The global climate impact of Swedish consumption: an input–output analysis time series of CO_2e emissions from 1993 to 2005

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Abstract

In recent years, increased attention has been given to growth in consumption being responsible for the increasing human global climate impact. In this study, the development of the global climate impact of the Swedish final demand is assessed using an environmentally extended input–output model. The environmental input–output model developed is done in a single regional framework where CO_2e emissions from imports have been estimated using emission intensities for the Swedish import countries. Included in the CO_2e emissions are CO_2, CH_4 and N_2O. To build the time series, a method for updating input–output tables is developed. A sensitivity analysis is undertaken based on a variation of assumptions, e.g., the valuation of GDP based on purchasing power parity rates or market exchange rates. The most conservative results show an increase in CO_2e emissions of 12 percent in the period studied, from 84 Mton in 1993 to 94 Mton in 2005. These results go contrary to the Swedish official UNFCCC territorial emission statistics which show a decrease of 8 percent during the same period. The results suggest that Sweden has not yet decoupled economic growth from increasing global climate impact.

Keywords: Input–output analysis time series, updating input–output tables, emissions embodied in trade, consumption-based accounting, purchasing power parity, greenhouse gases, Sweden.

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Introduction

Consumption-based accounting and environmental applications of input–output analysis have gained wide-spread interest among sustainability researchers in recent years.[1] The rationale behind the growing interest can be interpreted as an urge to understand the discrepancy between the sometimes decreasing environmental pressure from typical Western countries with high and increasing standards of living, and ever increasing global environmental pressure. The question is whether the decreasing environmental pressure of some countries can be explained in terms of consumption being met by production in other countries.[2]

Although a lot of studies have been published world-wide the last decade in the area of environmental input–output analysis and consumption-based accounting,[3] only a few have produced time series.[4] The same situation holds for Sweden,[5] but in the last year a couple of time series studies have been published.[6] In a couple of studies by Peters et al., a time series from 1990 to 2008[7] and to 2010,[8] covering 113 countries, is built by means of extrapolation based on single-year multiregional input–output tables for the years 1997, 2001 and 2004 from the GTAP database.[9] The studies by Peters et al. are multiregional analyses and therefore should be considered more robust, at least for the years 1997, 2001 and 2004. This present study of the consumption-based emissions in Sweden, although single-regional, contributes to the picture of the climate impact of the Swedish consumption, building on consistent time series of national accounts and environmental accounts data from a single source (Statistics Sweden). It is also the first continuous Swedish time series that includes all the three most important greenhouse gases (CO_2, CH_4, and N_2O), without using the more simple domestic technology assumption.[10]

In this paper, I will briefly present the main methodological findings and results from this ongoing research project[11] where the environmental pressure over time resulting from the Swedish final demand is estimated. Here, I will concentrate on the climate impact from the Swedish final demand, in the period 1993–2005, based on the emissions of CO_2, CH_4 and N_2O. A sensitivity analysis is performed by means of a variation of various methods and assumptions, resulting in a range of various emission curves.

In the following section, I will describe the methodology of the environmental extension of input–output analysis and its foundation in the national accounts and environmental accounts system. I will also describe the updating method used to build a time series of input–output tables. Subsequently, a section follows presenting the results

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[1] Leontief, 1970 gives an early account. See Wiedmann, 2009 and Wiedmann et al., 2011, for two recent overviews.
[2] This is sometimes in a general sense called carbon leakage. For a discussion, see e.g. Peters & Solli, 2010, Davis & Caldeira, 2010, and Weber & Peters, 2009.
[3] See Wiedmann, 2009 for an overview.
[4] Notable exceptions are Weber & Matthews, 2007, Wiedmann et al., 2010, Peters et al., 2011, and Peters et al., 2012.
[5] Single-year studies include Statistics Sweden, 2000, Carlsson-Kanyama, 2007, and Swedish EPA, 2008. An overview of studies in the Nordic countries is performed in Peters & Solli, 2010.
[6] Peters et al., 2011, Peters et al., 2012, Berglund, 2011, and Swedish EPA, 2012.
[7] Peters et al., 2011.
[8] Peters et al., 2012.
[9] Global Trade Analysis Project.
[10] However, preliminary results from this research were first published in Berglund, 2011.
[11] Started as a master thesis at the Global Energy Systems group at Uppsala University, and now continued at the environmental accounts of Statistics Sweden. See Berglund, 2011.

and the conclusions. The paper is concluded with a section of further questions to investigate and possible extensions of the research project.

