive to changes in prices, thus trapping these countries in a state of low development.

There also exist arguments noticing the possible environmental benefits from trade. Researchers have argued the existence of an Environmental Kuznets Curve (EKC), which main assertion is that the economic growth following industrialization in the end will lead to a decoupling of Gross Domestic Product (GDP) per capita and environmental impact. The literature on this topic began in

1992 with the paper by Grossmann and Krueger [3]. An EKC is shown in the figure, where the pollution intensity is given as a function of GDP per capita. The figure shows the pollution intensity reaches a maximum in point B, from which further economic growth in general will result in lower pollution intensities. EKC's are widely used to consider macro-changes in the environmental condition resulting from economic growth. Still, the nature of the EKC-mindset implies that the effects of pollution are non cumulative, or in other words, the environmental effects are reversible. Not many EKC's exist for CO_2, the majority are considering issues like SO_2 emissions and water quality. It is easy to see why, these are problems that are more tangible and can be handled by relatively inexpensive technology compared to greenhouse gases. There are several analysis questioning the EKC's usefulness as a tool for environmental assessment. Holtz-Eakin and Selden [4] conclude that for CO_2, the EKC-relationship does not hold. Further, as indicated by De Bruyn [5], the empirical evidences for the EKC-theories remains weak. Stern, [6] and [7], gives a critical view of EKC and the findings in EKC studies. Cole [8] examines the linkages between trade, pollution and the EKC.



The empirical research on quantifying pollution embodied in trade, however, is in its infancy. Effort is required in order to establish a robust framework suitable for quantifying the emissions. Still, to be able to analytically investigate the various aspects, it is of crucial importance to possess an extensive data collection containing both environmental and economic parameters. Since USA's economy, and its induced environmental repercussions, is quite satisfactorily described in the literature, most studies have used USA data as the basis for the analysis. This assumption allows one to perform quantitative exercises on the environmental repercussions induced by the trade between countries. On the other hand, the assuming that all the trading partners' economic and environmental data corresponds to USA's data basis, ignores the fact that the production regimes in the various countries might be of a very different nature. Thus, the comparative differences in the conditions of productions are not accounted for. Consequently, these studies do not accurately depict the carbon embodied in trade.

Wyckoff and Roop presented an article in 1994 titled "The embodiment of carbon in imports of manufactured products." [9] A quotation from the article's introduction summarizes well the issues that initiated the research. "The design of many greenhouse gas policies is predicated on controlling emissions by reducing domestic greenhouse gas emissions (GHG). This ignores the importance of carbon embodied in international trade flows which could take on increased importance if emission reduction schemes are undertaken which include only a subset of GHG emitting countries"[9]. One of their important findings was that some countries could have up to 40 percent of CO_2 embodied in imports of manufactured goods, compared to total CO_2 emissions.

Determining and modelling the pollution content of trade flows, allows us to investigate

- Whether countries are net importers or net exporters of pollution.
- Whether or not consuming domestic produced goods is preferable to consuming imported goods in an environmental context.
- Build scenarios for shifts in trade patterns and determine their effect on the environment.

This thesis is a continuing of a project titled "Pollution embodied in Norway's import and export: Indication for environmental benefits of trade?" initiated by Hertwich et. al. [10]. Three questions were asked:

1. Is the environmental profile of domestically consumed goods significantly different from that of exported goods?
2. How does the profile of the imported goods harmonize with the domestically production for consumption and exports?
3. What amount of the emissions induced by a representative Norwegian household occurs abroad?

Hertwich. et. al use Norwegian data in the analysis, but perform some estimates that indicates that by including foreign data for the import can lead to significant differences in the results.

The work presented in this thesis extends the work of Hertwich et. al. in the following areas:

1. An analytical framework is developed to include foreign emissions data.
2. The Norwegian emission data and economic data are updated from 1997 numbers to 2000 numbers.
3. Explicit emission data and economic data is used for USA, China, Japan and the Netherlands to calculate the embodied emissions in imports.

Section 2 will present the fundamentals of Input-Output analysis. Then, in section 3, a review of previous work is given. The computational structure used in this thesis and the various data collected are given in section 4 and 5 respectively. The final calculations and results are described in section 6. Finally, discussions and conclusions are given in section 7.

2. FUNDAMENTALS OF INPUT-OUTPUT ANALYSIS

2.1 Introduction

Input-output (IO) analysis is an analytic framework developed by Wassily Leontief in the late 1930s, which fundamental purpose is to analyze the interdependence of industries in an economy. It provides a theoretical framework for specific questions about the relationship between economic structure and economic action. Over the years its theoretical structure has been refined and its practical applications has been widened. The detailed way in which IO economics is able to examine economic activities opens the way for studies that deal not only with industrial production, which was the focus in the earliest IO studies, but increasingly with other aspects of human activities as well, such as the effects of production and consumption on the physical environment. By Leontief's own words, "The general nature of the approach has made the development of input-output analysis a cumulative process. Each refinement in theoretical structure and each addition to or improvement in the accuracy of factual information incorporated in its data base potentially improved the performance of the general model in application to all special problems" [11].

Related to environmental assessment, Environmental Input-Output Analysis (EIOA) offers a convenient way to determine the environmental impacts due to a given final demand of different production processes in an economy. Producing one commodity requires inputs from other industries. The industries producing the inputs again need inputs to produce the commodities used as inputs in other industries, and so on. By knowing the total induced economic activity and the emission intensities of the different economic sectors, one is able to calculate the emissions associated to the production of a given commodity. Leontief explored the use of the IO framework to analyze environmental repercussions of the economy in an article in 1970, [12]. This work initiated a number of publications on EIOA, including [13], [14], [15], [16] and [17]. Other work regarding EIOA includes among others [18], [19], [20], [21], [22], [23] and [24]. Recommended background literature on the fundamentals of IO analysis includes [25], [26], [27] and [28].

In addition to the earlier EIOA-works mentioned above it is worth mentioning the article "Total energy cost of household consumption in Norway, 1973" [29], written by Robert Herendeen. He presents some further ideas on the environmental effects induced by consumption. Herendeen uses energy intensities and consumption data to compare the energy intensities for the Norwegian households with the US households' intensities. He defines, though only theoretically, a total energy cost of living equation equalling citizens' energy cost of personal consumption added energy cost of government's consumptions per capita.

These earlier works laid the foundations for further development of models. However, they are not very sophisticated regarding the addressing of the emissions.

The next section presents the foundations of the IO framework.

2.2 The make and use framework

Unless other reference is specified, this section is based on [27, 30, 21]. IO tables are generated from the national accounts, and give a detailed overview over the supply and use of goods and services in the economy. The annual accounts compiled by Statistics Norway contains about 180 industries and 1200 products. The process of compilation starts with independent supply and demand estimates of all goods and services. Finally, supply and demand for each of these is balanced by using supplementing information and quality assessments of the various statistical sources [31]. The Use table describes which types of products are being used as inputs in different industries. The Make table shows the output of products from the respective industries. These two tables can be used to construct a requirements- or symmetric coefficient matrix, often notated as A. This matrix can either be on an industry-by-industry or product-by-product form and describes the inputs from industries $i = 1, ..., n$ needed to produce one unit amount of output in industries $j = 1, ..., n$.

Tab. 2.1: Basic nomenclature for the make and use framework

i	Vector containing only ones
m	Number of products
n	Number of industries
$U_{m,n}$	Intermediate Use matrix
$M_{m,n}$	Intermediate- and final Make matrix
$q_m = M \cdot i$	Product intermediate- and final output vector
$g_n = M^t \cdot i$	Industry intermediate- and final output vector
$B_{m,n} = U \cdot \hat{g}^{-1}$	Intermediate input structure matrix
$C_{m,n} = M \cdot \hat{g}^{-1}$	Output structure matrix

continued on next page

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$D_{n,m} = M^t \cdot \hat{q}^{-1}$	Market share matrix

Table 2.1 shows the notation and the basic expressions within the make and use framework. The product- and industry final output vectors q_m and g_n are obtained by summing $M_{m,n}$ for all m and n respectively. In order to obtain $M_{m,n}$ and $U_{m,n}$ appearing on a relative basis, they are adjusted in relation to q_m and g_n respectively to generate $D_{n,m}$ and $B_{m,n}$, the market share matrix and the input structure matrix. $B_{m,n}$ thus shows the different product inputs $b_{i,j}$ needed by different industries $i = 1, ..., n$ per unit output of the respective industry. On the other hand, $D_{n,m}$ views the industries' market shares $d_{i,j}$ of products $i = 1, ..., m$ per unit output of the respective product.

There are two main methods to combine the make and use matrices mathematically to generate the symmetric input-output matrix, A, either the industry technology assumption (ITA) or the commodity technology assumption (CTA). The ITA assumes that the input structure are identical for every product produced by a given industry, i.e. the technology follows the industry. The CTA assumes that the input structure belongs to the product, i.e. the input structure of the technology that produces a product is the same, no matter what sector it is produced within. There are advantages and disadvantages with both approaches. The ITA is the most common assumption, but has a major disadvantage as it breaks the fundamental economic rule that products with different prices at a given moment must reflect different cost or different technology. Thus, economically, the CTA, which does not break this rule, seems more preferable. However, it has problems related to matrix inversion because of negative entries in symmetric input-output tables. It also requires that the make and use matrices are square, as commented in [27] and [30]. The basis for generating the A matrix for both the industry- and commodity technology assumption is described in table 2.2 below.

Tab. 2.2: Industry -and commodity technology assumption

Industry technology	**Commodity technology**
$A_{ITA(n,n)} = D \cdot B$	$A_{CTA(n,n)} = C^{-1} \cdot B$
$A_{ITA(m,m)} = B \cdot D$	$A_{CTA(m,m)} = B \cdot C^{-1}$

Nevertheless, due to the above-mentioned practical problems attached to the commodity assumption, the industry technology assumption is used here, as is often the case in national accounts, [27]. The columns of A describes the inputs $a_{i,j}$ one industry purchases from other industries and itself to produce one base unit of output. Equation 2.1 shows the industry output vector x as the sum of the inter-industry production activity Ax and the final demand vector y. A given final demand y allows us to solve equation 2.1 for x, and find the total industry output required, as viewed in equation 2.2. I is the identity matrix, with ones diagonally and zeros elsewhere.

$$x = Ax + y_f \tag{2.1}$$

$$(I - A)x = y_f \Leftrightarrow x = (I - A)^{-1} y_f \tag{2.2}$$

The expression $(I - A)^{-1}$ is called the Leontief inverse and allows us to calculate both the direct- and indirect economic effects induced by a given final demand y_f. Table 2.3 shows the structural basis for calculating indirect effects, or the upstream effects, in an logical iterative manner. An exogenous shock is initiated by an exogenous increase in net final demand, as shown in the first line. This exogenous shock requires inputs to its production as given in the A matrix, and these inputs needs further inputs to be produced and so on. Thus, each tier requires inputs determined by the inputs needed in the previous tier multiplied by the A matrix.

Tab. 2.3: Iterative view of input requirement caused by increase in output

Exogenous shock	y_f	y_f
1^{st} **tier**	$A(y_f)$	Ay_f
2^{nd} **tier**	$A(Ay_f)$	A^2y_f
3^{rd} **tier**	$A(A^2y_f)$	A^3y_f
.	.	.
.	.	.
.	.	.
n^{th} **tier**	$A(A^{n-1}y_f)$	A^ny_f
Total impact		$(I + A + A^2 + A^3 + ... + A^n)y_f$

The total impact $(I + A + A^2 + A^3 + ... + A^n)y_f$ displays the total inputs required to produce the exogenous increase in final demand, y, for n tiers upstream. It is shown by Miller and Blair [26] that

$$\lim_{n \longrightarrow \infty}(I + A + A^2 + A^3 + ... + A^n) = (I - A)^{-1} \tag{2.3}$$

thus connecting the Leontief inverse to the economic reasoning in table 2.3 and thereby explaining its economic meaning. For further explanation and discussion on the fundamentals of the make and use framework and a more in-depth examination of the Leontief inverse, see [25], [26], [27] and [32].

2.2.1 Emission intensity

To be able to quantify the environmental repercussions of economic activity, one needs an indicator that attach pollutants to the economic transactions described in the IO-tables. One way of doing this is to address an industry's emissions to the gross output of that industry. Thus, the emission intensity matrix, EI, is generated by dividing the total environmental impacts from different industries with the gross output from the respective industries, for example kg CO_2-equivalents per million NOK output. Table 2.4 shows the general emission intensity framework.

