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Application of Life Cycle Based Coefficients for Imports in Environmentally Extended Input Output Models

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Abstract

Input output analysis is often used to identify total material, energy and emission flows induced in a particular economy due to the supply of products and services to the final demand. With growing international trade and moving industries to developing countries, a rising part of the material and energy flows emerges out of the studied economy. A question of dealing with imports in input output models arises with this fact.

In this paper we present an input output model with environmental extension based on a combination of domestic technology assumption for imports with equivalent domestic production and life cycle coefficients for imports with no or different domestic production technology. The need for life cycle based coefficients results from the lack of representative domestic production of several materials, which are widely used within the Czech economy: metal ores, crude oil and natural gas. Metal ores are not supplied by domestic producers at all and using the domestic technology assumption for natural gas and crude oil might result in high error due to small amounts of these materials, which are extracted from the domestic environment.

The data from Ecoinvent process database for life cycle assessment are incorporated into the model of the economy with environmental extension. The method presented in this paper is applied in the calculation of the total airborne emissions induced by final demand.

Keywords: Input output analysis, Imports, Life cycle assessment.

1. Introduction

Because of the material throughput, energy exchange and a close relation with its surroundings, the anthroposphere is often compared to natural systems and some authors introduced the concept of socioeconomic, resp. industrial metabolism (Baccini and Brunner, 1991; Fischer-Kowalski and Haberl, 1993; Fischer-Kowalski and Haberl, 1998; Ayres, 1989; Ayres, 2004). As it was argued by for example Schmidt-Bleek (1993), Ayres and Simonis (1994), Weizsäcker and Lovins (1997) and Bringezu (2002) the influence of socioeconomic system on the environment is closely linked to the amount of material, emissions and energy exchanged between socioeconomic sphere and the environment. The increasing environmental problems have resulted in an effort to measure, control and minimize the material consumption and emissions in individual countries.

Materials which enter the domestic economic system by extraction activities and emissions from domestic economy are quantified and reported by national offices. The methodological problems are related to imports, which cover not only raw materials, but more likely semi-manufactured and final products. With increasing international trade and moving industries to developing countries, the information about a part of the environmental pressure is lost for imported goods. Hence, the effort is to quantify the imports in raw materials equivalent (RME), which is the sum of all materials entering the economical system all over the world in order to support the production of these imports. Analogously for emissions, the embodied emissions in imported goods are of concern.

Having the imports in a form of RME and embodied emissions allows for the calculation of total embodied emissions and material consumption of the particular country. This is necessary for not avoiding the environmental pressure outside the particular economy when measuring the material consumption and emission trends. In this sense it is also important for precise measuring of decoupling. The decoupling shows whether the link between economic growth and related environmental pressure/impact has been broken or not (OECD 2002; EC 2006). The accomplishemnt of decoupling is dependent on changes in law, technology, and human lifestyles.

In this article we present domestic emissions as shown in the Czech NAMEA (CZSO, 2006a), calculated emissions embodied in imports, emissions embodied in exports, emissions embodied in domestic final demand of products and total emissions induced by the Czech Republic. We quantify emissions of CO_2, SO_2, NO_x and PM_{10}.

2. Methods

2.1 Input output model

For domestic emissions, the data published by Czech Statistical Office in NAMEA (CZSO, 2006a) are used.

The emissions embodied in imports are calculated using input output analysis (IOA), which was introduced in 1930´s by Leontieff (1936, 1970). It is widely used for estimating the emissions embodied in international trade of goods (Machado et al., 2001; Munksgaard and Pedersen, 2001; Ahmad, and Wyckoff, 2003; Mongelli et al., 2006).

Through whole calculation, the same production technology as the domestic one is assumed for all imports (excluding the imports for which the life cycle inventory data are used). Using this assumption, the emissions embodied in imports can be interpreted as the environmental pressure avoided in the domestic country by importing goods (Machado et al., 2001).