Methods and data

The general framework

Consumption-based emissions data can be regarded as one step of a series of steps in collecting and compiling environmental data:[12]

1. The collection of emission statistics based on the territory of a country – *territorial emissions*.
2. The restructuring of emissions statistics data from the territory of a country to the production sectors of a country – *production-based emissions* and direct emissions by final consumers.
3. Transforming emissions per producing sector to emissions per final demanded product group, by means of input–output analysis, and adding the direct emissions by final consumers – *consumption-based emissions*.

This can be understood by organizing national accounts data and environmental data into a single NAMEA-framework,[13] as depicted in Figure 1. The territorial emissions can there be regarded as the emissions on the second lowermost row in the figure. On that same row, the emissions have been divided onto various product groups – these are the production-based emissions – and onto direct emissions by final consumers. Through input–output analysis, the emissions per product group are transformed into emissions per final consumed product group, depicted to the left in the lowermost row in the figure. The whole lowermost row, including the direct emissions by final consumers, are the consumption-based emissions.

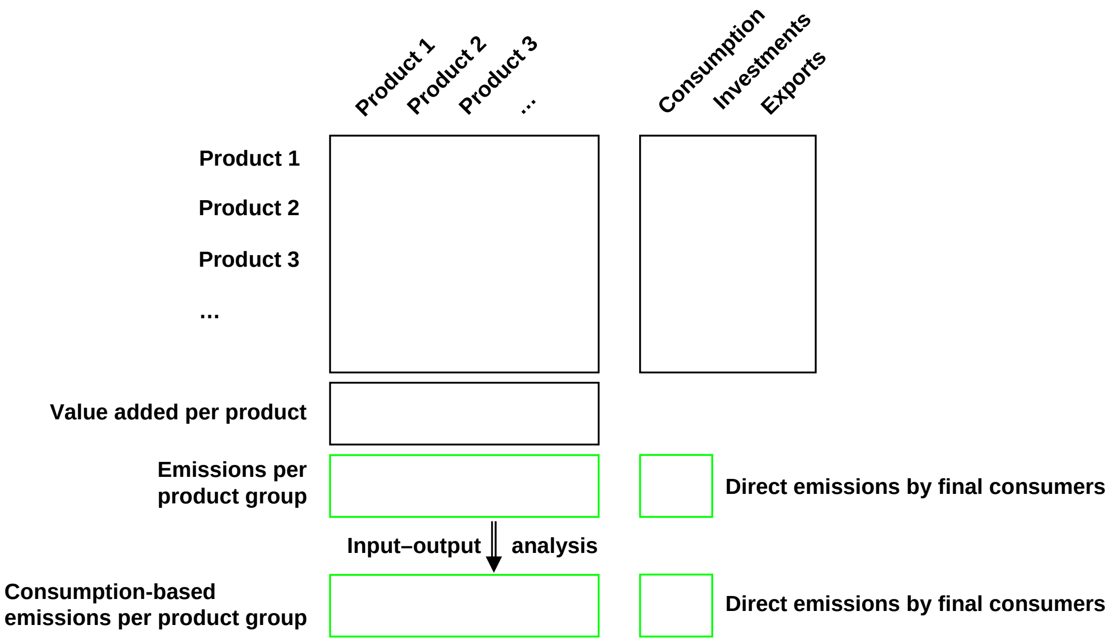

Figure 1. NAMEA-framework with an environmentally extended input–output table.

[12] See Peters & Hertwich, 2008, and Peters, 2008, for a similar approach.
[13] National Accounting Matrix with Environmental Accounts.

Workflow used in this study

In this study, data of consumption-based emissions are generated and subsequently a sensitivity analysis of these consumption-based emissions data, is performed. The data compilation and the calculations done, can be divided into the following steps:

- Obtaining national accounts data, and building time series of input–output tables.
- Obtaining environmental accounts data.
- Performing the environmental input–output analysis.
- Taking into account the emission intensities in the imports.
- Sensitivity analysis.