Tab. 2.4: General framework when generating emission intensity matrices

e	Emissions
n	Number of industries
g_n	Industry output vector
$E_{(n,e)}$	Emission matrix
$B_{(n,e)} = E^t \cdot \hat{g}^{-1}$	Emission intensity matrix

Further, when analyzing how these emissions intensities affect the environment, the $B_{(n,e)}$ matrix is multiplied by a characterization matrix $W_{(n,effect-category)}$. Hence, this multiplication gives the total environmental impacts within different effect categories, for example Global Warming Potential and Acidification Potential. The results depends on which characterization method that is used. The characterization method CML 2 baseline 2000 [33] is viewed in table 2.5

Tab. 2.5: Impact categories used in CML 2 baseline 2000 characterization method

Impact category	**Explanation**	**Characterization equivalents per kg emissions**[a]
ADP	Abiotic Depletion Potential	kg Sb
GWP (100)	Global Warming Potential (100 years time horizon)	kg CO_2
ODP	Ozone Depletion Potential	kg $CFC - 11$
HTP	Human Toxicity Potential	kg $1,4 - dichlorobenzene$
FAETP	Fresh water Aquatic EcoToxicity Potential	kg $1,4 - dichlorobenzene$
MAETP	Marine Aquatic EcoToxicity Potential	kg $1,4 - dichlorobenzene$
TETP	Terrestrial EcoToxicity Potential	kg $1,4 - dichlorobenzene$
POCP	Photochemical Ozone Creation Potential	kg C_2H_4
AP	Acidification Potential	kg SO_2
NP	Nutrification (eutrophication) Potential	kg PO_4

[a] With the exception of ADP where it is per kg minerals and fossil fuels extracted

3. REVIEW OF PREVIOUS WORK

Equation 2.2 displays the most generalized version of the IO framework. When used to investigate more sophisticated issues than calculating the total economic impacts and its environmental repercussions due to a net final demand, it is necessary to expand and modify the model. As introduced in section 1.1, the traditional way of calculating import-induced foreign economic activity in IO-analysis has been to assume that the countries whose goods and services are imported from, all have the same industrial input structure and emissions matrices, see for example [10], [21] and [34]. This assumption may not influence the result to a large degree in cases when the import-country are in a similar economic situation compared to the country investigated. However, if the country are not in such a state, then this assumption is unrealistic. The main reason why it is used, often rests on the lack of vital economic and environmental information from the countries which goods and services are imported from. Additionally, it is also easier to obtain a general framework for the calculations when making these simplifications. When including IO-tables from the different import-countries in order to perform more robust and accurate analysis, the development of neat, concise formulas becomes tricky.

As an example, when using Norway's emission inventory on imports, this leads to a distortion of the results. This is because Norway has very low emissions due to a high share of hydro-power in the energy producing sector. The assumption is normally justified by pointing out that collecting emission data from all countries is a formidable time and resource consuming exercise. The inventory might not exist at all, or might be presented inconveniently compared to the domestic inventory.

If we know that this assumption is not satisfying, what is the most preferable approach? Status quo, or trying to incorporate the abroad IO-tables and emission inventories that are actually available?

Using domestic inventory on imports generates wrong answers. The challenge is to obtain a logical and consistent framework that do not necessarily require a perfect inventory for all import partners. Let us say that the emission and economic inventory for four of Norway's most important trading partners are fairly well documented. Then, one suggestion could be to group Norway's other import partners on the basis of an assumed similar-looking emission structure and economic structure compared to these four groups. This is the technique used in this thesis.

3.1 Framework covering imports and exports

United Nation's approach [27] is chosen as a starting point for describing how imports can be treated in IO analysis.

3.1.1 UN's approach

The original nomenclature used in [27] is slightly modified here. It starts with the general formula $x = Ax + y_f$, identical to equation 2.1 on page 7. Stating that $A = A^d + A^m$ and $y_f = y_f^d + y_f^m$ equation 2.1 could be expanded to

$$x = A^d x + A^m x + y_f^d + y_f^m - M \tag{3.1}$$

Total imports M go to either intermediate or final demand, thus

$$M = A^m x + y_f^m \tag{3.2}$$

Substitution for M in equation 3.1 then gives

$$x = A^d x + A^m x + y_f^d + y_f^m) - A^m x + y_f^m \Leftrightarrow x = A^d x + y_f^m \tag{3.3}$$

That is, imports do not affect domestic output if A^d and y^d are constant. The domestic and abroad production, x^d and x^m, induced by total final demand $y_f = y_f^d + M$ can now be written as

$$x^d = x = (I - A^d)^{-1} y_f^d \tag{3.4}$$

$$x^m = (I - A^f)^{-1} M \tag{3.5}$$

Final demand y_f consists of several parameters. The next section will explore how capital investment are embodied into the framework.

3.1.2 Capital expenditures in final demand

Unless other reference is given, the contents of this section is based on Lenzen [21]. First the general case is viewed, whereupon treatment of capital-imports are shown. Equation 3.6 describes the most aggregated version of the National

Accounts (NA)[1]. Gross Domestic Product (GDP) plus import (im) equals the supplies to the economy, whereas Gross National Expenditures (GNE) plus export (ex) views the demand in the economy.

$$GDP + im = GNE + ex \tag{3.6}$$

The demand side is dividable into more specific terms. This is shown in equation 3.7.

$$GDP = y_{hc} + y_{gc} + y_{prk} + y_{pek} + y_{gk} + y_{st} + y_{ex} \tag{3.7}$$

where y_{hc} and y_{gc} denotes private and governmental consumption respectively, while y_{prk}, y_{pek} and y_{gk} refers to private, public enterprises' and governmental gross fixed capital expenditures respectively. Finally, y_{st} denotes changes in stocks, or the depreciation rate, and y_{ex} represent the export.

In the basic Leontief model described in section 2.2, final demand is notated as y_f, containing both final demand for consumption and final demand for investments, or capital expenditures. Final consumption demand is given as

$$y_c = y_{hc} + y_{gc} + y_{st} + y_{ex} \tag{3.8}$$

Thus, final demand can be divided into consumption- and capital demand, as viewed in 3.9

$$y_f = y_c + y_k \Leftrightarrow y_f = y_c + Kx \tag{3.9}$$

where K is a (n, n) capital matrix including the industry intermediate capital-coefficients $k_{i,j}$ referring to total output x. Its dimensions are equivalent to the A matrix, thus describing the capital investments from sectors $i = 1, ..., n$ into sectors $j = 1, ...n$. Combining equation 3.9 and 2.2 yields equations

$$x = Ax + y_c + Kx \quad \Leftrightarrow \quad x = (I - (A + K))^{-1} y_c \tag{3.10}$$

$$x = Ax + y_c + y_k \quad \Leftrightarrow \quad x = (I - A)^{-1} (y_c + y_k) \tag{3.11}$$

So, now we have obtained two expressions for the total production stating that

[1] In Norway, Input-Output (IO) tables, showing the flows of products and services in economy, are produced every year. These tables constitute the basis for the National Accounts (NA).

$(I - (A + K))^{-1} y_c = (I - A)^{-1}(y_c + y_k)$. Hence, the final production will be the same whether the capital investment is given as final demand or as intermediate industry coefficients.

Regarding imports, the procedure is identical with the UN-method described in section 3.1.1. So, when separating final consumption -and final capital demand equations 3.4 and 3.4 appear as

$$x^d = (I - A^d)^{-1}(y_c^d + y_k^d) = (I - (A + K)^d)^{-1} y_c^d \quad (3.12)$$
$$x^m = (I - A^f)^{-1} M = (I - (A + M_k)^f)^{-1} M_c \quad (3.13)$$

3.1.3 Lenzen

Manfred Lenzen has published a series of articles regarding impacts of import, amongst others "A Generalized Input-Output Multiplier Calculus for Australia" [21]. Here he seeks to develop a set of multipliers, which can be used to calculate the production factors[2] required in consequence of a given final demand. These multipliers were used as basis for the analysis performed by Hertwich et. al. [10], and also initially thought used as analytical basis for this thesis. However, through a more closely examination of the equations derived by Lenzen, and when comparing them to the works of UN [27], I raise some objections to some of Lenzens equations. The same objections have been made by Glen Peters in a working note [35]. To show what is questioned, the original nomenclature is kept. This is explained in table 3.1.

Tab. 3.1: Nomenclature used by Lenzen

A	Domestic produced domestic intermediate demand referring to x
A^D	Domestic produced domestic intermediate demand referring to x^D
A_M	Abroad produced domestic intermediate demand referring to x
x	Total produced output
x^D	Domestically produced output
x^M	Foreign produced output, allocated indirectly as domestic output
y_d	Domestic final demand referring to x
y_d^D	Domestic final demand referring to x^D
y_d^M	Domestic final demand referring to x

[2] Production factors can be economic parameters such as employment, capital, imports, extraction of natural resources and environmental stress.

Lenzen comes up with the equation:

$$x = x^D + x^M = A(x^D + x^M) + y_d^D + A_M(x^D + x^M) + y_d^M = (A + A_M)x + y_d \quad (3.14)$$

Translating this equation to the nomenclature used in this thesis yields

$$x^d + x^m = A^d(x^d + x^m) + y_f^d + A^m(x^d + x^m) + y_f^m \quad (3.15)$$

Subtracting both sides of the equation with x^m as given in equation 3.2, should lead to the same expression for x^d as in equation 3.3.

$$\begin{aligned} (x^d + x^m) - x^m &= A^d(x^d + x^m) + y_f^d + A^m(x^d + x^m) + y_f^m - A^m x^m + y_f^m \\ x^d &= A^d x^d + y_f^d + A^d x^m + A^m x^d \end{aligned} \quad (3.16)$$

Equation 3.16 shows that $x^d_{Lenzen} \neq x^d_{UN}$. It contains, in addition to its contemporary, equation 3.3, the intermediate demands $A^d x^m$ and $A^m x^d$.

3.1.4 Strømman and Gauteplass

Anders Strømman and Aslak Gauteplass explores in their paper, "Domestic Fractions of Emissions in Linked Economies. Exploring the Environmental Repercussions of the Mirrored-economy Assumption" [34], the domestic fraction of environmental impacts generated in a case when two identical countries are trading with each other. As the title indicates, it is assumed that the economies are identical, which of course does not match with the intention of this thesis. Yet, it presents important relations that helps understanding the basic import-export framework, and hence might lighten the development of additional import-framework for quantifying more sophisticated import- and export related issues.

The nomenclature used is a straightforward extension of the general IO-framework presented in table 2.1. All matrices are divided into an import (m) part and a domestic (d) part. It is chosen not to cover all their expressions here, since the procedure is pretty self-explanatory.

A general equation for an economy with imports and exports is presented as in equation 3.17.

$$x = x^d + x^m = A^d x^d + A^m x^d + y_f^d + y_f^m + y_{ex} \quad (3.17)$$

$A_d x_d$ and $A_m x_m$ denotes the inter-industry demand of domestic produced products- and imported products in domestic production respectively. Further, y_f^d and y_f^m, refer to the domestic final demand of domestic produced commodities and imported commodities respectively. Finally, y_{ex} represents the export.

The assumptions made by the authors are:

- The countries are identical.
- The economy consists of two countries and the export from one country equals the other country's import and vice versa.
- Final consumption consists of final products generated within the economy.
- Both exports and imports include only intermediate products.