In our calculations we use monetary sector-by-sector input output model with environmental extension (Suh, 2004; Weisz and Duchin, 2006). The model is calculated with the supply table excluding exports (only domestic products are included in the total supply of products) under the assumption of fixed product sales structure. Since there are several imported products without representative domestic production in the economic system of the Czech Republic, we use life cycle inventory data (LCI) for emissions embodied in these products (crude oil, natural gas, metal ores, and basic metals). The data on price and weight of these imported materials are available from the Czech Statistical Office database on imports and exports (CZSO, 2008). The LCI data are taken from Ecoinvent life cycle inventory process database (Ecoinvent, 2006).

Before the model is calculated, the supply, use and emission matrices have to be changed in order to incorporate the LCI data. We assume the imports of crude oil, natural gas, and metal ores to be produced in the Czech Republic. We replace the output of their characteristic sector as found in the supply table of the Czech Republic with the sum of this output and the economic value of corresponding imports. Hence, we have to subtract these imports from the vector of imports in order to avoid double-counting. At the same time we use the Ecoinvent database to quantify airborne emissions related to imports of products in question and sum them to the domestic airborne emissions of the characteristic sectors of these products.

For the imported products in category "basic metals" a new sector was created in the use and supply tables. All imported products in this category and also all airborne emissions embodied in these imports are considered to originate from this new sector. This approach is necessary, because of huge difference in domestic production and LCI data.

After these modifications of original use, supply and emission matrices, the input output model is calculated using the following equation:

$$\mathbf{A = M^T .(diag(t - p'))^{-1}.U.(diag(g))^{-1}}$$

where A is the technology coefficients matrix (model of the economy), M is the modified supply matrix, t is a vector of total product supply, p is the modified vector of imports, U is the modified use matrix and g is the modified output of sectors. For more details on input output models see e. g. Miller and Blair (1985), United Nations (1999), Eurostat (2002) or the most recent Eurostat (2008).

The matrix F with emissions per monetary output of sectors is calculated by:

$$\mathbf{F = F\_r.(diag(g'))^{-1}}$$

where F_r is a matrix of emissions by sectors in absolute value.

2.2 Calculation of embodied emissions

The embodied emissions are calculated using the introduced input output model. The final demand, imports and also exports are expressed in product groups and not in output of sectors. Therefore, it is necessary to transform the vector of products into the vector of output of sectors. This is done using the following equation:

$$\mathbf{y\_s = M^T.(diag(t - p'))^{-1}.y}$$

where y_s is the final demand expressed in output of sectors, M is the modified supply matrix, t is a vector of total product supply, p´ is the modified vector of imports and y is the final demand of products, for which we want to calculate the embodied emissions.

The total output of all sectors to produce all products for final demand can be calculated using the input output model by:

$$\mathbf{x = (I - A)^{-1}.y\_s}$$

where x is a vector of total output of all sectors, I is an identity matrix, A is the technology coefficients matrix as introduced above.

Furthermore, the emissions from whole production chain can be calculated as:

$$\mathbf{e = F.x = F. (I - A)^{-1}. M^T.(diag(t - p'))^{-1}.y}$$

where e is a vector of embodied emissions.

In the calculation of embodied emissions, the vector y is sequentially substituted by vectors of total final demand, imports (the original vector of imports), domestic final demand and exports.

In order to compare them with calculated embodied emissions, we also estimated the CO_2 emissions from the final demand of fossil fuels, which were not incorporated in the input output model. Our estimate was based on the data on household consumption of fuels (CZSO, 2006b), IPCC emission factors (Garg, 2006; Gómez, 2006) and NAMEA data on emissions from transport activities by households (CZSO, 2006b).

3. Results and discussion

Calculated emissions embodied in total final demand, imports, domestic final demand, exports, the data on domestic emissions published by CZSO and the LCI data from Ecoinvent database are presented in Table 1 and in Figure 1. Because of a discussion of the benefits of incorporating LCI data into the model, also the results without the model modification are presented for all calculated values. The total CO_2 emissions from the final demand of fossil fuels are estimated to be approximately 17 Mton (8 % of CO_2 emissions embodied in total final demand).