Building a time series of input–output tables

Since the official Swedish input–output tables are only produced every fifth year, only the 1995, 2000 and 2005 table were available in the period studied. In order to make a complete time series of input–output tables, the supply and use tables which are produced annually, are used to compile input–output tables.[14] However, the input–output tables thus obtained are in market prices and lack information of the division between domestic and imported inputs. The following paragraphs describe the method used in this study to build a time series of input–output tables including both domestic and imported inputs. See Figure 2, for a visual presentation of the procedure.

The calculations are done in three steps.[15]

1) For every year in the period 1993–2005, the intermediate matrix in the input–output table is calculated as

(*i*) $$\boldsymbol{F} = \boldsymbol{U}\,\boldsymbol{S}_c'$$

where $\boldsymbol{U}$ is the use matrix of the use table, and $\boldsymbol{S}$ is the make matrix of the supply table.[16] $\boldsymbol{S}_c$ is the coefficient matrix of the make matrix, i.e. a matrix describing the share of each product to the total output of an industry. In mathematical terms it means $\boldsymbol{S}_c = \boldsymbol{S}\,\hat{\boldsymbol{x}}_{ind}^{-1}$, where $\hat{\boldsymbol{x}}_{ind}$ should be interpreted as the vector of output from industries, diagonalized as a matrix. Through equation (*i*) the intermediate matrix of the input–output table has now been obtained in market prices for every year between 1993–2005. The final demand part of the input–output table is obtained from the final demand part of the use tables.

2) Taking the year 1995 as an example, a domestic–imports ratio input–output table is generated, based on the domestic–imports shares in the official input–output table for that year, and on the input–output table in market prices generated in step 1) above for that year. The domestic–imports ratio input–output table contains three layers. The lowermost layer, contains for every cell, the share of domestic input in that cell. The middle layer, contains, for every cell, the share of imported input in that cell. The uppermost layer contains, for every cell, the share of taxes less subsidies in that cell. The uppermost layer marks the difference between the input–output table in basic

[14] Official input–output tables and supply and use tables are from Statistics Sweden, 2006a, 2006b, 2008, 2009, and 2011a.

[15] See Berglund, 2011 for a more thorough description.

[16] This is the industry technology assumption. See Berglund, 2011, for a more detailed explanation.

prices and in market prices. The domestic layer is obtained through dividing element-wise every cell in the domestic part of the official input–output table with the corresponding cell in the market-price input–output table generated in step 1) above. The corresponding procedure is done for the imports layer.

To obtain an input–output table for say year 1997, these shares are then, for each cell, multiplied element-wise by the cells in the market-price input–output table for year 1997, obtained through equation (*i*) above. Through this operation an input–output table is obtained in basic prices, with a division between domestic and imported inputs.

The same procedure is followed for the other official input–output tables from 2000 and 2005. From the official 1995 input–output table, input–output tables for the year 1993–1997 are generated. From the official 2000 input–output table, input–output tables for the year 1998–2003 are generated. From the official 2005 input–output table, input–output tables for the year 2004–2005 are generated.

3) As a final step, every input–output table for any given year generated in the preceding steps, are then calibrated. This is done by making sure the domestic and imported part of the input–output table sums up to the total domestic output and the total imports respectively for that year.

