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Regional material flow analysis and data uncertainties: Can the results be trusted?

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Abstract

Regional material flow analysis (MFA) has been proposed to be a useful tool for priority setting and follow-up in environmental management. However, data that are used in regional MFA are usually connected to varying degrees of uncertainties. This paper analyses and discusses how data uncertainties affect the results from a regional MFA study of nitrogen flows in a Swedish municipality. It is argued that the intended use of MFA is associated with considerable difficulties.

1. Introduction

Regional material flow analysis (MFA) has been proposed to have a part in various environmental management/decision-making situations, for example as a tool for early recognition of major problem flows or stocks, priority setting, effective policy and goal making, follow-up/analysing trends, and screening (Burström 1999, Hendriks 2000, Udo de Haes 1998). However, data uncertainties in MFA, as in other environmental system analysis tool, such as LCA, is very often of varying standard. This leads to questions like: How reliable are the results? How big recorded difference between flows is necessary to guarantee that one is larger than the other? Has an improvement really occurred from one year to another? For LCA there exist a number of methods to deal with data uncertainties (Björklund 2000). Data uncertainties connected with MFA studies are however mostly not dealt with. The usual way of handling these questions is to conclude that despite of the unknown uncertainties the result is good enough and that the correct order of magnitude of the different flows are accounted for.

The aim of this paper is to discuss data uncertainties in MFA and analyse how these uncertainties affect the results and the possibilities to draw conclusions related

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to environmental policy and management. In this paper two situations where regional MFA are proposed to be useful will be investigated: priority setting and follow-up respectively. In recent years, MFA has been proposed to be used in the system of environmental accounting on regional and national level to support strategic and operational environmental management with relevant information. Consequently, new kinds of environmental data need to be collected. Given the efforts to incorporate MFA in environmental accounting and information systems, and in light of the study of data uncertainties, the paper will also outline some implications for future collection of environmental data.

2. Materials and methods

In this study a newly developed model to determine, present and calculate data uncertainties in MFA studies is applied on data from an earlier case study of nitrogen metabolism in the Swedish municipality of Västerås 1995 and 1998. Priority setting is investigated by analysing data uncertainties for different flows and their mutual relation within one year, 1995 or 1998. Following up is looked upon by analysing the change of particular flows between the two years 1995 and 1998.

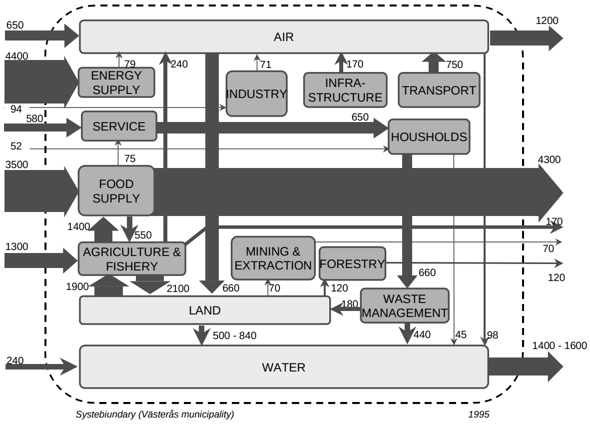
2.1 Case study of nitrogen metabolism

The case study was carried out for the territory of the municipality of Västerås. Västerås is situated by lake Mälaren in the middle-south part of Sweden approximately 100km west of Stockholm, the Swedish capital. The municipality has approximately 124 000 inhabitants and covers an area of 956 km^2 (130 inhabitants/km^2). The territory consists mainly of agricultural land and forests. There is only one large population centre, Västerås town.

The method used in the case study (Danius/Burström 2001) is called the ComBox model, which is based on MFA but specifically adapted for use in studies of material and substance flows in relation to municipal environmental management (Burström 1998). In the ComBox model, the region (constituted of all societal activities and ecosystem processes within the municipal territory) is thought of as an open system exchanging materials, energy and information with its surroundings via the atmosphere, the hydrosphere and society. Flows of material between different sectors in society, between different compartments of the environment, from societal sectors to the environment, and from the environment to the societal sectors are recorded. There are 12 main sectors in society and three main environmental compartments, which are all further divided in different sub-sectors and sub-compartments. Flows are accounted for a period of one year, thus giving a „snapshot“ for that period. In this study the years 1995 and 1998 was investigated (figure 1).

The data used in the case study comes from many different sources and vary considerbly in uncertainty. The data can be deployed in a number of groups: measured data from companies and authorities, statistics at local, regional and national level, data from modelling, general data and finally estimations done by experts at authorities and companies.

