Modeling the Environmental Impacts of Finnish Imports Using the EE-IO Method and Various Data Sources

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Abstract

In the research project (ENVIMAT) an extensive environmentally extended input-output (EE-IO) model for Finland was constructed. There were several aims to reach in the methodological part of the project, but in this paper the focus is on modeling the environmental impacts of Finnish imports using four different approaches: 1) Domestic technology assumption, Finnish emission factors are used for all imported goods. 2) Emissions derived from EIOLCA (USA) for all imported goods. 3) Emissions derived from Ecoinvent and Danish LCA Food Database for the largest volume of imported goods. The gap is filled with hybrid domestic emission factors. 4) The same as in (3) except the gap is filled with emissions from EIOLCA (USA). The comparative results show that the environmental impacts of imports based on the domestic emission factors are mostly lower than the alternative approaches, the USA approach being the closest. The mixed datasets due to generic LCI data produce higher impacts.

Keywords: input-output tables, environmentally extended input-output model, life cycle assessment**,** LCA, databases

1. Introduction

Due to rapid globalisation the relevance of imports and exports has grown greatly in national economies. At the same time the environmental impacts have spread all over the world. For example, the share of imports for the year 2002 in Finland was about 31 % of Gross Domestic Product (GDP). The largest imported material flows were fuels (oil, coal, natural gas), wood (logs, pulp wood) and ores/concentrates (e.g. iron ore). Their shares of the total mass of imports were respectively 43 %, 20 % and 8 %. For instance for foodstuffs it was 3.6% .

An environmentally extended input-output (EE-IO) model, which represents a "top-down" approach, is widely used for assessing the environmental impacts caused by a national economy (Tukker and Jansen 2006). In the basic EE-IO method the impacts

caused by material manufacturing abroad are often estimated by domestic emission factors due to the lack of available input-output data. In hybrid models part of the data is replaced by LCI data for the specific products representing a "bottom-up" approach. In our study, we completed the Finnish EE-IO model using LCI data for imports in order to assess the total environmental impacts of the Finnish economy.

In the research project (ENVIMAT) an extensive EE-IO model for Finland was constructed for the first time. There were several aims of the methodological part of the project *e.g.* combining environmental interventions, assessing impacts using alternative characterisation factors (LCIA methods), exploring a Finnish approach to land use and ecotoxicity issues, and integrating material flow accounts including Direct Material Input (DMI) and Total Material Requirement (TMR) into the monetary model of the Finnish economy.

In addition to the above mentioned aspects (which are presented in other papers) one of the important targets in the project was to assess impacts of imports based on different data sources including domestic, USA and LCI data. The aim of this paper was to analyze the differences between the results obtained from the different approaches and introduce the most suitable combination for the Finnish EE-IO model.

2. Materials and methods

2.1. General structure of ENVIMAT model

The structure of the ENVIMAT model is outlined in Figure 1. The core elements of the model are monetary input-output tables, physical input-output tables, and environmental impact assessment.

Figure 1

The monetary input-output model is based on the supply and use tables of Statistics Finland. The tables are rather detailed with 151 industries and 925 products. The use table is furthermore divided into domestic and imported products. The industry*industry input-output model for domestic products is solved from domestic supply and use tables. For the use of imports a more detailed product*industry coefficient table with 722 imported products is applied.

The monetary tables were constructed with physical i/o tables with the same dimensions as the monetary ones. In the physical tables the flows of goods are measured in mass units. The physical tables are used to estimate the TMR indices for domestic production and imports and moreover to facilitate the application of LCI-type data to the environmental impacts assessment of the model.

Environmental loads (emissions into air and water, use of abiotic natural resources, land use) include altogether 74 emission variables. They were compiled for each domestic industry from the national emission inventories. For environmental imported products several alternative data sources and compilation methods have been used which are presented in more detail in chapter 2.2.

The 74 environmental interventions were transformed into 10 environmental impact categories using characterisation factors. In the ENVIMAT model there are four alternative characterisation systems.

2.2. Different datasets for imports

The domestic emissions of 151 industries for the year 2002 were compiled and partly calculated from national emissions inventories. The customs foreign trade statistics reveal origin countries, monetary values, and also the mass volumes of the imported goods. On the basis of these statistics, four different emission datasets were formed based on four different data sources.