Table 1a

Table 1b

Figure 1

The following issues can be discussed based on the presented results:

- Model consistency
- Model improvement by LCI data
- Calculated embodied emissions

3.1 Model consistency

The input output model of the economic system with environmental extension can be checked by comparison of the domestic emissions calculated by the input output model and the domestic emissions published by the Czech Statistical Office. Since the system is linear, the domestic emissions calculated by the model can be expressed as the difference between emissions embodied in total final demand and emissions embodied in imports. It can be seen from Table 1, that this equation is valid.

3.2 Model improvement by LCI data

If the LCI data from Ecoinvent database are not incorporated into the model calculation, the total emissions embodied in total final demand can be calculated using two approaches:

- Without LCI data
- Sum the LCI data with the results from the model without LCI data

The influence on the first method is visible directly from the Table 1 for all presented elements. The results without LCI data include only about 90 % of total emissions for CO_2 and NO_x, 62 % for SO_2 and only 23 % for PM_{10}.

The second approach means, that we would use LCI data directly for the selected imported products and we would not incorporate it into the input output model. Therefore, the total emissions by this approach would be the sum of the calculation with model without LCI data and these LCI data. Such an approach gives better results than just omitting the LCI data, but the results are still different from what we get with incorporating LCI data into the input output model.

Furthermore, the influence on results is different for individual emissions and also calculated vectors of final demand for these approaches. It is impossible to simply estimate the influence of LCI data on the results.

We can conclude that it is meaningful to incorporate the LCI data for imported products without representative domestic production into the input output model as the difference between results with and without this amendment could be quite large (tens of percent).

3.3 Embodied emissions

Emissions embodied in imports can be interpreted as the pressure exerted by the country in question on the environment of other countries, while the emissions embodied in exports can be interpreted as the environmental pressure exerted on the country in question by other countries. From this point of view, the calculation of emissions embodied in trade balance is important. As seen from Table 1, the results are significantly dependent on incorporating the LCI data into the model. Only the results with LCI data are further discussed in more details. The emissions embodied in trade balance are almost CO_2 neutral. For all other emissions the Czech Republic exerts a pressure on other countries rather than other countries exert the pressure on the Czech Republic (the positive physical trade balance) The importance of shifts of environmental pressure through foreign trade can be emphasized by comparison of the emissions embodied in imports/exports and domestic final demand. These indicators are of the same order of magnitude. It means that the environmental pressure shifted to and from abroad is as large as the environmental pressure related to the domestic final demand of a whole country.

The emissions listed above can be divided into two groups according to the spatial dimension of their environmental impact:

- Regional
- Global

SO_2, NO_x and PM_{10} emissions can be characterized as emissions with regional environmental impact (with different spatial scale), while CO_2 emissions have global environmental impact. The spatial dimension is crucial in determining if the country really exerts the environmental pressure solely on other countries. This is true for regional environmental impacts, but questionable in the case of global impacts. With respect to the global climate change, the country with positive trade balance can exert environmental pressure also on itself. From the viewpoint of equity in resource sharing this country however violates the capacity of other countries to release CO_2 emissions when producing commodities for their domestic final demands.

4. Conclusion

In this article we present a calculation of emissions embodied in imports, exports and domestic final demand for the Czech Republic, year 2003, using a monetary input output model with environmental extension. The model was derived using additional LCI data for imports without representative production within the domestic economy.

The results show that the model is consistent in the sense of backward checking of calculated embodied emissions and the data on emissions published by the Czech Statistical Office. Incorporating the LCI data into the input output model proved as meaningful as the difference between results with and without this amendment was in tens of percents. As shown in Figure 1, the emissions embodied in international trade are significant: they amounted to similar volumes as emissions related to domestic final demand. From the trade balance point of view, the Czech Republic is CO_2 neutral, but it exerts the environmental pressure on other countries through emissions of SO_2, NO_x and PM_{10}.