Constricted by these assumptions, two versions of equation 3.17 are created, one for each country.

$$x_1 = x_1^d + x_1^m = A^d x_1^d + A^m x_1^d + y_1^d + y_1^m + y_1^{ex} \tag{3.18}$$

$$x_2 = x_2^d + x_1^m = A^d x_2^d + A^m x_2^d + y_2^d + y_2^m + y_2^{ex} \tag{3.19}$$

Additionally, following the assumption stated above, the exports y_1^{ex} and y_2^{ex} can be viewed as:

$$y_1^{ex} = x_{2,i} = A_i x_{2,d} \tag{3.20}$$

and

$$y_2^{ex} = x_{1,i} = A_i x_{1,d} \tag{3.21}$$

Thus, the export terms e_1 and e_2 can be eliminated, making us able to solve for the different final demands. This is an easy algebraic operation, hence not included here. Further, the equations can be presented as matrices, as viewed in equation 3.22 where they are solved for final production.

$$\begin{bmatrix} I - A^d & & -I & \\ -A^m & I & & \\ & & I & -A^m \\ & -I & & I - A^d \end{bmatrix}^{-1} \begin{bmatrix} y_1^d \\ y_1^m \\ y_2^d \\ y_2^m \end{bmatrix} = \begin{bmatrix} x_1^d \\ x_1^m \\ x_2^m \\ x_2^d \end{bmatrix} \tag{3.22}$$

Finally, the emissions connected to the economic activity induced for a given final demand can be calculated by implementing an emission intensity matrix B.

$$\begin{bmatrix} B & & & \\ & B & & \\ & & B & \\ & & & B \end{bmatrix} \begin{bmatrix} I - A^d & & -I & \\ -A^m & I & & \\ & & I & -A^m \\ & -I & & I - A^d \end{bmatrix}^{-1} \begin{bmatrix} y_1^d \\ y_1^m \\ y_2^d \\ y_2^m \end{bmatrix} = \begin{bmatrix} e_1^d \\ e_1^m \\ e_2^m \\ e_2^d \end{bmatrix} \tag{3.23}$$

Then, the domestic fraction of total economic activity, X_f, and the thus produced fraction of domestic emissions, B_f, for a given final demand are given in equations 3.24 and 3.25

$$X_f = \frac{[x_1^d]_{i,j}}{[x_1^d]_{i,j} + [x_2^d]_{i,j}} \tag{3.24}$$

$$B_f = \frac{[e_1^d]_{i,j}}{[e_1^d]_{i,j} + [e_2^d]_{i,j}} \tag{3.25}$$

4. COMPUTATIONAL STRUCTURE

4.1 Introduction

We have obtained IO-tables and emission intensities for USA, China, Japan and the Netherlands. The idea is to use these four data sets as basis for a sorting procedure performed on all the other countries exporting to Norway, thus attaching a USA, China, Japan or the Netherlands economic and environmental structure to each country. The intention of performing this exercise is to obtain a more realistic view of the direct and upstream emissions connected to Norwegian import.

The main challenges when constructing a reasonable framework for this thesis are given below.

- Converting the various IO-tables and emission intensities for the different countries to the Norwegian 2-digit NACE classification.
- Allocating the imported commodities table, which are classified by SITC-Standard Industrial Trade Classification, to the Norwegian 2-digit NACE classification[1].
- Developing a quantitative indicator calculated for each country exporting to Norway, thus being able to sort the countries as mentioned above.
- Converting the monetary data from UK, USA, Japan and China, which all refers to different monetary units, to NOK. A crucial task is handling the problems related to continually changing exhange rates.

Before further examining these aspects, a general, idealized framework will be presented.

4.2 Framework

The following notation is used:

---

[1] As given in section 5.4.2 on page 26 these import numbers are used to estimate the origin of import.

Tab. 4.1: Notation for computational structure

A^d	Coefficient matrix of domestic intermediate demand
A^m	Coefficient matrix of imports for intermediate demand
A^f	Coefficient matrix of foreign intermediate demand
y^d_{hc}	Final domestic household consumption demand on domestic production
y^m_{hc}	Final domestic household import consumption demand on foreign production
y^d_{gc}	Final domestic governmental consumption demand on domestic production
y^m_{gc}	Final domestic governmental import consumption demand on foreign production
y^d_k	Final domestic capital demand on domestic production
y^m_k	Final domestic import capital demand on foreign production
y^d_{ex}	Final export demand domestic production
y^m_{dex}	Final direct export demand on imported products
x^d	Domestic production
x^m_{II}	Foreign production induced by A^m
x^m	Foreign production induced by final domestic import demand
B^d	Domestic emissions intensity matrix (emissions per unit output)
B^f	Foreign emissions intensity matrix(emissions per unit output)
E^d	Domestic emissions due to x^d
E^m_{II}	Foreign emissions due to x^m_{II}
E^m	Foreign emissions due to x^m

In the following equations the y_f vector are defined as:

$$y_f = y_{hc} + y_{gc} + y_{ex} + y_k \tag{4.1}$$

Let us start with the domestic emissions, E^d. These emissions are induced by the total domestic production, x^d. Thus, the total domestic emissions can be viewed as

$$E^d_{total} = B^d_{direct} x^d = B^d_{direct}(I - A^d)^{-1} y^d_f \tag{4.2}$$

Further, the domestic final import demand, y^m_f, generates an abroad production for final demand, x^m. Hence, the emissions due to this production becomes

$$E^m_{total} = B^m_{direct}x^m = B^m_{direct}(I - A^f)^{-1}y^m_f \tag{4.3}$$

Finally, the emissions caused by the production of the intermediate imports A^m, $E^m_{II,total}$, must be included. We have to account for the *total* domestic intermediate import demand, $A^m(I - A^d)^{-1}y^d_f$, and then demanding this amount abroad, as given below.

$$x^m_{II} = (I - A^f)^{-1}A^m(I - A^d)^{-1}y^d_f \tag{4.4}$$

Thus, an expression for the emissions related to import of intermediate demand can be obtained.

$$E^m_{II,total} = E^f_{direct}x^m_{II} \tag{4.5}$$

In addition to this intuitive approach, the emission matrices can also be established as shown below.

Matrix approach

Equation 4.6 below is simply equation 2.1 on page 7, the only difference is that it is divided between domestic and foreign production.

$$\begin{bmatrix} x^d \\ x^m_{II} \\ x^m \end{bmatrix} = \begin{bmatrix} A^d & 0 & 0 \\ A^m & A^F & 0 \\ 0 & 0 & A^F \end{bmatrix} \begin{bmatrix} x^d \\ x^m_{II} \\ x^m \end{bmatrix} + \begin{bmatrix} y^d_f \\ 0 \\ y^m_f \end{bmatrix} \tag{4.6}$$

On the basis of equation 4.6, we seek to find expressions of x^d, x^m_{II} and x^m, whose country-specific emission intensities can be attached. At first, the equations directly derived from equation 4.6, are viewed in equation 5.2.

$$\begin{aligned} A^d x^d + \quad 0 + \quad 0 + y^d_f &= x^d \\ A^m x^d + A^f x^m_{II} + \quad 0 + \ 0 &= x^m_{II} \\ 0 + \quad 0 + A^f x^m + y^m_f &= x^m \end{aligned} \tag{4.7}$$

Rearranging these equations on production basis and substituting x^d into the expressions for x^m_{II} yields equations

$$x^d = (I - A^d)^{-1} y^d_f \tag{4.8}$$
$$x^m_{II} = (I - A^f)^{-1} A^m (I - A^d)^{-1} y^d_f \tag{4.9}$$
$$x_m = (I - A^f)^{-1} y^m_f \tag{4.10}$$
$$\tag{4.11}$$

By introducing emission intensity matrices E_d and E_F, an emission matrix e can be derived as in equation 4.12 below.

$$\begin{bmatrix} B^d_{direct} & 0 & 0 \\ 0 & B^f_{direct} & 0 \\ 0 & 0 & B^f_{direct} \end{bmatrix} \begin{bmatrix} \hat{x^d} \\ x^m_{II} \\ x^m \end{bmatrix} = \begin{bmatrix} E^d_{total} \\ E^m_{II,total} \\ E^m_{total} \end{bmatrix} \tag{4.12}$$

This alternative approach leads to the same result as for the approach above.

One note on the expression for x^m_{II}. Since the A^d matrix only contains the domestic input coefficients, how can the domestic emissions connected to the final refinement of the intermediate imports be included? The reason is that the domestic emission intensity matrix B^d covers all the emissions per unit domestic production, thus also covering the emissions induced by the domestic use of intermediate imports.

Now, the general framework for the calculation of emissions has been established. The next section will describe the collection and preparation of the data used.

5. COLLECTION AND PREPARATION OF DATA

5.1 Introduction

This chapter describes the data, from where it is collected, what the notation means and how the various data are manipulated here. Most appendices are given electronically and denoted as E-Appendix. A CD-ROM including all appendices is enclosed at the back of the report. An overview over the different E-Appendices are given in Appendix B

First, one important note on how the economic data is valued here.

Generally there exist three ways of describing the price of a product or a service. Base value or gate value, producer value and purchaser value. The base value is basically the production costs, the producer value equals the base value plus the direct taxes[1]. In addition to producer prices, purchasers' prices contains margins incurred by services such as transport, storage, insurance, wholesale and retail. Normally, when working with IO analysis, the final demand is set in base values. Practically, that means that one buys steel directly from the factory. However, in reality, when demanding steel from the metal producing sector in the IO table, one also "buys" taxes from the government and buys sales margins from a wholesale and retail sector. Thus, the final demand given in purchaser price consists of a base value (factory), taxes (government) and sales margins (producer/manufacturer).

However, in this project it is chosen to work with base values.

5.2 Notations and expressions

Tab. 5.1: Additional notation used

c1	commodity aggregation 1
c2	commodity aggregation 2
CHS	China's industry aggregation

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[1] Direct taxes equals commodity taxes less subsidies.

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ci	country aggregation i
cii	country aggregation ii
ciii	country aggregation iii
cm	competing imports
cpi	consumer price index
CH	China
CNY	Chinese Yuan Renminbi
diag	diagonalize
e	emission category
e2	emission category 2
fr	fraction
JP	Japan
JPS	Japan's industry aggregation
JPY	Japanese Yen
NACE	Norway's industry sectors
NAICS	USA's industry aggregation
ncm	non-competing imports
NL	The Netherlands
NLS	The Netherlands' industry aggregation
NOK	Norwegian Kroner
pm	Product import
s	Services in trade matrix
sm	Service import
SITC	Standard Industrial Trade Classification
USA	United States of America
USD	US dollar

Table 5.2 shows all the matrices and vectors that are collected from different sources.

Tab. 5.2: Collected data

Received	**Dimension**	**Size**	**Source**	**Appendix**
M^d	(c1,NACE)	(1271,56)	[36]	E-Appendix 1
U^{total}	(c1,NACE)	(1271,56)	[36]	E-Appendix 2
U^{cm}	(c1,NACE)	(1271,56)	[36]	E-Appendix 3
U^{ncm}	(c1,NACE)	(1271,56)	[36]	E-Appendix 4

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Received	**Dimension**	**Size**	**Source**	**Appendix**
U^{sm}	(s,cii)	(20,70)	[36]	E-Appendix 5
U^{pm}	(ci,SITC)	(187,27)	[37]	E-Appendix 6
K^{total}	(c1,NACE)	(1271,56)	[36]	E-Appendix 7
y_{hc}^{total}	(c1,1)	(1271,1)	[36]	E-Appendix 8
y_{hc}^{cm}	(c1,1)	(1271,1)	[36]	E-Appendix 9
y_{hc}^{ncm}	(c1,1)	(1271,1)	[36]	E-Appendix 10
y_{gc}^{total}	(c1,1)	(1271,1)	[36]	E-Appendix 11
y_{gc}^{cm}	(c1,1)	(1271,1)	[36]	E-Appendix 12
y_{gc}^{ncm}	(c1,1)	(1271,1)	[36]	E-Appendix 13
y_{ex}^{total}	(c1,1)	(1271,1)	[36]	E-Appendix 14
y_{dex}^{cm}	(c1,1)	(1271,1)	[36]	E-Appendix 15
y_{dex}^{ncm}	(c1,1)	(1271,1)	[36]	E-Appendix 16
y_{k}^{cm}	(c1,1)	(1271,1)	[36]	E-Appendix 17
y_{k}^{ncm}	(c1,1)	(1271,1)	[36]	E-Appendix 18
E_{direct}^{d}	(e,NACE)	(21,56)	[36]	E-Appendix 19
B_{total}^{US}	(e,NAICS)	(21,91)	[38]	E-Appendix 20
A^{NL}	(NLS,NLS)	(105,105)	[39, 33]	E-Appendix 21
B_{direct}^{NL}	(e,NLS)	(21,105)	[39, 33]	E-Appendix 22
B_{total}^{JP}	(e,JPS)	(21,186)	[40]	E-Appendix 23
B_{total}^{CH}	(e,CHS)	(21,124)	[10]	E-Appendix 24

Table 5.3 gives the different dimensions of the matrices and vectors and where they can be found.

