What matters most? Identifying the key issues in environmentally extended input-output models with sensitivity analysis.

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Abstract

An environmentally extended input output (EE-IO) table of the Finnish national economy was subjected to linear sensitivity analysis. Sector interaction coefficients, emission factors and final demand were analysed from the viewpoint of their influence on climate change and eutrophication. The analysis revealed that the environmental impacts were sensitive to less than 0,1% of the more than 20 000 coefficients in the model. The analytical sensitivity analysis highlighted as important factors which were for the most part already included in environmental policy (i.e. food production, electricity production, energy use in steel and paper industry). However, the sensitivity analysis reduced the complexity of the model facilitating dissemination to stakeholders and the general public. In addition the highlighted factors should be prioritized in further data acquisition, uncertainty analysis and dynamic model construction.

Keywords: Environmentally extended input output analysis, sensitivity analysis, key issues, eutrophication, climate change

1. Introduction

Environmentally extended input-output (EE-IO) tables are a practical method for describing the complex economic interactions which cause many of the environmental problems of today. However, due to their completeness they are often so complex that their interpretation is difficult. For example, the detailed IO model of Finland has 151 sectors with 21 483 interactions. The large amount of variables makes it necessary to filter the resuls in order to reveal the main interactions for the given research question. This will allow the researcher to focus on the more influential factors in further studies. In this paper we apply a simple sensitivity analysis to the EEIO tables of the Finnish National Economy with two goals in mind:

(1) To identify the variables in the EEIO-model where further studies should focus in order to reduce uncertainties in the model results

(2) To identify the components in a national economy, where environmental management will have the greatest leverage (greatest effect with the least change).

This study focuses on two environmental impact categories: eutrophication and climate change. These represent the main issues in current Finnish environmental policy. However this study belongs to the methodological part of the ongoing research project *Environmental impacts of material flows caused by the Finnish economy* (ENVIMAT), which includes several other environmental impact categories. For more information on the project, see: http://www.ymparisto.fi/default.asp?contentid=195528&lan=fi&clan=en

2. Material and methods

We applied sensitivity analysis to the system described by the Finnish domestic input-output tables of 2002, combined with the satellite matrices of greenhouse gas and nutrient emissions (VAHTI-database). For analysis, the satellite matrices were multiplied by a characterisation matrix in order to transform emissions into environmental impacts. This is a similar to the computational structure of life cycle assessment (Heijungs and Suh, 2002) and the characterization factors of Guinee *et al.* (2002) were used.

The purpose of the sensitivity analysis was to identify factors which, when changed by a little, would have a great influence on the environmental impacts. There are several methods for sensitivity analysis (c.f. Saltelli *et al.* 2007), but here we applied the simplest method: partial derivatives of the environmental impact functions[1]. Partial derivatives of eutrophication and climate change were calculated with respect to input-output coefficients, emission factors and final demand. After derivation the absolute values of the partial derivatives were normalized with the absolute parameter values. The chosen sensitivity indices describe the relative change of environmental impacts following a relative change in the input parameters:

$$\gamma_k(f_i) = \left| \frac{\Delta g_k / g_k}{\Delta f_i / f_i} \right| \qquad (1)$$

where $\gamma_k(f_i)$ = the sensitivity of g_k to f_i, f_i = input parameter i, g_k = environmental indicator k, Δ = marginal change in variable.

[1] This method is transparent, complete and analytical, but it cannot identify relevant factors with low sensitivity but high variablity (i.e. very uncertain parameters). In addition it applies only to linear systems, such as static IO-tables. (Saltelli et al. 2007)

Morán and Gonzales (2007) developed a similar sensitivity analysis framework for analyzing the CO_2 emissions of Spain. Our approach differed from theirs in three aspects: (1) analytical sensitivity equations were used instead of numerical simulations, (2) also other greenhouse gases than CO2 were taken into account and (3) also eutrophication was considered. The derivation of the partial derivatives is similar to the one presented by Heijungs and Suh (2002) and will not be repeated here.

Johdatteleva lause raja.arvoista… In the input-output coefficient matrix the coefficients which had a sensitivity (γ_k) greater than 1% (i.e. a perturbation of 10% would result in a change of 0,1% in the environmental impact) were considered as relevant. For emission factors and final demand, sensitivites were calculated with (eq. 1) and five of the most sensitive variables were chosen for a more detailed study.