1) Domestic technology assumption (DOM). Imported products are assumed to be produced using the same intermediate input use and emission coefficients as in Finland. Then the emissions embodied in imports were estimated using the Finnish i/o table with domestic emission coefficients. The accounting model is presented more precisely in the Appendix (equations (3) and (4)).

2) EIO-USA. For all imports, data was used from the economic input-output life cycle assessment model (EIOLCA) made for the U.S. The EIO-USA model gives the total upstream emissions of products per one million dollar of product value. The emission coefficients were first deflated into 2002 prices by the US producer price indices and the transformed into euro values using the 2002 exchange rate.

3) EI-LCA/DOM. Generic LCI data from the Ecoinvent database was gathered for the largest volumes of imported material flows and from the Danish LCA Food database for food products. The LCI emission coefficients are usually per one mass unit (kg or ton) of product. They were transformed into per million euro units by the euro/kg data of the foreign trade statistics. For an estimation of the total upstream emissions for the imports absent in the LCI databases (mostly fabricated goods and services) a hybrid domestic technology model was used (see equations (8)-(10) in the Appendix).

4) EI-LCA/USA. EI-LCA emission factors were used for imports for which they were found and EIO-USA emission factors were used for other imports.

The alternative emission matrixes for imports are summarized in Table 1.

Table 1

In the datasets EI-LCA/DOM and EI-LCA/USA the Ecoinvent data covers about 88 % of the total volume imports and Danish emission data covers 57 % of the mass of imported foodstuffs. The missing volume mostly includes consumer goods and small quantities of industrial materials which are assessed using either the domestic emission factors or the USA factors.

3. Comparative results

For assessing environmental impacts based on different emission datasets results were calculated using the ENVIMAT model for the following impact categories: climate change, acidification, eutrophication, tropospheric ozone formation, and human toxicity. In this paper environmental impacts are presented as normalised results using the CML 2002 method (Guinee, ed. 2001). Emissions were first multiplied with characterisation values and then normalised using worldwide normalisation values (updated values from the internet).

Table 2

The DOM dataset shows lower environmental impacts than the other emission datasets in the impact categories of climate change, acidification, and tropospheric ozone formation (Figures 2 , 4 and 5). The profiles of the results of different datasets resemble each other except within the sectors of mining and quarrying, the chemical industry and the metal industry. The two first mentioned sectors have much higher greenhouse gases (GHGs) based on the Ecoinvent data compared to the EIO/USA data. The emissions are mostly caused by energy minerals (natural gas, coal, and oil), basic chemicals and plastics. The metal industry in contrast has greater impacts in the EIO/USA option.

Figure 2

If the two main emissions causing climate change, carbon dioxide CO2 and methane CH4, are examined more closely, it can be seen that share of them varies in different datasets. For instance, a quarter of CO2 emissions are caused by the metal industry in the DOM and EIO/USA whereas in the other two datasets it is in the chemical industry. Methane emissions from mining and quarrying have about a 50 % share in all other datasets (caused by natural gas) except DOM in which it is only 7 % . The low Finnish value derived solely from peat extraction, because no other energy minerals are extracted in Finland. In DOM metal industry (mostly steel industry) contributes to the methane emissions with a share of about 20 %.

Figure 3

In the impact category of eutrophication the greatest variations in the data sources are shown in agriculture, mining and quarrying and the foodstuff industry. In DOM the peat extraction lifts up the normalised value of the quarrying of energy minerals. Initially data on nitrogen and phosphorous releases into water are missing in EIO-USA, but they have been added as domestic values. The Danish food database seems to have higher emission values than in other datasets, especially the impacts of growing grain (cereals) are greater compared to the others.

Figure 4

Methane, sulphur dioxide, nitrogen oxides and carbon monoxide contribute to tropospheric ozone formation. All of these emissions in the DOM according to the Finnish emissions inventory seem to be much lower than in the other data sources which explain the results of Figure 4. The profile for acidification looks similar to the profile for tropospheric ozone formation. The same explanation is also valid in acidification related to SO2 and NOx emissions (Figure 5). Impacts of electrical energy seems to raise in EI-USA data in many impact categories but is most obvious in acidification. Figure 5. highlights the differences between datasets in electrical power sector 10. It can be explained by the different electricity production profile. In EI-LCA/DOM and EI-LCA/USA import electricity from Sweden and Russia has been used, which are mostly water and nuclear power.