Tab. 5.3: Matrix and vector dimensions

Dimension	**Appendix**
c1	E-Appendix 25
c2	E-Appendix 26
CHS	E-Appendix 27
ci	E-Appendix 28
cii	E-Appendix 29
ciii	E-Appendix 30
e	E-Appendix 31
e2	E-Appendix 32

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Dimension	**Appendix**
JPS	E-Appendix 33
NACE	E-Appendix 34 and Appendix A
NAICS	E-Appendix 35
NLS	E-Appendix 36
s	E-Appendix 37
SITC	E-Appendix 38

5.3 Preparation of data

5.3.1 Aggregation matrices

The foreign data appears on different aggregation levels, and must be converted to fit the dimensions of the Norwegian data. Also, some of the domestic data are revised to fit the calculation procedures. These conversions are performed by constructing converting matrices which connects two and two matrix dimensions to each others. These are displayed in table 5.4.

Tab. 5.4: Collected data

Matrix	**Explained**	**Appendix**
$P_{(c2,c1)}$	To avoid q_m, see table 2.1 on page 6, containing zeros the commodities in c1 are aggregated to c2. Then q_m can be inverted	E-Appendix 39
$P_{(ci,cii)}$	The countries in ci in U^{pm} are aggregated to cii to appear on same country aggregation as U^s	E-Appendix 40
$P_{(ciii,cii)}$	The cii countries are aggregated to ciii, to be able to estimate where the imports come from.	E-Appendix 41
$P_{(CHS,NACE)}$	The Chinese sectors are converted to NACE sectors	E-Appendix 42
$P_{(JPS,NACE)}$	The Japanese sectors are converted to NACE sectors	E-Appendix 43
$P_{(NACE,SITC)}$	The SITC commodities in U^{pm} are	E-Appendix 44

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Matrix	**Explained**	**Appendix**
	aggregated to assumed NACE producing sector.	
$P_{(NAICS,NACE)}$	The USA's NAICS sectors are converted to NACE sectors.	E-Appendix 45
$P_{(NLS,NACE)}$	The Japanese sectors are converted to NACE sectors	E-Appendix 46
$P_{(s,NACE)}$	The imported services in U^s are distributed to assumed NACE producing sectors	E-Appendix 47

5.3.2 Monetary units and year of reference

The Norwegian and the foreign data are from different years, and refers to different currencies. Since all the domestic data are referring to 1000 NOK in 2000, the foreign data needs to be adjusted according to that. Table 5.5 shows the monetary manipulations that were performed.

Tab. 5.5: Monetary data information

Region	**Year**	**Currency**	**NOK**	**Norwegian cpi relative to 1996**	**Adjusted exchange rate**	$1000NOK_M$
NO	2000	1000-NOK	1.000	110	1.000	1.000
USA	1996	USD	6.516	100	7.168	$1000 \cdot 7.168^{-1}$
NL	1995	USD	6.259	99.3	6.934	$1000 \cdot 6.934^{-1}$
JP	1995	JPY	0.07399	99.3	0.08196	$1000 \cdot 0.08196^{-1}$
CH	1997	CNY	0.8618	102.5	0.9249	$1000 \cdot 0.9249^{-1}$

The 1000-NOK multipliers, $1000NOK_M$, were derived by using the NOK exchange rates for the currencies in the respective years, and then multiply them by the increase in Norwegian consumer price index from the respective years to 2000. The foreign matrices or vectors can then be multiplied by the multiplier in order to adjust them to 1000-NOK in year 2000. The currencies were taken from [41] and the consumer price index from [42].

5.4 Categorization of countries and origin of import

5.4.1 Categorization

As mentioned in section 4.1 on page 17, the countries USA, the Netherlands, Japan and China serve as categories (identical to country aggregation ciii) which the other countries exporting to Norway are assumed to be similar to, since there are no data for these other countries. First, $P_{(ci,cii)}$ given in table 5.4, aggregates from *ci* to *cii* on a geographical basis. The geographical information are collected from [43]. Then, $P_{(ciii,cii)}$ in table 5.4 attaches the *cii* countries to the *ciii* groups. Three indicators are used to estimate which group the countries should belong to. This country-specific information were collected from the World Bank [44].

1. Commercial energy use.
2. CO_2 emissions.
3. GNI (Gross National Income) per capita.

Table 5.6 shows which countries or regions that are attached to the different groups *ciii*.

Tab. 5.6: USA, NL, JP and CH grouping

USA	USA and Canada
NL	Europe and Oceania
JP	Japan
CH	Africa, Asia excluding Japan, Central America and South-America

5.4.2 Region of production

The import matrices received from Statistics Norway are not country specific, simply because this specification does not exist on such a detailed level. However, matrix $U^{pm}_{(ci,SITC)}$ in table 5.2 shows from which country (ci) commodities (SITC) are imported. This matrix covers import of commodities both to domestic final demand and intermediate demand. Based on this matrix, an import-fraction vector $u^{fr}_{(ciii,1)}$, is obtained.

$$\begin{aligned} U^{pm}_{(cii,NACE)} &= (P_{(ci,cii)})^t U^{pm}_{(ci,SITC)} (P_{(NACE,SITC)})^t \\ u^{pm}_{(ciii,1)} &= P_{(ciii,cii)} U^{pm}_{(cii,NACE)} i_{(NACE,1)} \\ u^{fr}_{(ciii,1)} &= u^{pm}_{(ciii,1)} (i_{(1,ciii)} u^{pm}_{(ciii,1)})^{-1} \end{aligned} \tag{5.1}$$

$u^{fr}_{(ciii,1)}$ gives the fractions telling where it is imported from. It is not distinguished between final demand and intermediate demand. Nor is it distinguished between different NACE sectors and different final demands. That is, all products are assumed to have an identical import fraction.

5.5 Preliminary calculations

All calculations were performed in MatLab, and the MatLab scripts are given in E-Appendix 48.

5.5.1 Intermediate demand

The additional Use matrix containing import of services, $U^{sm}_{(s,cii)}$, needs to be included into the two intermediate import matrices. It appears on country basis, but it is chosen to sum it all up to a NACE-vector, and then use the domestic market share matrix to attach the services to their assumed producing sector. It is assumed that $\frac{2}{3}$ are competing import, and that the remaining $\frac{1}{3}$ are non-competing import. This assumption is justified by the fact that these are the fractions for the import of products. Equation 5.2 shows how the A matrices are established. The i-vectors contain only ones.

$$
\begin{aligned}
q^d_{c1,1} &= M^d_{(c1,NACE)} i_{(NACE,1)} \\
g^d_{NACE,1} &= (M^d_{(c1,NACE)})^t i_{(c1,1)} \\
q^d_{c2,1} &= P_{c2,c1} q^d_{c1,1} \\
D^d_{(NACE,c2)} &= (P_{(c2,c1)} M^d_{(c1,NACE)})^t \hat{q}^{-1}_{(c2,1)} \\
U^{sm}_{(c2,NACE)} &= (D^d_{(NACE,c2)})^t diag((P_{(s,NACE)})^t U^{sm}_{(s,cii)}) i_{(cii,1)}) \\
B^{sm}_{(c2,NACE)} &= U^{sm}_{(c2,NACE)} \hat{g^d_{NACE,1}}^{-1} \\
B^{cm}_{(c2,NACE)} &= (P_{c2,c1} U^{cm}_{(c1,NACE)})(\hat{g}^d_{NACE,1})^{-1} + 0,67 B^{sm} \\
B^{ncm}_{(c2,NACE)} &= (P_{c2,c1} U^{ncm}_{(c1,NACE)})(\hat{g}^d_{NACE,1})^{-1} + 0,33 B^{sm} \\
B^{total}_{(c2,NACE)} &= (P_{c2,c1} U^{total}_{(c1,NACE)})(\hat{g}^d_{NACE,1})^{-1} \\
A^{total}_{(NACE,NACE)} &= D^d_{(NACE,c2)} B^{total}_{(c2,NACE)} \\
A^{cm}_{(NACE,NACE)} &= D^d_{(NACE,c2)} B^{cm}_{(c2,NACE)} \\
A^{ncm}_{(NACE,NACE)} &= D^d_{(NACE,c2)} B^{ncm}_{(c2,NACE)} \\
A^d_{(NACE,NACE)} &= A^{total}_{(NACE,NACE)} - (A^{cm}_{(NACE,NACE)} + A^{ncm}_{(NACE,NACE)})
\end{aligned}
\tag{5.2}
$$

5.5.2 Final demand

All the final demands are given on c1-commodity basis, and needs to be converted so that they are demanding from NACE-sectors. It is assumed that all the final demands, except for the capital-demand, are demanded from the respective NACE sectors that produce the commodities in c1, that is, the domestic market share collects the demands of commodities to the sectors that are producing the given commodities. Equation 5.4 explains the procedure.

$$\begin{aligned}
y^{total}_{hc,(NACE,1)} &= D^{d}_{(NACE,c2)}P_{(c2,c1)}y^{total}_{hc,(c1,1)} \\
y^{cm}_{hc,(NACE,1)} &= D^{d}_{(NACE,c2)}P_{(c2,c1)}y^{cm}_{hc,(c1,1)} \\
y^{ncm}_{hc,(NACE,1)} &= D^{d}_{(NACE,c2)}P_{(c2,c1)}y^{ncm}_{hc,(c1,1)} \\
y^{d}_{hc,(NACE,1)} &= y^{total}_{hc,(NACE,1)} - (y^{cm}_{hc,(NACE,1)} + y^{ncm}_{hc,(NACE,1)}) \\
y^{total}_{gc,(NACE,1)} &= D^{d}_{(NACE,c2)}P_{(c2,c1)}y^{total}_{gc,(c1,1)} \\
y^{cm}_{gc,(NACE,1)} &= D^{d}_{(NACE,c2)}P_{(c2,c1)}y^{cm}_{gc,(c1,1)} \\
y^{ncm}_{gc,(NACE,1)} &= D^{d}_{(NACE,c2)}P_{(c2,c1)}y^{ncm}_{gc,(c1,1)} \\
y^{d}_{gc,(NACE,1)} &= y^{total}_{gc,(NACE,1)} - (y^{cm}_{gc,(NACE,1)} + y^{ncm}_{gc,(NACE,1)}) \\
y^{total}_{ex,(NACE,1)} &= D^{d}_{(NACE,c2)}P_{(c2,c1)}y^{total}_{ex,(c1,1)} \\
y^{cm}_{dex,(NACE,1)} &= D^{d}_{(NACE,c2)}P_{(c2,c1)}y^{cm}_{dex,(c1,1)} \\
y^{ncm}_{dex,(NACE,1)} &= D^{d}_{(NACE,c2)}P_{(c2,c1)}y^{ncm}_{dex,(c1,1)} \\
y^{d}_{ex,(NACE,1)} &= y^{total}_{ex,(NACE,1)} - (y^{cm}_{dex,(NACE,1)} + y^{ncm}_{dex,(NACE,1)})
\end{aligned} \tag{5.3}$$

Using the domestic *product or services* market share matrix $D^{d,(NACE,c2)}$ to convert the capital so that capital investment is demanded from NACE-sectors makes no sense. Thus, a capital market share matrix $D_{k,(NACE,c2)}$, describing which sectors are investing in which products, needs to be established.

$$\begin{aligned}
K^{total}_{(c2,NACE)} &= P_{(c2,c1)}K^{total}_{(c1,NACE)} \\
q_{k,(c2,1)} &= K^{total}_{(c2,NACE)}i_{NACE,1} \\
D_{k,(NACE,c2)} &= (K^{total}_{(c2,NACE)})^{t}\hat{q_{k,(c2,1)}}^{-1} \\
y^{total}_{k,(NACE,1)} &= D_{k,(NACE,c2)}q_{k,(c2,1)} \\
y^{cm}_{k,(NACE,1)} &= D_{k,(NACE,c2)}P_{(c2,c1)}y^{cm}_{k,(c1,1)} \\
y^{ncm}_{k,(NACE,1)} &= D_{k,(NACE,c2)}P_{(c2,c1)}y^{ncm}_{k,(c1,1)} \\
y^{d}_{k,(NACE,1)} &= y^{total}_{k,(NACE,1)} - (y^{cm}_{k,(NACE,1)} + y^{ncm}_{k,(NACE,1)})
\end{aligned} \tag{5.4}$$

Since the inversion of the $\hat{q}_{k,(c2,1)}$ matrix is impossible when $q_{k,(c2,1)}$ contains zeros, a MatLab script shown in E-Appendix 48 is written in order to avoid this. This simply sets $(D_k)_{i,j} = 0$ when $(q_k)_i = 0$.