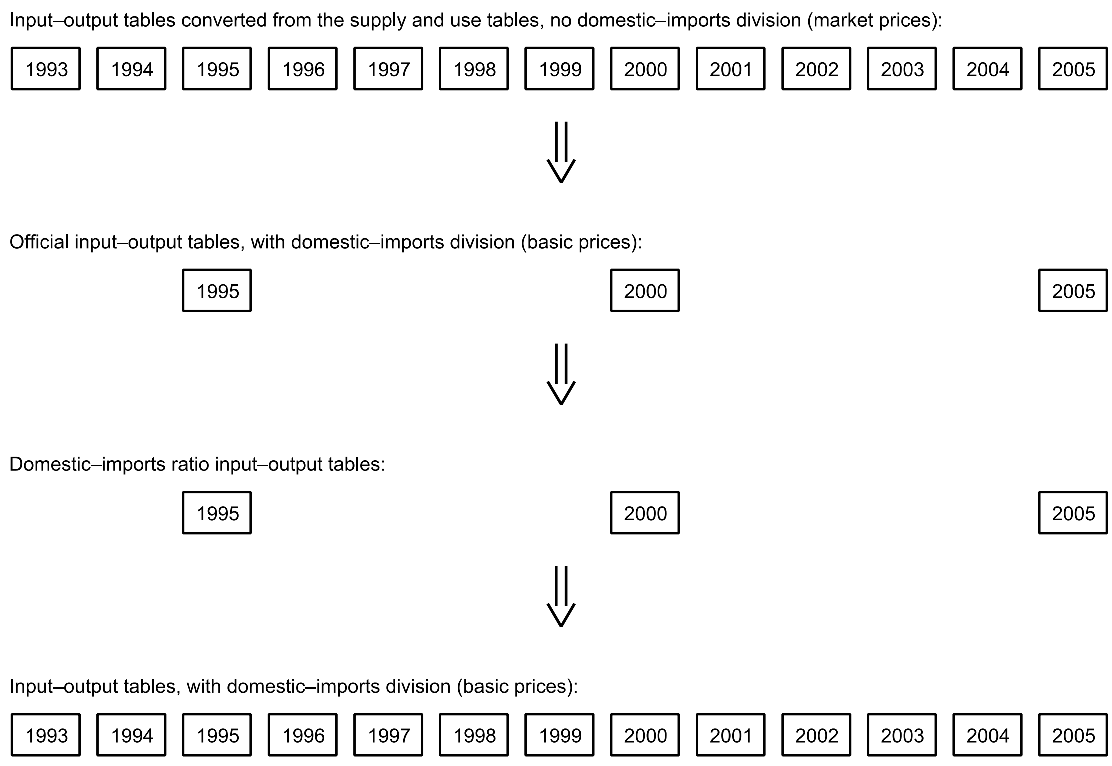

Figure 2. Outline of the procedure used for generating time series of input–output tables.

Environmental accounts data

Emissions data were obtained from the environmental accounts[17] as emissions per industry, $\boldsymbol{E}_{ind}$. These were transformed to emissions per product through[18]

(*ii*) $$\boldsymbol{E}_p = \boldsymbol{E}_{ind}\, \boldsymbol{S}'_c.$$

Emission intensities were then obtained through

(*iii*) $$\boldsymbol{E}_i = \boldsymbol{E}_p\, \hat{\boldsymbol{x}}_p^{-1}.$$

The environmental input–output analysis[19,20]

In order to proceed with the environmental input–output analysis, it is feasible to make a mathematical description of the input–output tables. These can be described as

(*iv*) $$(\boldsymbol{F}_d + \boldsymbol{F}_m)\boldsymbol{i} + (\boldsymbol{y}_d + \boldsymbol{y}_m) = \boldsymbol{x}_p + \boldsymbol{m}\ ,$$

where $\boldsymbol{F}_d$ and $\boldsymbol{F}_m$ are the domestic and imported part respectively of the intermediate matrix of the input–output table, $\boldsymbol{y}_d$ and $\boldsymbol{y}_m$ are the domestic and imported part respectively of the final demand matrix of the input–output table, $\boldsymbol{x}_p$ is the domestic output per product group, $\boldsymbol{m}$ is the imports, and $\boldsymbol{i}$ is the unit vector.