Figure 5

Figure 6

Metal emissions dominate the human toxicity results (Figure 6). They are concentrated in the metal and chemical industry as well as in mining. In EI-LCA/DOM the environmental impacts of intermediate copper products rise more sharply than the others in Figure 6. In all other datasets intermediate use of copper products for electrical equipment are included with other metals.

4. Conclusions and future outlook

The environmental impacts of imports based on the emissions derived from the Finnish data are mostly lower than other datasets with the USA national i/o tables being the closest. The mixed datasets due to generic LCI data produce higher impacts. It is, however, noteworthy that in the Ecoinvent data infrastructure is included whereas in other options it is excluded. This increases the Ecoinvent results by some percentage.

Problems with generic databases are well-known. LCI data can generally only be found for raw materials and semi-finished goods. Finding an adequate technological and geographical variation can be difficult or even impossible. Data can also be out of date. Thus uncertainties can be high when generic databases are used.

The quality of domestic data for top-down approaches is the most accurate because they are compiled from official inventories. In Finland, chemical releases are not so broadly monitored, but the situation is going to change in the near future. In this approach, the data allocation for products and unsuitability to import goods adds uncertainty.

A product selection within the product groups varies from country to country which may misrepresent results in top-down approaches. For instance, in Finland there are no natural resources like coal, oil, natural gas or iron ore, but they are imported extensively. The USA data is in the better situation, because it’s a big country with various technology and natural resources. Additionally, different classifications, aggregations and money conversions (dollars to euros) in mixed datasets can create uncertainty in the results.

Can the best datasets of these alternatives to the Finnish EE-IO model be chosen? The results show that the most environmentally relevant material flows from abroad are connected with mining and quarrying, the chemical industry and the metal industry. From the eutrophication point of view foodstuffs are also relevant. The EI-LCA/DOM dataset is preferred on condition that the most relevant material flows of imports will be assessed using country-specific data. So far it is not very straightforward but the development work of databases probably will dispose this problem in the future. Thus it is suggested here that the hybrid model considerably improves the total environmental coefficients for imports compared to the pure domestic technology model. An alternative could also be EI-LCA/USA, but the USA data are classified differently and are not as transparent as the domestic matrix. Nitrogen and phosphorous releases are also missing as well as resource depletion in the USA data.

In the future the import part of the Finnish EE-IO model will be developed with new product- and country-specific data. Attention will also be paid to the growing consumer goods market which is supplied more and more by Asia where the production and environmental impacts differ from Finlands.

Acknowledgements

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Appendix: Imports in the EE-IO model

A simple environmentally extended input-output model is of the form:

1) $e^{TOT} = E(I - A)^{-1}f,$

where A is the input-output coefficient matrix, f the vector of the final products, E the matrix of the (direct) environmental load coefficients of the industries and e^{TOT} the vector of the total (direct and indirect) environmental loads of the final use vector. The matrix $E(I - A)^{-1}$ gives the total environmental loads of one unit of products of each industry. It is well known, that the matrix $E(I - A)^{-1}$ is analogous to the upstream environmental loads of unit products in the life cycle inventory.

In the following we differentiate more precisely between domestic and imported products. We assume that there are n industries and k environmental loads. Let us denote:

A^D = nxn matrix of domestic input coefficients,
A^M = nxn matrix of imported input coefficients,
$A = A^D + A^M$ = technology coefficient matrix,
f^D = nx1 vector of domestic final products,
f^M = nx1 vector of imported final products,
$f = f^D + f^M$ and
E^D = mxn matrix of m direct environmental loads coefficients of domestic industries.