5.5.3 Emission data

Emission categories

The emission category dimension e, contains all the emissions covered by the Norwegian emission matrix. Table 5.7 shows which emission categories that are covered in the emission inventories for USA, NL, JP and CH.

Tab. 5.7: Emission categories included in the inventory for the regions

e	**Domestic**	**USA**	**NL**	**JP**	**CH**
CO2	x	x	x	x	x
methane	x	-	x	-	-
N2O	x	x	x	-	-
SOx	x	x	x	x	x
NOx	x	x	x	x	x
non methane VOC	x	x	x	-	x
CO	x	x	x	-	x
ammonia	x	x	x	-	x
dust (PM10)	x	x	x	-	-
dust (PM2.5)	x	-	-	-	-
Pb	x	x	x	-	-
Cd	x	x	x	-	-
Hg	x	x	x	-	-
As	x	x	x	-	-
Cu	x	x	x	-	-
Cr	x	x	x	-	-
PAH's	x	x	x	-	-
dioxin (TEQ)	x	-	-	-	-
HFCs	x	-	-	-	-
PFCs	x	-	-	-	-
SF6	x	-	-	-	-

Since only emissions of CO_2, SO_x and NO_x are included in all emission inventories, these gases are the ones that will be used as emission data in this thesis. In the final calculations in MatLab, the e dimension is thus changed to $e2$.

Domestic emissions

The domestic emissions received are total direct emissions. Therefore $E^{d}_{direct,(e,NACE)}$ must be normalized with respect to the total domestic industry output, $g^{d}_{(NACE,1)}$, as shown below.

$$\begin{aligned} B^{d}_{direct,(e,NACE)} &= E^{d}_{direct,(e,NACE)}(\hat{g}^{d}_{(NACE,1)})^{-1} \\ B^{d}_{total,(e,NACE)} &= B^{d}_{direct,(e,NACE)}(I - A^{d}_{(NACE,NACE)})^{-1} \end{aligned} \tag{5.5}$$

Foreign emissions

Emissions from USA, JP and CH were received as total emission intensities, $B_{total} = B_{direct}(I - A)^{-1}$, as shown in table 5.2. As for the Netherlands, $A^{NL}_{(NLS,NLS)}$ and $B^{NL}_{direct,(s,NLS)}$ were received. Thus, rearranging the abroad emission intensities to NACE aggregation and converting them to NOK in year 2000 yields

$$\begin{aligned} B^{USA}_{total,(e,NACE)} &= NOK_{USA}B^{USA}_{total,(e,NAICS)}P_{(NAICS,NACE)} \\ B^{JP}_{total,(e,NACE)} &= NOK_{JP}B^{JP}_{total,(e,JPS)}P_{(JPS,NACE)} \\ B^{CH}_{total,(e,NACE)} &= NOK_{CH}B^{CH}_{total,(e,CHS)}P_{(CHS,NACE)} \\ B^{NL}_{total,(e,NACE)} &= NOK_{NL}(B^{NL}_{direct,(e,NLS)}(I - A_{(NLS,NLS)})^{-1})P_{(NLS,NACE)} \end{aligned} \tag{5.6}$$

6. FINAL CALCULATIONS

6.1 Comparison of using domestic or foreign inventory on the import

Only competitive imports[1] will be used in the comparison. Non-competitive imports[2] are left out, even though one could assume product similarity[3] for some sectors.

6.1.1 Corresponding emissions when import assumed produced domestically

The import structure are characterized by the $u^{fr}_{(ciii,1)}$ vector, consisting of 11,0 % USA, 69,6 % NL, 5,2 % JP and 14,2 % CH. The total emissions attached to the competitive import are then

$$E^{cm}_{total,(e2,NACE)} = B^{m}_{total,(e2,NACE)} y^{cm} \tag{6.1}$$

where

$$\begin{aligned}
y^{cm} &= y^{cm}_{hc} + y^{cm}_{gc} + y^{cm}_{dex} + y^{cm}_{k} + y^{cm}_{II} \\
&\quad \textit{and} \\
B^{m}_{total,(e2,NACE)} &= u^{fr,US}_{(ciii,1)} \cdot B^{USA}_{total,(e2,NACE)} \\
&+ u^{fr,NL}_{(ciii,1)} \cdot B^{NL}_{total,(e2,NACE)} \\
&+ u^{fr,JP}_{(ciii,1)} \cdot B^{JP}_{total,(e2,NACE)} \\
&+ u^{fr,CH}_{(ciii,1)} \cdot B^{CH}_{total,(e2,NACE)}
\end{aligned}$$

[1] Competing products consist of products that are also produced domestically, hence the traditional assumption that the production actually taking place abroad, is performed by identical sectors in Norway

[2] Non-competing product import consist of products that are not produced domestically.

[3] Assuming product similarity means to address non-competing import products to domestic industrial sectors that is assumed to have a similar production structure. For instance, the abroad production of an imported potato type not produced in Norway, is assumed to have an input structure that is similar to the domestic produced potatoes.

That is, the emissions from the different regions f are given by

$$E^{cm,f}_{total,(e2,NACE)} = u^{fr,f}_{(ciii,1)} B^{f}_{total,(e2,NACE)} y^{cm} \tag{6.2}$$

The corresponding emissions, if one assumes that the import from region f are produced using domestic technology, are given by

$$E^{d,f}_{total,(e2,NACE)} = u^{fr,f}_{(ciii,1)} B^{d}_{total,(e2,NACE)} y^{cm} \tag{6.3}$$

Figures 6.1, 6.2 and 6.3 shows the differences in emissions that follows when using either abroad or domestic inventory. Note that the y-axes are logarithmic scaled for a better visualization of the differences. Tables 6.1, 6.2 and 6.3 gives the data for the graphs.

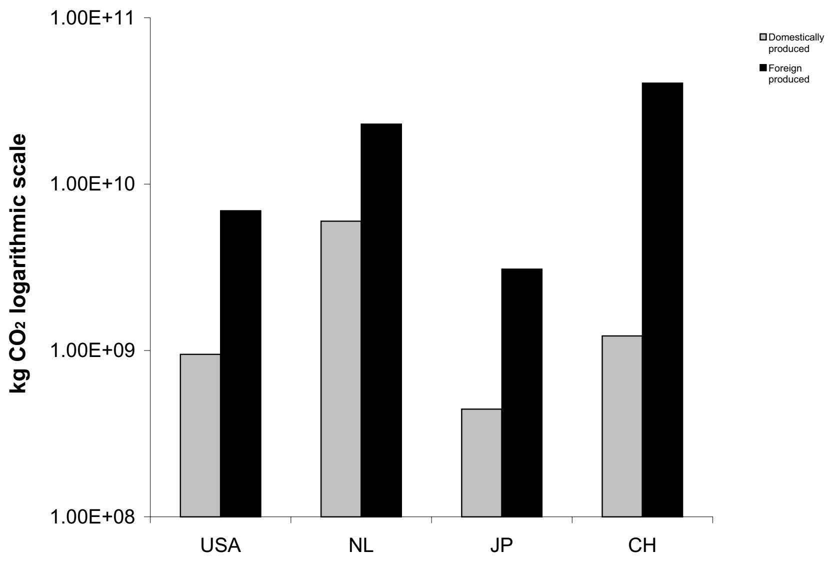


Fig. 6.1: kg CO_2 emissions when using either domestic or abroad inventory on competing imports

Tab. 6.1: kg CO_2 induced by y^{cm}

	Foreign	**Domestic**	$\frac{F}{D}$
USA	6.92E+09	0.948E+09	7.3
NL	22.9E+09	5.99E+09	3.8
JP	3.08E+09	0.444E+09	6.9
CH	40.5E+09	1.22E+09	33.1
Total	73.4E+09	8.60E+09	**8.5**

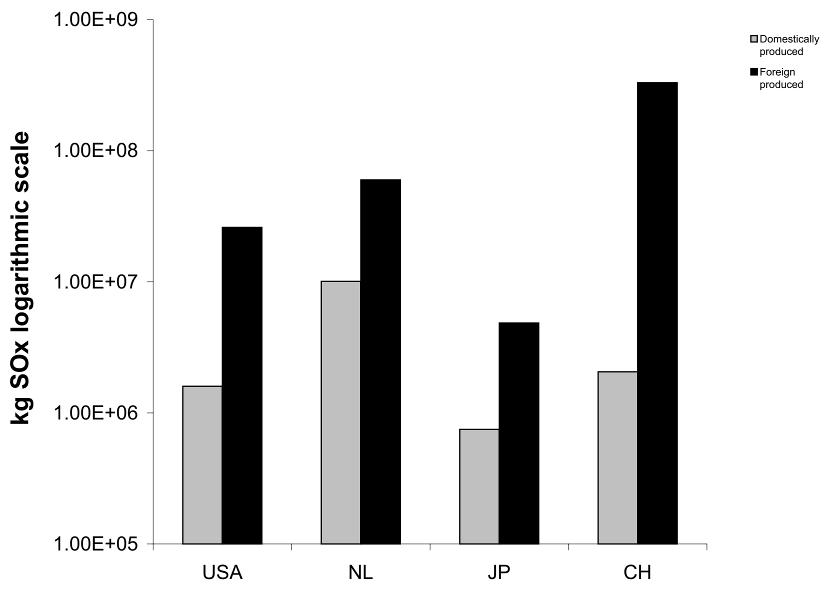


Fig. 6.2: kg SO_x emissions when using either domestic or abroad inventory on competing imports

Tab. 6.2: kg SO_x induced by y^{cm}

	Foreign	**Domestic**	$\frac{F}{D}$
USA	26.0E+06	1.60E+06	16.3
NL	60.0E+06	10.1E+06	5.9
JP	4.85E+06	0.748E+06	6.5
CH	331E+06	2.06E+06	160.5
Total	422E+06	14.5E+06	**29.1**

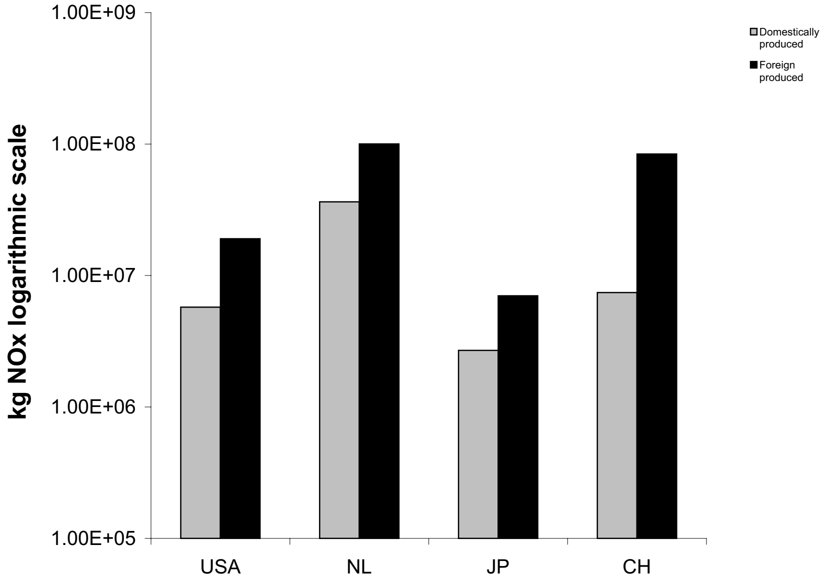


Fig. 6.3: kg NO_x emissions when using either domestic or abroad inventory on competing imports

Tab. 6.3: kg NO_x induced by y^{cm}

	Foreign	**Domestic**	$\frac{F}{D}$
USA	19.0E+06	5.75E+06	3.3
NL	100E+06	36.3E+06	2.8
JP	7.01E+06	2.69E+06	2.6
CH	84.0E+06	7.41E+06	11.3
Total	210E+06	52.2E+06	**4.0**

The results show large variations between using domestic or abroad data on the imports. When using domestic inventory it is assumed CO_2 emissions that is about 8.5 times lower compared with using foreign inventory. For SO_2, the difference is even greater, the domestic assumption implicitly assumes about 29.1 times lower emissions. The emitting of NO_x shows smaller variations, assuming domestic production yields emissions 4.0 times lower than using abroad inventory.