The corresponding technological matrices describing the amount of input needed in production per dollar's worth of output, are then

(*v*) $$\boldsymbol{A}_d = \boldsymbol{F}_d\, \hat{\boldsymbol{x}}_p^{-1}$$

and

(*vi*) $$\boldsymbol{A}_m = \boldsymbol{F}_m\, \hat{\boldsymbol{x}}_p^{-1}.$$

Through equation (*iv*), (*v*) and (*vi*) it is possible to describe the domestic output of the economy as

(*vii*) $$\boldsymbol{A}_d\, \boldsymbol{x}_p + \boldsymbol{y}_d = \boldsymbol{x}_p\ .$$

Rearranging gives us that

(*viii*) $$\boldsymbol{x}_p = (\boldsymbol{I} - \boldsymbol{A}_d)^{-1}\, \boldsymbol{y}_d,$$

meaning that the output is a function of the final demand, given a certain fixed industrial structure $\boldsymbol{A}_d$. $\boldsymbol{L}_d = (\boldsymbol{I} - \boldsymbol{A}_d)^{-1}$ is the Leontief inverse (domestic version). If the rest of the world were to have the same input–output table as the Swedish, it can be shown that the total output needed in the whole world due to Swedish final demand of Swedish and imported products, are $\boldsymbol{L}_{tot}\, \boldsymbol{y}_{tot}^{nexp}$, where $\boldsymbol{L}_{tot} = (\boldsymbol{I} - \boldsymbol{A}_d - \boldsymbol{A}_m)^{-1}$, and $\boldsymbol{y}_{tot}^{nexp}$ indicates that the final demand exclude exports. Thus the production occurring abroad

[17] Statistics Sweden, 2011b.
[18] Östblom, 1998, uses a similar approach.
[19] A general introduction to environmental input–output analysis is given in Miller & Blair, 2009 and in Peters & Hertwich, 2009.
[20] A detailed derivation of the following equations can be found in Berglund, 2011.

due to Swedish final demand is $\boldsymbol{L}_{tot}\,\boldsymbol{y}_{tot}^{nexp} - \boldsymbol{L}_d\,\boldsymbol{y}_d^{nexp}$, and the production occurring domestically due to Swedish final demand is $\boldsymbol{L}_d\,\boldsymbol{y}_d^{nexp}$.[21]

Since the production needed to satisfy some final demand are associated with some environmental pressure according to equation (*iii*), the total emissions due to the Swedish final demand can be expressed as

$$(ix) \qquad \boldsymbol{e}_{tot} = \boldsymbol{E}_i \boldsymbol{L}_d \boldsymbol{y}_d^{nexp} + \hat{\boldsymbol{k}}\,\boldsymbol{E}_i\,(\boldsymbol{L}_{tot}\boldsymbol{y}_{tot}^{nexp} - \boldsymbol{L}_d \boldsymbol{y}_d^{nexp}) + \boldsymbol{e}_{dir}\ ,$$

where $\hat{\boldsymbol{k}}$ (diagonalized version of $\boldsymbol{k}$) indicates a scaling factor for the possibly bigger emission intensities which applies abroad, and $\boldsymbol{e}_{dir}$ is the direct emissions from final consumers.

Emissions intensities in imports

To estimate the emissions occurring abroad due to the Swedish final demand, the emission intensities is scaled by a factor $\boldsymbol{k}$. In Berglund, 2011, this factor was derived by taking the emission intensity for the whole world divided by the Swedish emission intensity – a world average intensity approach. Another possibility is to use the following:

$$(x) \qquad k = k_1 m_1 + k_2 m_2 + \ldots + k_{20} m_{20}.\ ,$$

where m_i is the share of commodity imports from country *i* among Sweden's 20 biggest import countries in any year, and k_i is

$$(xi) \qquad k_i = \frac{emissions_i \,/\, GDP_i}{emissions_{Sweden} \,/\, GDP_{Sweden}}\ .$$

In this way the emission intensity of the production abroad is scaled by a factor which is a weighted average of the Swedish import countries' emission intensities in relation to the Swedish emission intensity. This is here called the import countries' intensities approach. The *k* factor is calculated for CO_2, CH_4 and N_2O, making up the vector $\boldsymbol{k}$.

Emissions data for the countries included in $\boldsymbol{k}$ come from the EDGAR emissions database.[22] GDP data come from the World Bank.[23]

Sensitivity analysis

A sensitivity analysis is performed through variation of methods used to calculate *k*. On the one hand, the world average intensity approach or the import countries' intensities approach is used. On the other hand, GDP can be valued according to market exchange rates (MER), or according to purchasing power parity rates (PPP). This gives us a total of four ways to generate the CO_2e emissions curve.