For domestic environmental loads of domestic final products we have analogous with (1) as:

2) $e^{D,TOT} = E^D(I - A^D)^{-1}f^D.$

If we assume, that the imported products are produced in other countries by the same intermediate product use and by the same environmental loads as in domestic production, we have total environmental loads for both domestic and imported products as:

3) $e^{TOT} = E^D(I - (A^D + A^M))^{-1}f =. E^D(I - A)^{-1}f.$

The mxn matrix

4) $E^{TOT} = E^D(I - A)^{-1}$

gives now the total domestic and foreign upstream environmental loads per one unit of each n industry product. When applying E^{TOT} to the imported goods we can call it as **the assumption of domestic technology coefficients**.
Let us secondly assume that the “true” total upstream environmental load coefficients $E^{M,TOT}$ are known. Then the foreign environmental loads which each domestic industry directly causes through its intermediate use of imports by product unit are

5) $E^{M,TOT}A^M.$

The total foreign environmental load coefficients of domestic final products will then be:

6) $E^{M,TOT}A^{M}(I - A^{D})^{-1}$

and the total domestic and foreign environmental coefficients are:

7) $E^{TOT} = (E^{D}+E^{M,TOT}A^{M})(I - A^{D})^{-1}$.

Let us suppose thirdly that the true total environmental coefficients are known for a part, M1 of the imported products and we have to estimate the coefficients for the rest, M2, of the imported products using domestic technology assumption but also using the information of the M1 products.
First we split the intermediate import coefficient matrix into the product groups M1 and M2:

8) $A^{M} = A^{M1} + A^{M2}$.

Let us denote the known total environmental coefficient matrix of product group M1 as $E^{M1,TOT}$. Applying (3) and (7) together, we have:

9) $E^{TOT} = (E^{D}+E^{M1,TOT}A^{M1})(I - (A^{D} + A^{M2}))^{-1}$.

And we can use E^{TOT} as estimates for M2 imports:

10) $E^{M2,TOT} = E^{TOT}$.

LCI data for environmental loads can be generally found only for raw materials and semi-finished goods. For these the variations of natural conditions in different parts of the world also cause larger environmental load variations as at the final fabrication stages of the production where the global transfer of technology smoothens out environmental loads also. Therefore we may presuppose that the model (8)-(9) considerable improves the total environmental coefficients for the unknown fabricated imports compared to the pure domestic technology model (4).
When using domestic technology assumption we have to group the imported products according to the same classification as the domestic industries are classified. However, when using known environmental coefficient models as M in (5)-(7) and M1 in (8)-(9) we can use different, more disaggregate classification for imported products than for domestic industries.

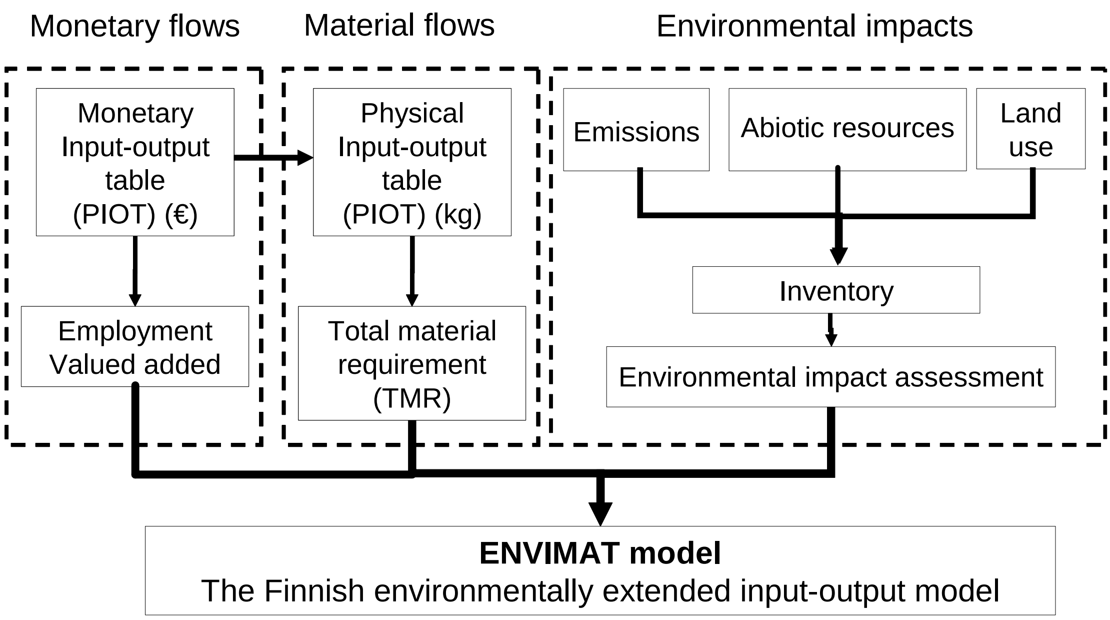

Figure 1. The structure of the ENVIMAT model.