Looking at the specific groups, CH stands out from the others. The CO_2 emissions attached to the imports are about 33.1 times higher when using CH-data. Further, for SO_x the result is very high, about 160.5 times the assumed domestic emissions.

The results indicate that using domestic inventory on imports can lead to errors of several orders of magnitude. That is, the results of Hertwich et. al. [10] who use domestic inventory is very conservative.

6.2 Emission contribution relative to the actual demands

From now on the total imports, that is both competitive and non-competitive, will be used since the following analysis is not a comparison between using domestic or abroad inventory, but an investigation of the actual situation. First, a look at the composition of the total final demand.

6.2.1 Composition of total demand

The domestic final demand y_f^d and the total import demand y_{total}^m are defined as

$$\begin{aligned} y_f^d &= y_{hc}^d + y_{gc}^d + y_k^d + y_{ex}^d \\ y_{total}^m &= y_{hc}^m + y_{gc}^m + y_k^m + y_{dex}^m + y_{II}^m \\ &where \\ y_{II}^m &= A^m(I - A^d)^{-1} y_f^d \end{aligned} \tag{6.4}$$

The import from the different groups and the domestic production are all normalized with reference to the total demand, $y^{total} = y_f^d + y_{total}^m$.

$$\begin{aligned}
y^{fr,d} &= \frac{i_{(1,NACE)}y^{d}_{f,(NACE,1)}}{i_{(1,NACE)}y^{total}_{(NACE,1)}} \\
y^{fr,USA} &= \frac{u^{fr,USA}_{(ciii,1)}i_{(1,NACE)}y^{m}_{total,(NACE,1)}}{i_{(1,NACE)}y^{total}_{(NACE,1)}} \\
y^{fr,NL} &= \frac{u^{fr,NL}_{(ciii,1)}i_{(1,NACE)}y^{m}_{total,(NACE,1)}}{i_{(1,NACE)}y^{total}_{(NACE,1)}} \\
y^{fr,JP} &= \frac{u^{fr,JP}_{(ciii,1)}i_{(1,NACE)}y^{m}_{total,(NACE,1)}}{i_{(1,NACE)}y^{total}_{(NACE,1)}} \\
y^{fr,CH} &= \frac{u^{fr,CH}_{(ciii,1)}i_{(1,NACE)}y^{m}_{total,(NACE,1)}}{i_{(1,NACE)}y^{total}_{(NACE,1)}}
\end{aligned} \tag{6.5}$$

Thus, table 6.4 shows how the total demand is distributed.

Tab. 6.4: Composition of total demand y^{total}

Domestic	79.0 %
USA	2.3 %
NL	14.6 %
JP	1.1 %
CH	3.0 %

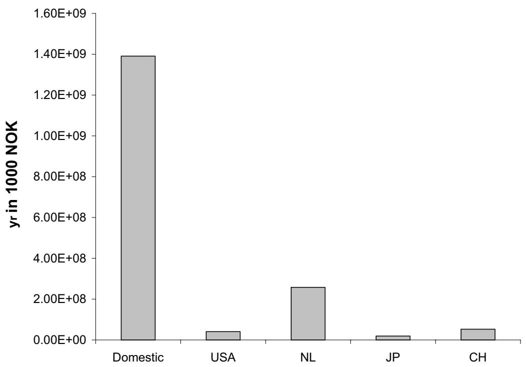
The import percentage might seem low, but this can to a large degree be explained, since the exports are included in the total domestic demand. If the domestic exports are excluded, that is $y^d_f = y^d_{hc} + y^d_{gc} + y^d_k$, the picture would be different, as table 6.5 shows.

Tab. 6.5: Composition of total demand y^{total} when y^d_{ex} excluded

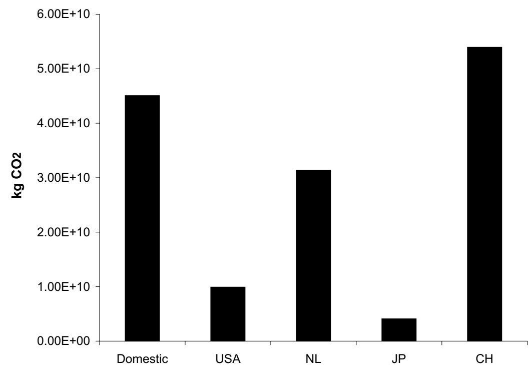
Domestic	67.2 %
USA	3.6 %
NL	22.8 %
JP	1.7 %
CH	4.7 %

6.2.2 Emissions normalized according to actual demand

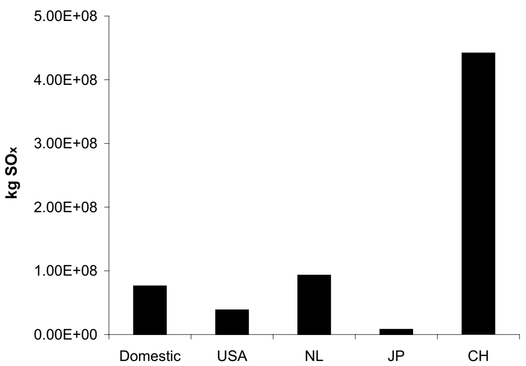
It is of great interest to investigate the amount of emissions related to the actual demand inducing the emissions. Since the demands are different for the various regions, one can not compare the different emissions directly. But by normalizing the emissions with accordance to the actual demands, one is able to compare the region-intermediate variations. First, figure 6.4 shows the demands and the CO_2, SO_x and NO_x emissions induced.



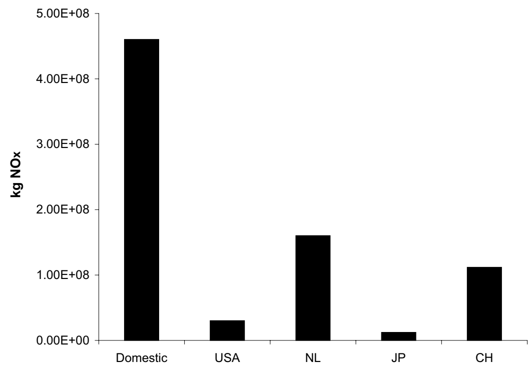
(a) y^c in 1000 NOK



(b) kg CO_2 emissions



(c) kg SO_x emissions



(d) kg NO_x emissions

Fig. 6.4: Total region-specific emissions induced by actual demand from regions

The emission intensities, referring to the actual demand, are defined as:

$$
\begin{aligned}
b_y^r &= \frac{e^r}{y^r} \\
&\textit{where} \\
r &= \textit{region} \\
e &= \textit{emission}
\end{aligned}
\tag{6.6}
$$

y^r is based on the demand fractions given in table 6.4 and equals the sum of demand from region r. Tables 6.6, 6.7 and 6.8 give the data used in figure 6.4 and the calculated emission intensities.

Tab. 6.6: kg CO_2 per region-specific demand

	y^r **1000 NOK**	e^r **kg**	b_y^r	b_y^r **per** $b_y^{domestic}$
Domestic	1391E+06	45.1E+09	32.40	**1.0**
USA	40.8E+06	9.91E+09	242.88	**7.5**
NL	258E+06	31.4E+09	121.76	**3.8**
JP	19.1E+06	4.08E+09	213.65	**6.6**
CH	52.6E+06	53.9E+09	1024.49	**31.6**

Tab. 6.7: kg SO_x per region-specific demand

	y^r **1000 NOK**	e^r **kg**	b_y^r	b_y^r **per** $b_y^{domestic}$
Domestic	1391E+06	76.4E+06	0.05	**1.0**
USA	40.8E+06	38.7E+06	0.95	**17.3**
NL	258E+06	93.2E+06	0.36	**6.6**
JP	19.1E+06	8.21E+06	0.43	**7.8**
CH	52.6E+06	442E+06	8.40	**152.9**

Tab. 6.8: kg NO_x per region-specific demand

	y^r **1000 NOK**	e^r **kg**	b_y^r	b_y^r **per** $b_y^{domestic}$
Domestic	1391E+06	460E+06	0.33	**1.0**
USA	40.8E+06	30.1E+06	0.74	**2.2**
NL	258E+06	160E+06	0.62	**1.9**
JP	19.1E+06	12.2E+06	0.64	**1.9**
CH	52.6E+06	112E+06	2.12	**6.4**

Regarding CO_2, the imports from NL are nearly 4 times as carbon intensive compared with the goods produced domestically. As for CH, the import demand causes about 31.6 times more CO_2 emissions per demand than what is the case with the domestic production.

The b_y^r for SO_x is not surprisingly very different between Norway and CH. It is high for the other groups too, the imports from USA cause about 17.3 times more SO_x per demand compared with the domestic produced goods. However, CH has, as shown in a different way in section 6.1.1, a significantly higher b_y^r for SO_x, about 150 times the Norwegian result. The 3.0 % demand from CH is causing 67.1 % of the total SO_x emissions, which is an important result.

Reducing the emissions of SO_x requires relatively simple technology and is quite inexpensive. The USA, NL and JP groups consist generally of industrialized countries whose implementation of this technology, in various degrees, have led to a decrease of SO_x emissions during the past decades. However, these SO_x treatment facilities have not been adopted to that extent in the developing countries.

The intensities for NO_x generally show smaller variations, although a sixfold b_y^r in CH compared to that of Norway is significant.

The results obtained indicate that Norway's emission structure is of a very different nature compared with the import-groups. This is mainly due to the high proportion of hydropower in Norway's energy producing sector. Since the emission inventory for Norway is based on the total direct emissions, thus not accounting for energy trade, the proportion remains constant. The CO_2 emissions are highly tied to which energy source that is used, since gas is not removed from the exhaust to a large extent in the energy producing sectors. As discussed above, the picture is different for SO_x, which is much easier captured in the combustion processes.

Since the emission inventory used here are given by Statistics Norway, the results should match Statistics Norway's (SN) official emission statistics. Also, the total import derived here, $y^m_{total,(NACE,1)}$, is checked against the official SN numbers. The emission data are found at [45], and the import data are given in [46]. A comparison is shown in table 6.9

Tab. 6.9: Comparing Statistics Norway's official data to the data used in this thesis

	SN	Here	Here / SN ratio
kg CO_2	5.48E+10	4.51E+10	82.3 %
kg SO_x	8.33E+07	7.64E+07	91.6 %
kg NO_x	5.13E+08	4.60E+08	89.7 %
1000 NOK y^m_{total}	370.3E6	302.9E6	122 %

The official emission data are higher than what is found here. This is probably a consequence of using base values on the economic data, see section 5 on page 21. The total domestic activity are lower, thus also the induced emissions.

The reason why the domestic emissions are calculated, and not taken directly from SN, is the desire to obtain the domestic emission in a similar manner as the abroad emission, and have a better insight in what is going on.

The high import numbers might be explained by inconsistences in the data that has been used. However, these discrepancies does not alter the results a whole. There are large differences between Norway and the import groups.

Until now it has bee focused on the total numbers. From a consumer perspective, however, it would be interesting to take a look at the differences between the NACE sectors of the different regions. The next section explores the emissions induced by the different demands in relation to the NACE levels.

6.3 Emission intensities based on bundle of demand on NACE level

First, an outline of all the NACE sectors' intensities is presented. Then, some sectors associated with household consumption are studied in more detail.