[21] A similar approach is used by Finnveden et al., 2007.
[22] EDGAR, 2010.
[23] World Bank, 2010.

The using of the MER or the PPP approach has in other studies been shown to generate considerable differences.[24] It may be that the PPP approach in the kind of calculation performed in this study is more accurate. The argument for this is that the exports share in the rest of the world are valued too high when using the MER approach, since the MER approach really underestimates the value of the production occurring in the rest of the world, according to the PPP method of calculating GDP. Consequently, the MER approach overestimates the responsibility we have for generating emissions through the production of exports in the rest of the world going to us. Therefore, the MER approach will give us a bigger ***k*** than the PPP approach gives us.

Another argument for using the PPP approach, is that when comparing emission intensities between countries, emission intensities are normally measured as emissions per GDP PPP, in the same way as comparisons of GDP among countries preferably are done with GDP PPP.[25] Since equation (*xi*) is just a scale factor describing the intensity of a country compared with another, it could be argued emission intensities in this kind of study should be measured with the PPP method.

Results and discussion

The results from the calculations done, are presented in Figure 3 below. The most conservative results which come from the using of import countries' intensities with the PPP approach, show an increase in CO_2e emissions from 84 to 94 Mton CO_2e per year, during the period studied, an increase of about 12 %. With the same method using the MER approach the emissions increase from 97 to 130 Mton CO_2e per year, an increase of about 34 %. The most extreme result comes from using the world average intensities approach with MER, which gives rise to emissions increasing from 122 to 159 Mton CO_2e per year, an increase of about 30 %.

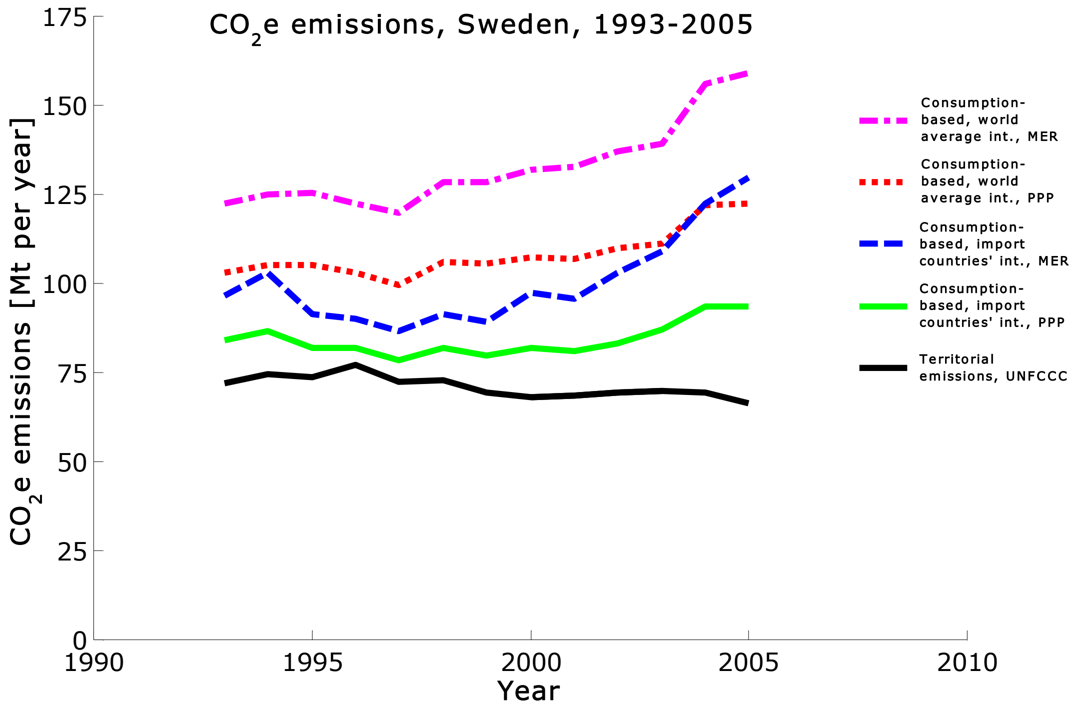

Figure 3. Consumption-based emissions of CO_2e in Sweden, 1993–2005.