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Figure 1

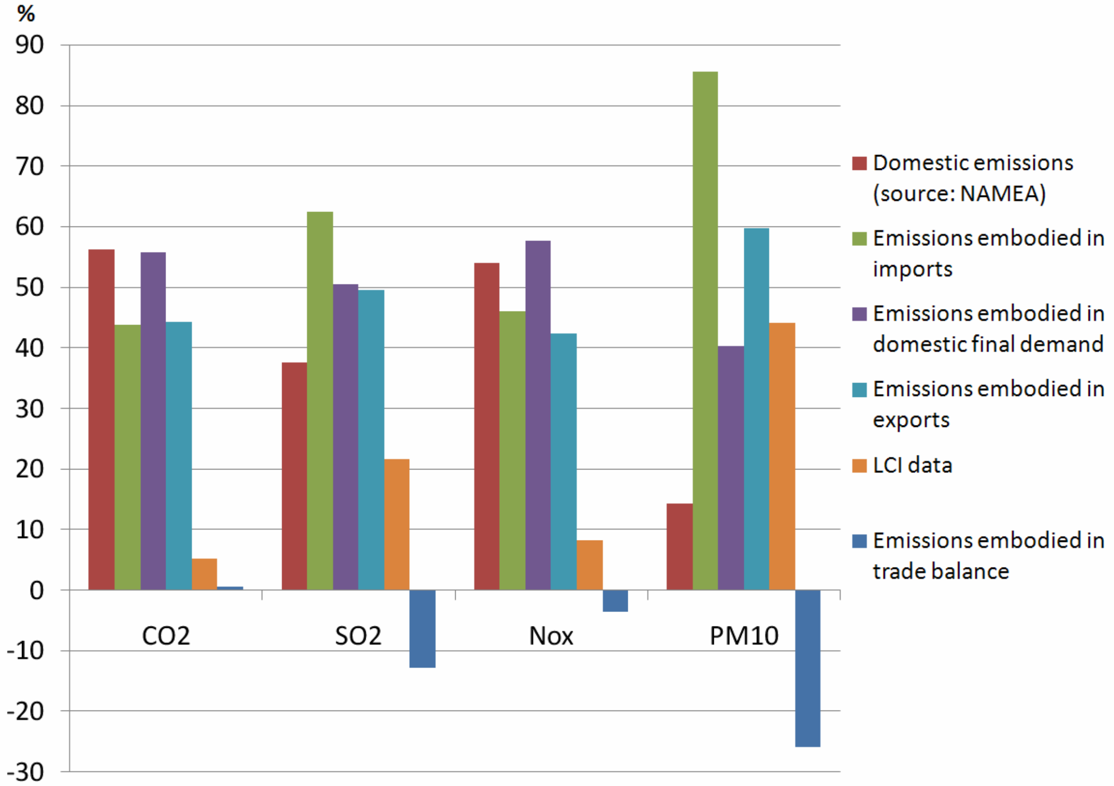

Figure 1: The domestic emissions, emissions embodied in imports, emissions embodied in domestic final demand and emissions embodied in exports as a ratio of emissions embodied in total final demand, Czech Republic, 2003.

Table 1a

	Embodied emissions in total final demand		Embodied emissions in imports		Domestic emissions	Emissions based on LCI data
Emission	With LCI data	Without LCI data	With LCI data	Without LCI data	Source: NAMEA	Source: Ecoinvent[1]
CO_2 (Mton)	209,0	189,9	91,5	72,5	117,5	10,7
SO_2 (kton)	537,9	332,1	335,4	130,1	202,1	116,6
NO_x (kton)	554,2	473,1	255,0	174,4	298,9	45,5
PM_{10} (kton)	173,9	40,6	148,9	15,7	24,9	76,7

Table 1a: Results and data sources, Czech Republic, 2003.

Table 1b

	Emissions embodied in domestic final demand		Emissions embodied in exports		Emissions embodied in trade balance (export – import)	
Emission	With LCI data	Without LCI data	With LCI data	Without LCI data	With LCI data	Without LCI data
CO_2 (Mton)	116,4	108,9	92,6	81,1	1,1	8,5
SO_2 (kton)	271,6	198,7	266,2	133,4	-69,2	3,3
NO_x (kton)	319,3	286,8	234,9	186,3	-20,1	11,9
PM_{10} (kton)	69,9	23,5	104,0	17,1	-45,0	1,4

Table 1b: Results, Czech Republic, 2003.

[1] This column presents embodied emissions in imports from Ecoinvent database. It is presented in order to show all sources of emissions in the model and to point out that the difference between results with LCI data and without LCI data is larger than just the LCI data.