6.3.1 Figures describing the NACE intensities

Figures 6.5, 6.6 and 6.7 view the b^r_y for CO_2, SO_x and NO_x in the different regions' NACE levels. The NACE aggregation are given in Appendix A. For each figure the NACE sectors are sorted by decreasing emissions. It is used logarithmic scaling for better readability. For the NACE sector's whose intensity equals zero, no point is displayed in the figure. The data which the figures are based on are given in E-Appendix 49, E-Appendix 50 and E-Appendix 51

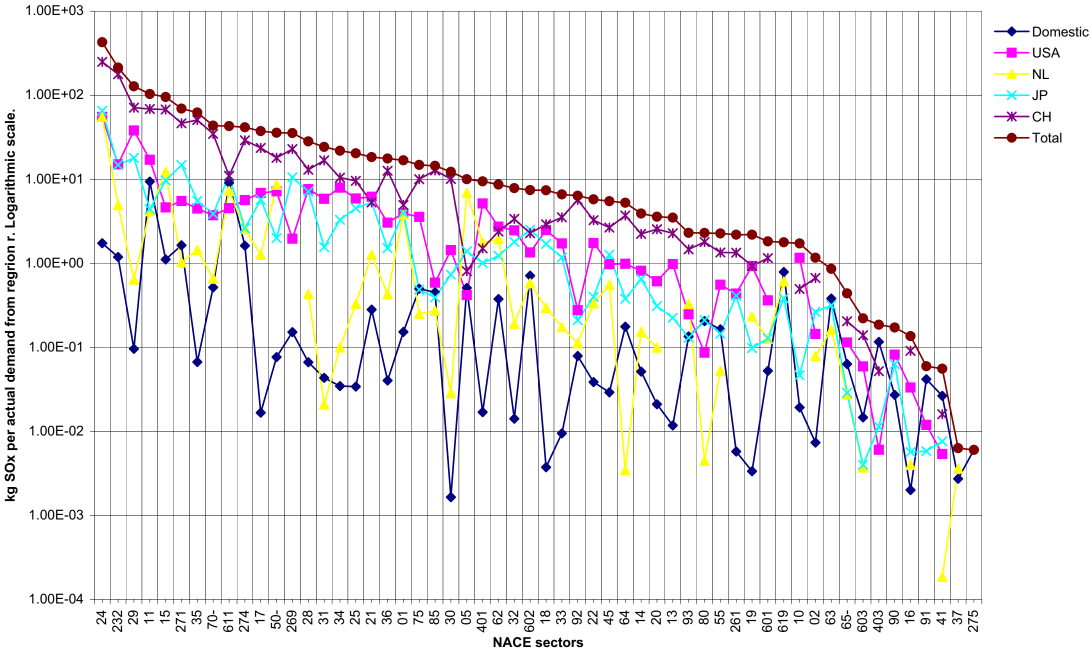


Fig. 6.5: kg CO_2 emissions per actual demand from NACE sectors in regions r

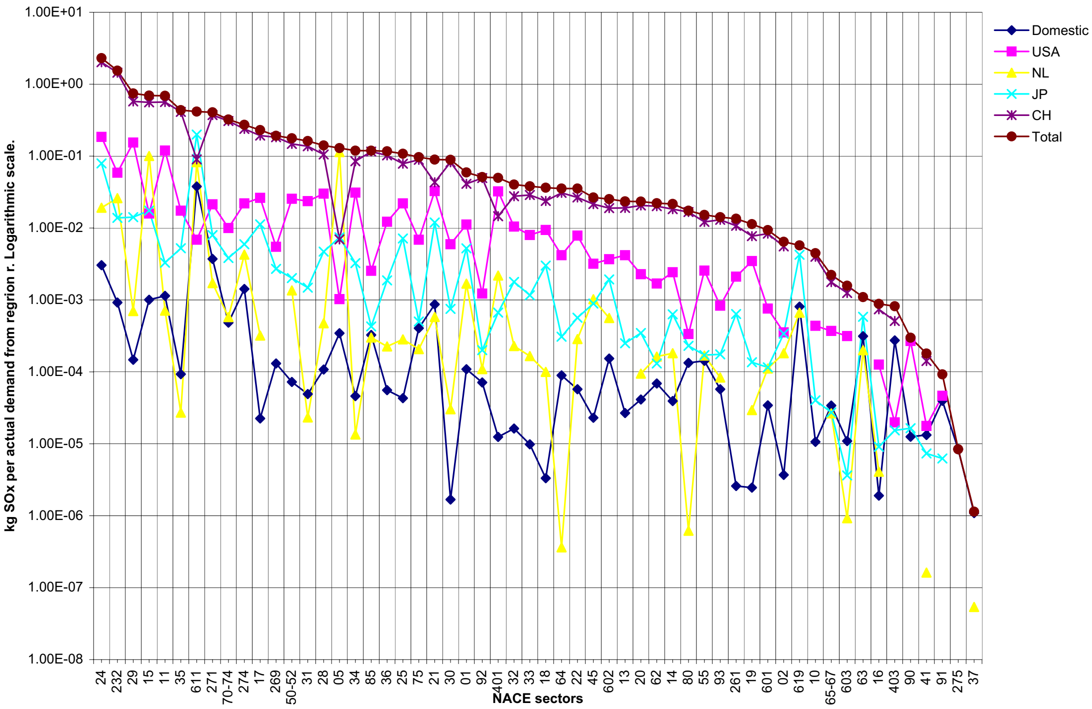


Fig. 6.6: kg SO_x emissions per actual demand from NACE sectors in regions r

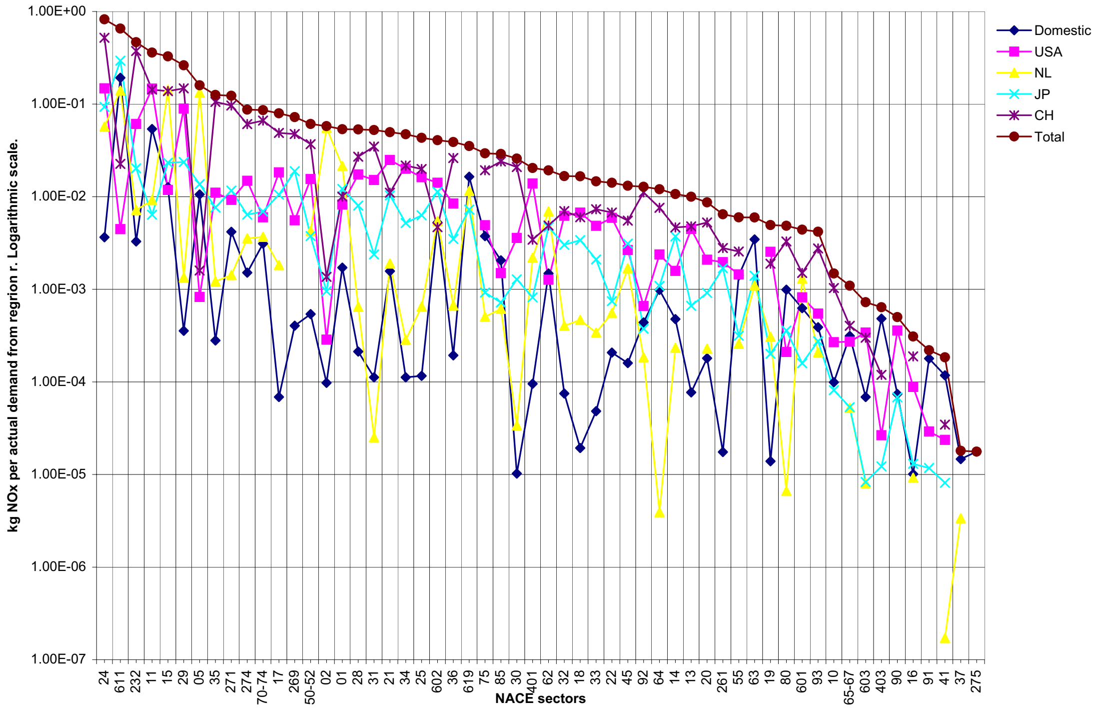


Fig. 6.7: kg NO_x emissions per actual demand from NACE sectors in regions r

Though the overall picture seems to be the same as for the total intensities used in the previous sections, the figures show that the emission intensities for each NACE sector are quite different compared with the average region intensities. The figures indicates that the differences between the domestic emission intensities and the foreign intensities are bigger for NACE sectors

- 17-Manufacture of textiles
- 18-Manufacture of wearing apparel; dressing and dyeing of fur
- 30-Manufacture of office machinery and computers

compared with the average differences found when analyzing the total NACE numbers in section 6.2.2.

Of particular interest is the CH-region. For SO_x it dominates the emission intensities, as figure 6.6 shows. This is consistent with the total results given in figure 6.4 on page 37.

6.3.2 Household consumption on NACE level

Related to household consumption, it is chosen to take a closer look at the following sectors

- 15-Manufacture of food products and beverages
- 17-Manufacture of textiles
- 31-Manufacture of electrical machinery and apparatus n.e.c.

Figure 6.8 shows the total demand of the three NACE sectors. The underlying data are given in table 6.10. The demand is divided into

$$y^m_{total} = y^m_{hc} + y^m_{gc} + y^m_k + y^m_{dex}$$

and

$$y^d_{total} = y^d_{hc} + y^d_{gc} + y^d_k + y^d_{ex}$$

It is chosen to work with total numbers, thus not specifying the actual household demand. This is due to uncertainties attached to the data at such a detailed level. However, in the end all imports and domestic production are consumed in some way, so working with total numbers might be justified by that. Further, the emissions resulting from imports and domestic demand from specific NACE sectors are not dependent on who is demanding.

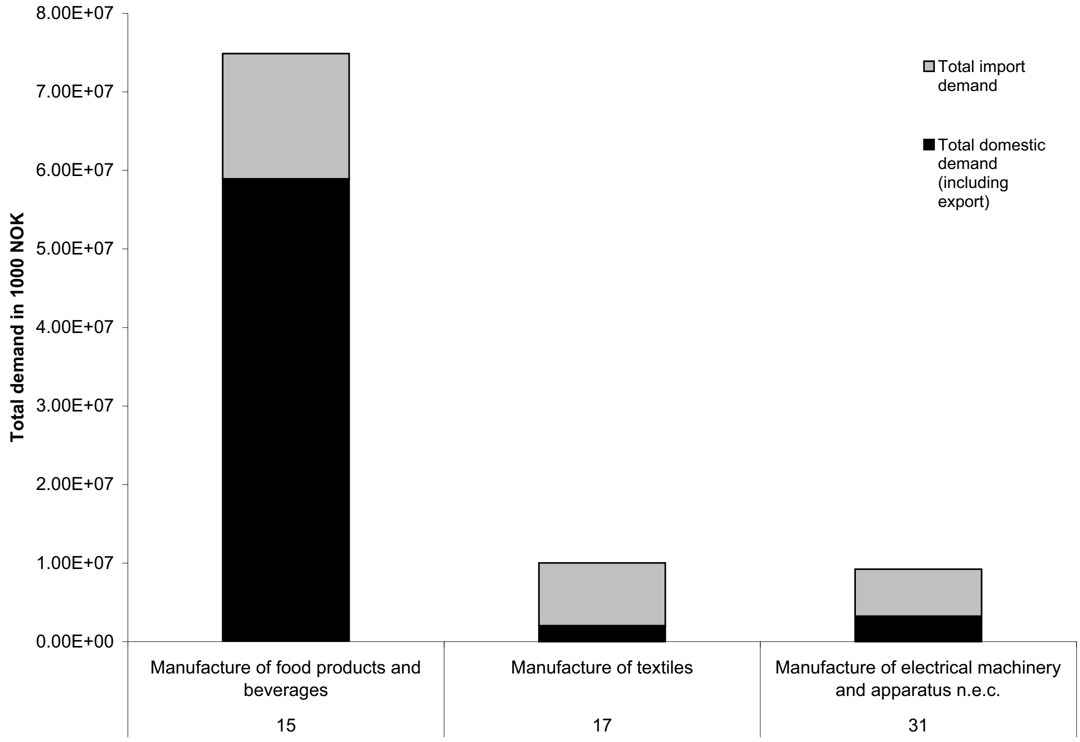


Fig. 6.8: Import demand and domestic demand for chosen NACE

Tab. 6.10: NACE specific demand data for figure 6.8 in 1000 NOK

	NACE sector	y^d_{total}	y^m_{total}
15	Manufacture of food products and beverages	5.89E+07	1.60E+07
17	Manufacture of textiles	2.03E+06	7.99E+06
31	Manufacture of electrical machinery and apparatus n.e.c.	3.23E+06	6.00E+06

Figures 6.9, 6.10 and 6.11 view the region and sector specific CO_2, SO_x and NO_x emissions connected to the different demands as given in table 6.10. Tables 6.11, 6.12 and 6.13 give the underlying data for the figures.