3. Results and Discussion

3.1. Sensitivity in input-output coefficients

Climate change and eutrophication were observed to be sensitive only to a few input-output coefficients out of the 21 483 (n=17 for eutrophication, n=14 for climate change) (Figure 1). Some of these coefficients were the same for both impact categories (i.e. pulp&paper production, meat and dairy industry, electricity use).

Figure 1.

Climate change was sensitive to coefficients describing interactions in the meat and dairy production, pulp & paper production, cement and wood use in construction and electricity use. The meat and dairy sector is identified as important because of agricultural methane and N_2O emissions. Pulp & paper industry is highlighted for its energy usage and cement use because the associated CO_2 process emissions. Only one of the input-output coefficient had a sensitivity index greater than 5%: the electricity use in pulp & paper industry. This result was somewhat biased, since the pulp & paper industry uses mainly renewable energy sources, an aspect which could not be taken into account in the EE-IO framework. However the results can be considered to indicate that further improvements in the electricity use efficiency in the pulp & paper sector would make renewable energy resources more available for other sectors.

For eutrophication the most relevant coefficients (sensitivity > 5%) were in the meat and dairy production sectors. Electricity use was indicated as a sensitive factor because of its nitrogen emissions and wood use because of emissions from forestry, but the sensitivity of these coefficients was much lower than in the meat and dairy chains. From this viewpoint, eutrophication could be reduced effectively by increasing the efficiency of feed use, reducing the waste of animal products and reducing the fraction of meat in diets.

3.2. Sensitive emission factors and final consumption

Five of the most sensitive emission and final consumption factors are presented in Table 1 for climate change and eutrophication. Climate change was most sensitive to variation in the emission factor of electricity production (sensitivity 36%, eq. 1). This was also the highest sensitivity index observed in this study, justifying the current focus in environmental policy towards less carbon intensive energy production. Other emission factors had less sensitivity ranging between 4-8 % and only 17 of the emission coefficients had sensitivity indices higher than 1%. These sectors represent high emission intensities, high production volumes or both.

Table 1.

Because of high export volumes, the pulp and paper was the most sensitive variable in total final demand categories, followed by apartments, electricity, steel and construction of residential buildings. From the viewpoint of the consumer, letting and owning of apartments was the most influential final demand category, followed by retail trade, electricity, dairy and meat products. These observations are in line with those made in the study of the environmental effects caused by Finnish households (http://www.ymparisto.fi/mittatikku). Here it should be noted that the imported products sold to consumers were not included in the analysis. For example, taking into account imported electronics would most likely alter the observed sensitivity ranking and reduce the relative importance of food items (c.f. Peters and Hertwich 2008).

However, for eutrophication the food production chain ranked very high both in emission factor and in final consumption sensitivity listings. In addition to food production (especially meat and dairy production), sewage treatment and electricity production were among the most sensitive factors causing eutrophication.

4. Conclusions and suggestions for further studies

Based on this sensitivity analysis study, the input-output model can be simplified for purposes of explaining the economical mechanisms of eutrophication and climate change. The environmental impacts were sensitive to less than 0,1% of the input parameters (input-output coefficients, emission factors and final demand). These identified “key issues” should be focused on in further analysis (uncertainty analysis, dynamic input-output analysis, etc.). Uncertainty estimates should be assembled for the most sensitive factors in order to give an estimate of the reliablity of the model predictions. These factors could also be used to construct a metamodel to be used for planning the mitigation of climate change in the Finnish economy and for building mechanistic explanations of the propagation of environmental problems.

In addition to model building, these sensitive issues in the model structure can be used to highlight focusing points for environmental policy. Many of the identified key issues are allready included in the mainstream of current policy, while others could still be included. Further studies could improve the applicability of the results by coupling the sensitivity results with socio-economical indicators (sensitivity of employment and value added), which would give the decision makers a more complete picture of the consequences of regulating these factors.

Acknowledgements

This study was a part of the project *Environmental impacts of material flows caused by the Finnish economy* (ENVIMAT, 2006-2008), funded by the Finnish Ministry of the Environment.