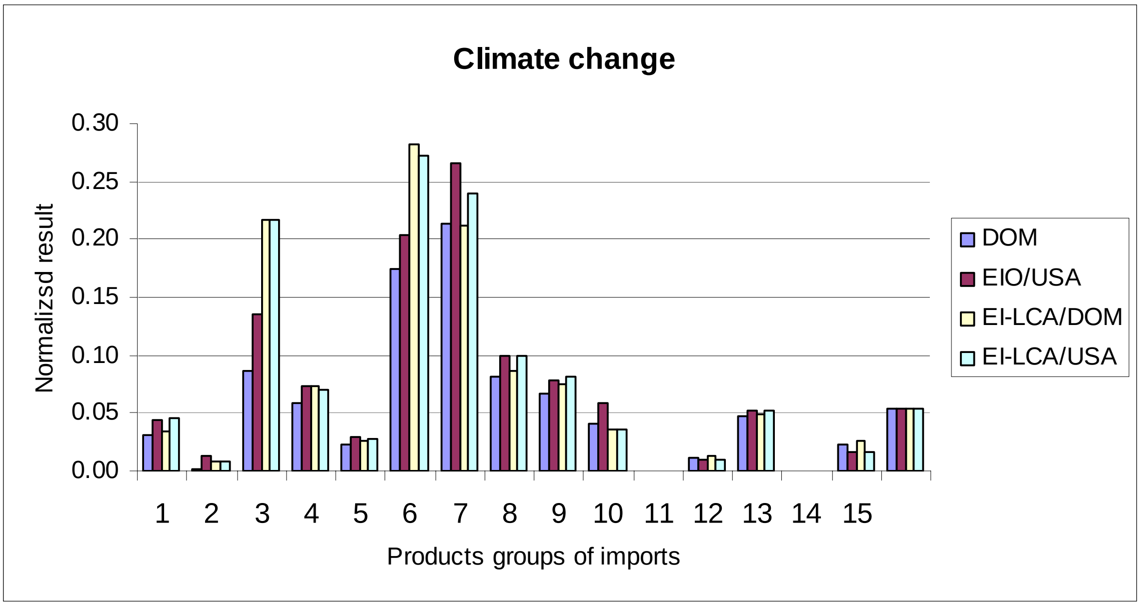

Figure 2. Normalised results of climate change calculated on the basis of different emission datasets. The emission datasets in Table 1 and product groups are listed in Table 2.

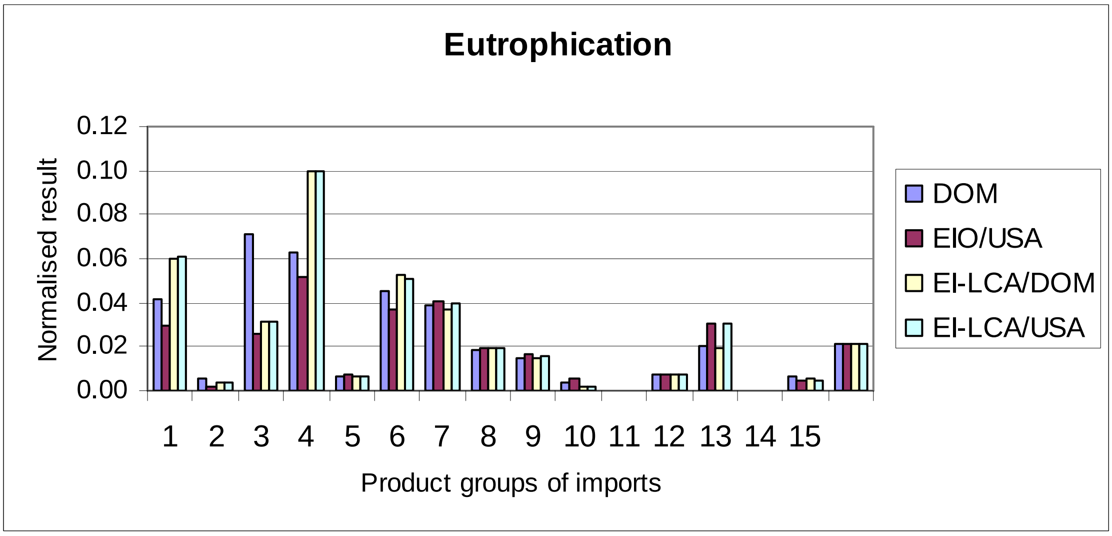

Figure 3. Normalised results of eutrophication calculated on the basis of different emission datasets. The emission datasets in Table 1 and product groups are listed in Table 2.