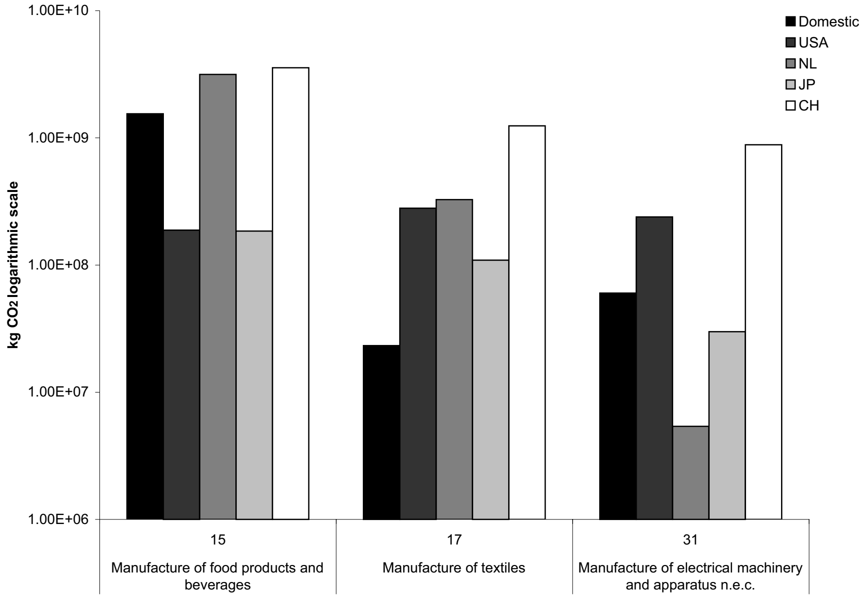


Fig. 6.9: kg CO_2 emissions

Tab. 6.11: NACE specific kg CO_2 emission data for figure 6.9

	NACE-15	**NACE-17**	**NACE-31**
Domestic	15.5E+08	0.233E+08	0.603E+08
USA	1.88E+08	2.80E+08	2.39E+08
NL	31.5E+08	3.27E+08	0.0539E+08
JP	1.85E+08	1.09E+08	0.299E+08
CH	35.6E+08	12.4E+08	8.82E+08

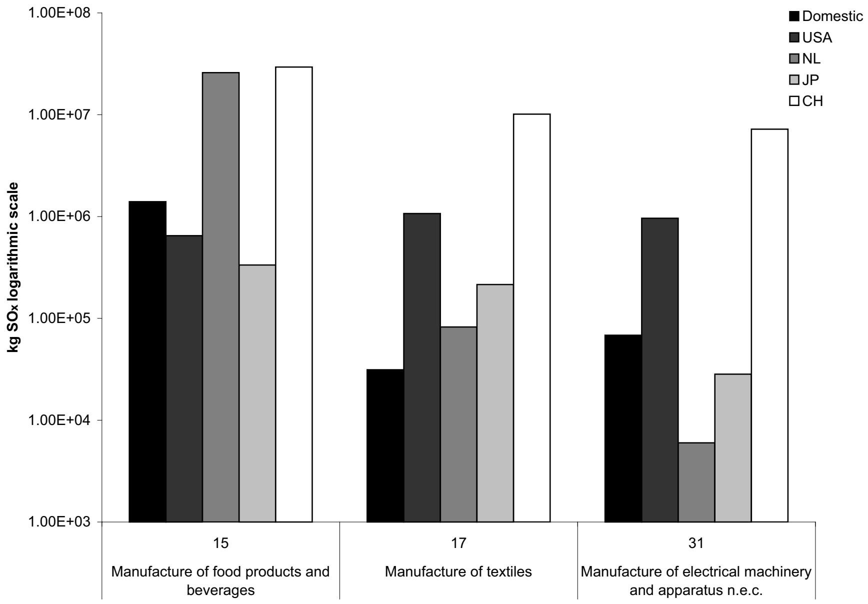


Fig. 6.10: kg SO_x emissions

Tab. 6.12: NACE specific kg SO_x emission data for figure 6.10

	NACE-15	**NACE-17**	**NACE-31**
Domestic	14.0E+05	0.313E+05	0.683E+05
USA	6.49E+05	10.7E+05	9.63E+05
NL	259E+05	0.823E+05	0.0599E+05
JP	3.34E+05	2.15E+05	0.283E+05
CH	294E+05	101E+05	72.1E+05

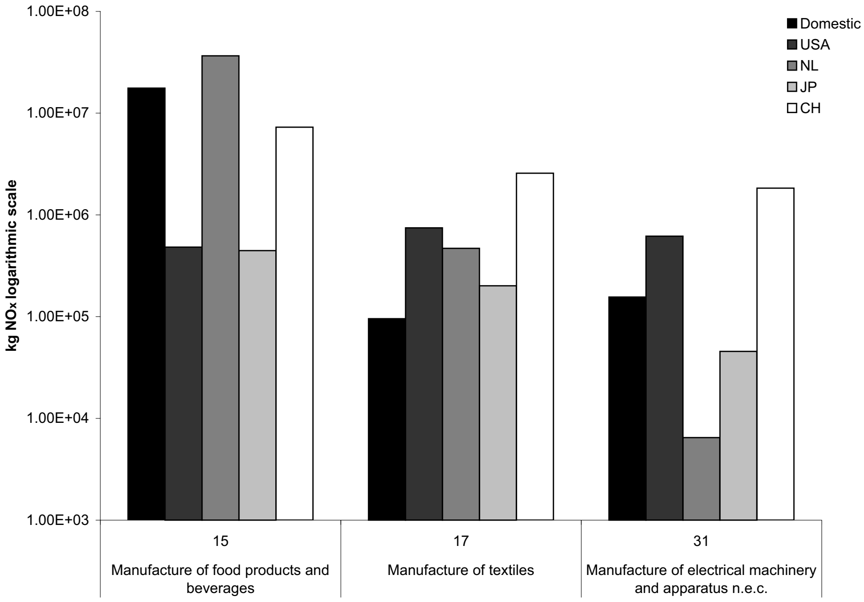


Fig. 6.11: kg NO_x emissions

Tab. 6.13: NACE specific kg NO_x emission data for figure 6.11

	NACE-15	**NACE-17**	**NACE-31**
Domestic	176E+05	0.955E+05	1.56E+05
USA	4.82E+05	7.46E+05	6.18E+05
NL	366E+05	4.69E+05	0.0647E+05
JP	4.45E+05	2.01E+05	0.455E+05
CH	72.7E+05	25.7E+05	18.3E+05

Again, when looking at the emission tables, the emissions from CH are much larger, especially for SO_x. These numbers are not normalized according to the region specific demands. As noted in section 6.3.1, figures 6.5, 6.6 and 6.7 view the b_y^r for CO_2, SO_x and NO_x in the different regions' NACE levels. So, the demand specific emission intensities for NACE sectors 15, 17 and 31 are given there.

7. DISCUSSIONS AND CONCLUSIONS

7.1 Uncertainties and further work

The results in this thesis are associated with uncertainties. In order to strengthen the analysis, some suggestions of improvements are given below.

- Assuming that all commodities are possessed by identical import fractions, as done in this thesis, can lead to huge errors. The first step of improvement could be to calculate NACE specific import structures by using the same SITC-product import table that was used to here to calculate the average import structure.

- The underlying data used to calculate the data used for the foreign countries should be studied in detail. This could for instance identify wether the abroad intensities are referring to base values or purchaser values.

- The aggregation procedures transforming the foreign industry sectors to Norwegian NACE aggregation are performed in an intuitive way. For some aggregation regimes there exist official transformation routines, but not for all. However, more specific information is needed.

In general one should strive for getting a better overview of the domestic economic data. Hence, a closer co-operation with Statistics Norway is necessary. The challenge is to have enough insight into the economics to be able to ask for the right data, and use it correctly.

Regarding household consumption, the different ways of pricing, as noted in section 5.1 on page 21 needs to be considered. On the other hand, before introducing additional problems, one should be confident that the fundamentals underlying the additional investigations are well known.

7.2 Conclusions

The main findings in this thesis is that assuming that the imports are produced with domestic technology can lead to incorrect results. Norway's energy production is mainly based on hydropower. When imports from countries whose energy production is based on coal is assumed produced domestically, the findings here shows that the resulting errors can be very high.

The sectors in the CH-region generally generate much higher emissions per demand compared to the corresponding domestic sectors.

Regarding household consumption, the results found here only indicate the possible pollution connected to households' consumption habits. This is because the NACE levels are aggregated, and caution should be taken when the households are assumed to buy products in base values from for instance the textile industry.

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APPENDIX

A. NACE SECTORS

Tab. A.1:

NACE code	NACE name
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
232	Manufacture of refined petroleum products
24	Manufacture of chemicals and chemical products
25	Manufacture of rubber and plastic products
261	Manufacture of glass and glass products
269	Manufacture of other non-metallic mineral products
271	Manufacture of basic iron and steel
274	Manufacture of basic precious and non-ferrous metals
275	Casting of metals

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NACE code	NACE name
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
401	Production and distribution of electricity
403	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
601	Transport via railways
602	Other land transport
603	Transport via pipelines
611	Sea and coastal water transport
619	Inland 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.

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NACE code	**NACE name**
92	Recreational, cultural and sporting activities
93	Other service activities

B. OVERVIEW OVER THE E-APPENDICES

Tab. B.1:

E-Appendix no	**Including**
E-Appendix 1	M^d
E-Appendix 2	U^{total}
E-Appendix 3	U^{cm}
E-Appendix 4	U^{ncm}
E-Appendix 5	U^{sm}
E-Appendix 6	U^{pm}
E-Appendix 7	K^{total}
E-Appendix 8	y_{hc}^{total}
E-Appendix 9	y_{hc}^{cm}
E-Appendix 10	y_{hc}^{ncm}
E-Appendix 11	y_{gc}^{total}
E-Appendix 12	y_{gc}^{cm}
E-Appendix 13	y_{gc}^{ncm}
E-Appendix 14	y_{ex}^{total}
E-Appendix 15	y_{dex}^{cm}
E-Appendix 16	y_{dex}^{ncm}
E-Appendix 17	y_k^{cm}
E-Appendix 18	y_k^{ncm}
E-Appendix 19	E_{direct}^d
E-Appendix 20	B_{total}^{US}
E-Appendix 21	A^{NL}
E-Appendix 22	B_{direct}^{NL}
E-Appendix 23	B_{total}^{JP}
E-Appendix 24	B_{total}^{CH}
E-Appendix 25	c1
E-Appendix 26	c2
E-Appendix 27	CHS
E-Appendix 28	ci
E-Appendix 29	cii

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E-Appendix no	**Including**
E-Appendix 30	ciii
E-Appendix 31	e
E-Appendix 32	e2
E-Appendix 33	JPS
E-Appendix 34	NACE
E-Appendix 35	NAICS
E-Appendix 36	NLS
E-Appendix 37	s
E-Appendix 38	SITC
E-Appendix 39	$P_{(c2,c1)}$
E-Appendix 40	$P_{(ci,cii)}$
E-Appendix 41	$P_{(ciii,cii)}$
E-Appendix 42	$P_{(CHS,NACE)}$
E-Appendix 43	$P_{(JPS,NACE)}$
E-Appendix 44	$P_{(NACE,SITC)}$
E-Appendix 45	$P_{(NAICS,NACE)}$
E-Appendix 46	$P_{(NLS,NACE)}$
E-Appendix 47	$P_{(s,NACE)}$
E-Appendix 48	MatLab
E-Appendix 49	NACE specific b_y^r CO_2
E-Appendix 50	NACE specific b_y^r SO_x
E-Appendix 51	NACE specific b_y^r NO_x

Program for industriell økologi (IndEcol) er et tverrfaglig universitetsprogram etablert i 1998 for en periode på minst ti år ved Norges teknisk-naturvitenskapelige universitet (NTNU). Programmet omfatter et studieprogram opprettet i 1999 og et stort antall doktorgradsprosjekter og forskningsprosjekter rettet mot vareproduserende industri, energi- og byggesektoren. Tverrfaglig forskning og undervisning står sentralt ved IndEcol, og målet er å knytte sammen teknologiske, naturvitenskapelige og samfunnsvitenskapelige bidrag i letingen etter bærekraftige løsninger på produksjon og forbruk av energi og ressurser.

The Industrial Ecology Programme (IndEcol) is a multidisciplinary university programme established at the Norwegian University of Science and Technology (NTNU) in 1998 for a period of minimum ten years. It includes a comprehensive educational curriculum launched in 1999 and a significant number of doctoral students as well as research projects geared towards Norwegian manufacturing, energy and building industries. The activities at IndEcol have a strong attention to interdisciplinary research and teaching, bridging technology, natural and social sciences in the search for sustainable solutions for production and consumption of energy and resources.

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