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[24] See e.g. Weber & Matthews, 2007.
[25] See e.g. Germanwatch, 2011.

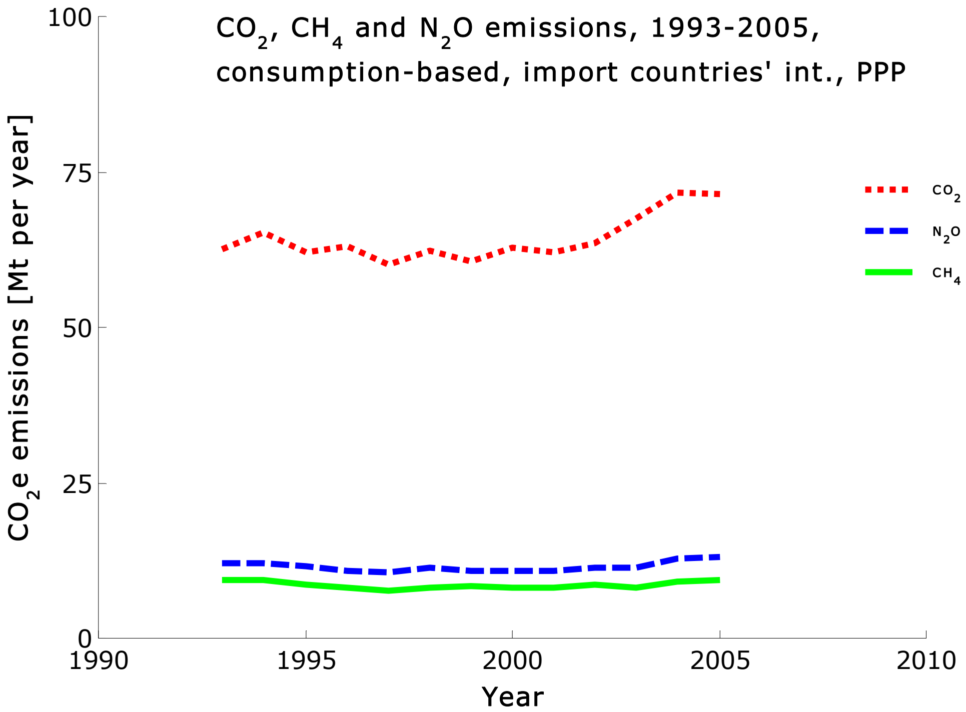

Figure 4. Consumption-based emissions of CO_2, CH_4 and N_2O measured as CO_2 equivalents, in the import countries' intensities approach, using the PPP method.

In Figure 4, the various components in CO_2e, i.e., CO_2, CH_4 and N_2O, are shown, suggesting CO_2 is the most important part in the rising trend. More analysis need be done however, since when using the MER approach, it can be seen in the data that CH_4 increases almost 30 % compared to almost no change in the PPP approach.

All these results differ substantially from the decreasing territorial emissions statistics reported to the UNFCCC, which decrease by 8 % during the period studied. These findings suggests that the climate impact of the Swedish society have not decreased with growing GDP and growing consumption, as is normally stated.

It is not necessarily so that the import countries' intensities approach gives the most accurate picture. A lot of the imports to Sweden only displays the dispatching country and not the producing country, meaning that some of the imports may in reality have been produced in China with higher emission intensities.[26] The real emissions may therefore be somewhere in between the world average intensities approach and the import countries' intensities approach.

Further on, earlier studies have shown that the import countries' intensities approach which uses the Swedish sector emission intensities scaled with the *k* factor, underestimates the emissions compared to when using the import countries' own sector emission intensities.[27]

[26] Swedish EPA, 2008.
[27] Statistics Sweden, 2000, and Swedish EPA, 2008.

Further research

What to do more in this research project:

- Extend the sensitivity analysis by using other data sources for the calculation of emission intensities. E.g. data from UNFCCC (now only data from the EDGAR database are used).
- Extend the time series to 2008 (if possible, also back to 1990).
- Improve the input–output table updating method with RAS techniques.
- Investigate the arguments for the PPP approach further, with sample data on actual emissions from industries exporting to Sweden.

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