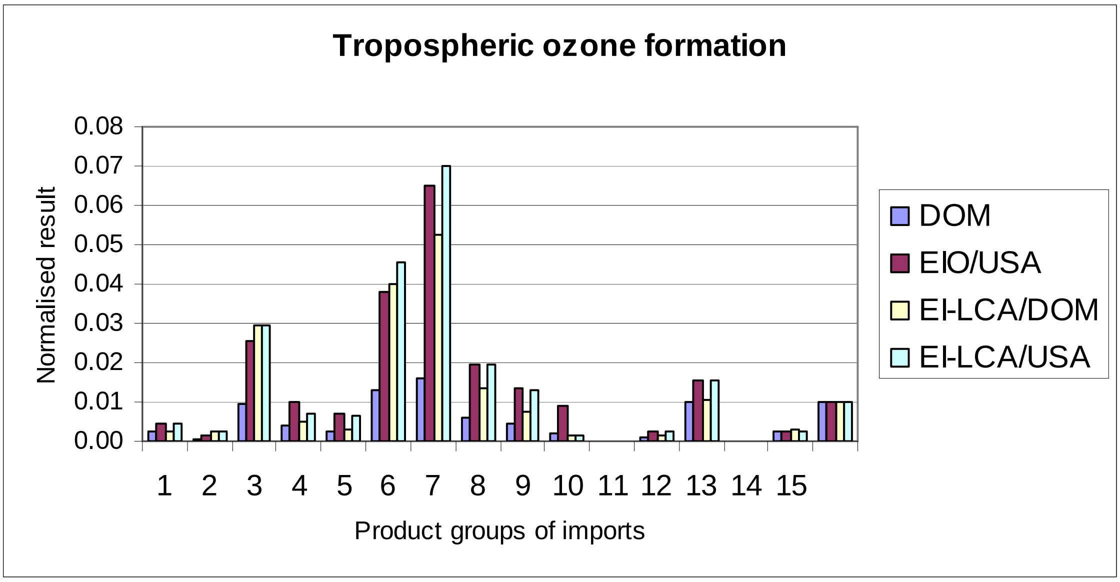

Figure 4. Normalised results of tropospheric ozone formation calculated on the basis of different emission datasets. The emission datasets in Table 1 and product groups are listed in Table 2.