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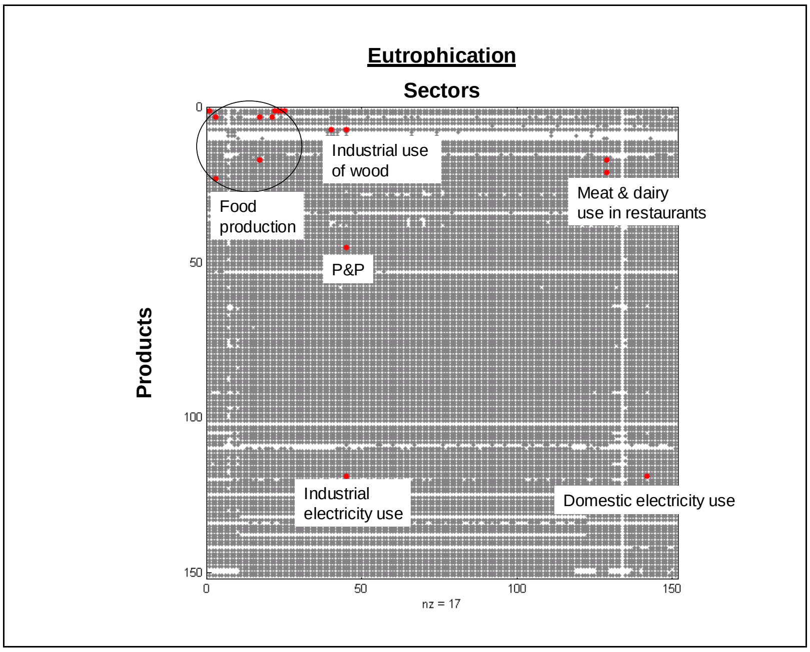

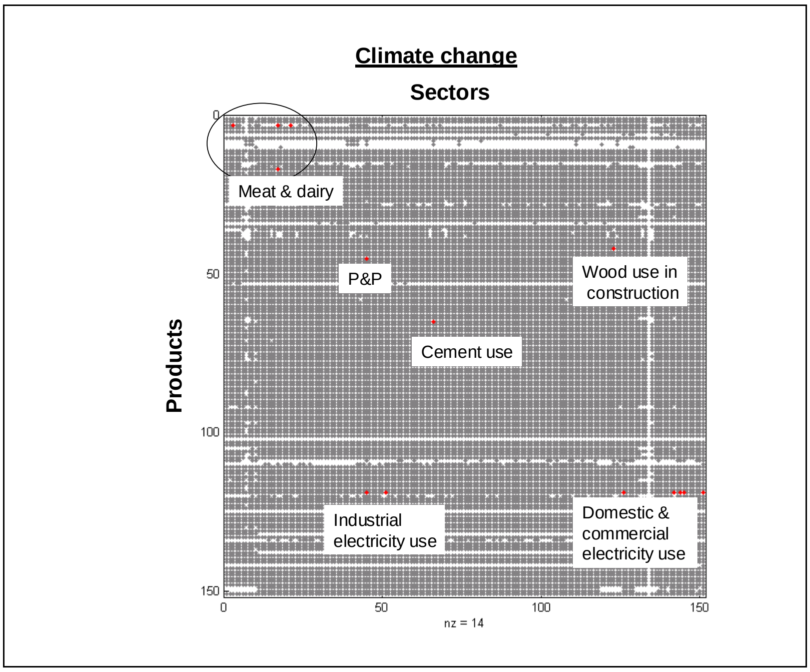

Figure 1. Filtering the most sensitive coefficients (sensitivity>1%) in terms of eutrophication and climate change from the 151x151 product-by-sector technical coefficient matrices revealed 17 relevant coefficients for eutrophication and 14 relevant coefficients for climate change.

Table 1. The most sensitive emission factors and final demand coefficients from the viewpoint of climate change and eutrophication. The numbers in parenthesis describe sensitivity indices calculated with equation 1.

Climate change		
Emission factor	**Final consumption –total**	**Final consumption - household**
Electricity production (36%)	Pulp & paper (12%)	Letting and owning of apartments (26%)
Animal farming (8%)	Letting and owning of apartments (9%)	Wholesale and retail trade (13%)
Iron and steel production (7%)	Iron and steel (6%)	Electricity (13%)
Pulp and paper production (5%)	Electricity (5%)	Dairy products (6%)
Waste management (4%)	Residential buildings (5%)	Meat products (6%)
Eutrophication		
Emission factor	**Final consumption – total**	**Final consumption – household**

Animal farming (35%)	Dairy products (12%)	Dairy products (17%)
Crop production (13%)	Pulp and paper products (9%)	Meat products (16%)
Sewage treatment (8%)	Meat products (9%)	Products of animal farming (9%)
Electricity production (7%)	Animal products (6%)	Restaurant services (9%)
Pulp and paper production (5%)	Plant products (5%)	Letting and owning of apartments (8%)