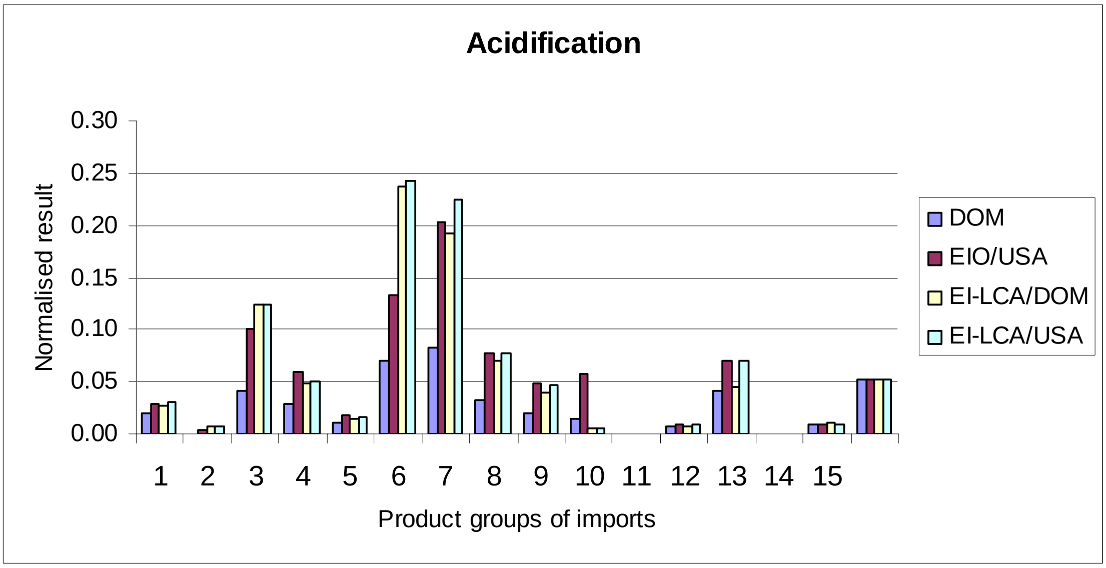

Figure 5. Normalised results of acidification calculated on the basis of different emission datasets. The emission datasets in Table 1 and product groups are listed in Table 2.

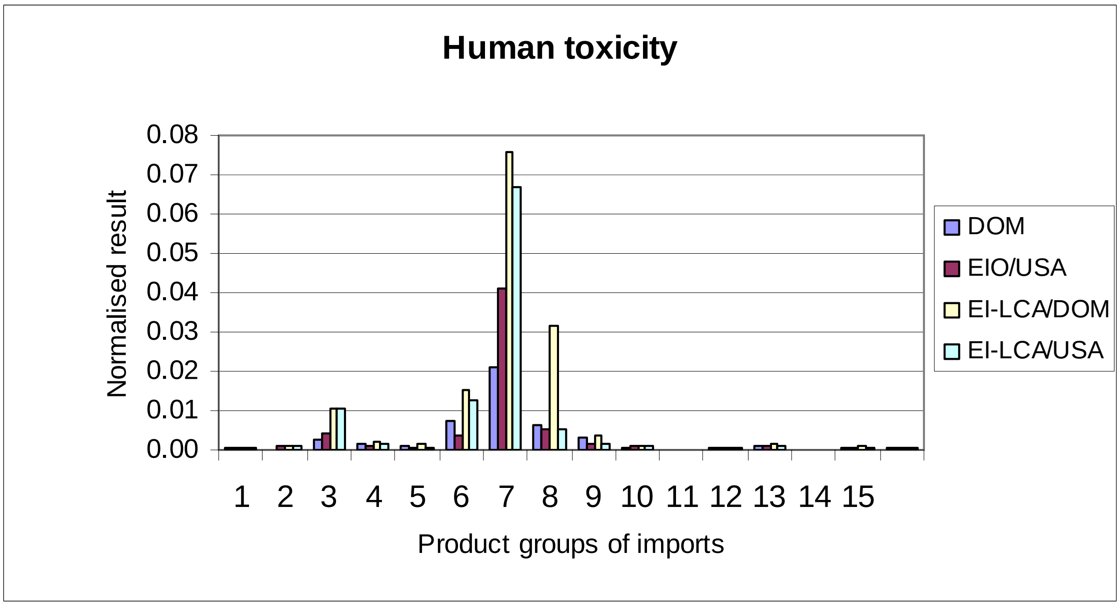

Figure 6. Normalised results of human toxicity calculated on the basis of different emission datasets. The emission datasets in Table 1 and product groups are listed in Table 2.

Table 1. Different emission datasets for imported products.

Datasets	Abbreviation	Definition
1	**DOM**	Domestic technology assumption, Finnish emission factors are used for all imported goods.
2	**EIO-USA**	Emissions derived from EIOLCA (USA) for all imported goods.
3	**EI-LCA/DOM**	Emissions derived from Ecoinvent (v1.3, v2.01) and Danish LCA Food Database for the largest volume of imported goods. The gap is filled with hybrid domestic emission factors.
4	**EI-LCA/USA**	The same as (3) except the gap is filled with emissions from EIOLCA (USA).

Table 2. Product groups of imports.

Product groups of imports
1 Products of agriculture, hunting and fishing
2 Products of forestry and logging
3 Products from mining and quarrying
4 Food products, beverages, tobacco
5 Products of forest industry
6 Products of chemical industry
7 Products of metal industry
8 Electrical equipment
9 Other manufactured goods
10 Electrical energy, gas, steam and water
11 Construction work
12 Trade, hotel and restaurant services
13 Transport and communication services
14 Real estate services
15 Other services
Correction for international transport