1995



1998

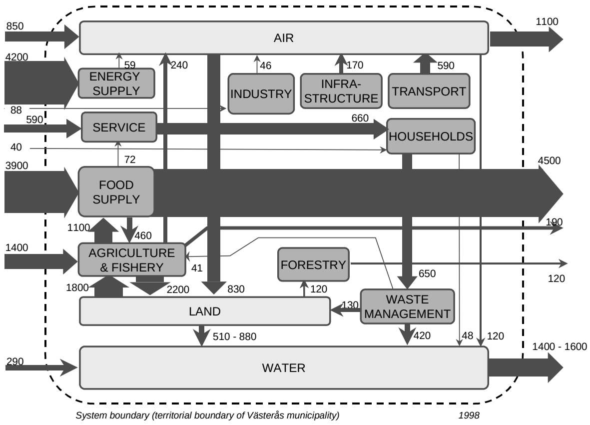


Figure 1: Nitrogen flows in Västerås municipality 1995 and 1998 (tonnes N-eq/year). Only fixed nitrogen (oxidised and reduced) is included, and the result is presented with two numbers of accuracy.

2.2 MFA data uncertainty model

The method used to investigate the data uncertainty was first developed and proposed by Hedbrant and Sörme (2001). This method was originally designed to evaluate data uncertainties in urban heavy-metal metabolism and is based on uncertainty intervals. The aim was to find the maximum upper limit since the project focused on potentially toxic substances. The level of uncertainty is determined for each and every one of the collected data. These data are then added and/or multiplied, and the uncertainties are calculated for the results with specific formulas. In this model uncertainty increases when data are multiplied (1), and decreases when added (2).

(1) $m_{a5b} = m_a \, 5 \, m_b$

$$f_{a\times b} = 1 + \sqrt{(f_a - 1)^2 + (f_b - 1)^2}$$

m = likely value
f = uncertainty factor

(2) $m_{a+b} = m_a + m_b$

$$f_{a+b} = 1 + \frac{\sqrt{[m_a \times (f_a - 1)]^2 + [m_b \times (f_b - 1)]^2}}{m_a + m_b}$$

The model's uncertainty factors have been slightly modified to suite data collected in the study of regional nitrogen metabolism (table 1). The modification consists of two new factors of uncertainties: interval */1 and interval */1.5. The interval */10 original proposed by Hedbrant and Sörme (2001) has been omitted.

2.3 Application

In relation to priority setting MFA is used as a tool to give information on the relative importance of environmental pressure from flows and their causes in society. Here, priority setting is looked upon by comparing flows that i) are approximately equal in mass, thus seems to contribute equally to the load on the environment, or ii) have the same order of magnitude but are close to the lower and higher limit respectively, thus where it seems that one flow is the main contributor to the load on the environment. In both cases, what distinguishes the flows is the data quality.

In i) the flow *waste treatment → water* is recorded mainly from measurements of effluents from sewage treatment plants, while the flow *land → water* is calculated from experts' estimations and three different sets of general values. The highest calculated flow *land → water* is based on general values where surface runoff influences

Uncertainty factors[2]	Source of information	Example
interval */1	Values in general (from literature)	Molecular weight, e.g. N_2, NO_2
interval */1.1	Official statistics on local, regional and national levels.	Number of households, apartments, and small houses.
	Values in general (from literature)	Nitrogen content in products.
	Information from facilities subjected to permit requirement.	Nitrogen emissions from facilities.
interval */1.33	Official statistics on regional and national levels.	Amount of harvest (kg), different grain per hectare.
	Values in general for content (from literature or on request).	Nitrogen content for products, e.g. wood, organic waste.
interval */1.5	Modelled data for the municipality.	Emissions of NOx from vehicles. Emission of NOx from traffic
	Information on request from authorities.	
interval */2	Official statistics on national level downscaled to local level.	Harvest (kg) grain per hectare.
	Information on request from authorities.	Nitrogen emissions from facilities
(interval */4	Values in general for flows (from literature).	Emissions of NH3 from livestock farming.

Table 1: Uncertainty factors as modified to this study from Hedbrant and Sörme 2001.

the result. In ii) the flow *transport → air*) is recorded from measurements of traffic volumes and detailed modelling of emissions renewed each year, while the flow *infrastructure → air* is recorded from experts' estimations not renewed since 1993

In relation to follow-up MFA is used as a monitoring tool to track trends and changes of flows and environmental pressure that is caused by the different flows. Follow-up with MFA is also used as a tool to evaluate abatement or other actions *ex post*. In this study comparing the results for different years, 1995 and 1998 looks upon follow-up.

[2] Instead of defining the uncertainty interval as +/- X, the uncertainty interval is defined as */X. This interval shows the magnitude of the variation for the entity. Example: The entity 100 kg (Y) can be as much as 200 kg, which means 100*2 kg (Y*X), or as little as 50 kg, which means 100*½ kg (Y*1/X). This is written as 100*/2 (Y*/X).

3. Results

3.1 On uncertainties and MFA for priority setting

For example i) the results show (see table 2) that when the general data that gives a low value for the flow *land → water* (a) are compared to the flow *waste treatment → water* both flows are of the same order of magnitude when data uncertainties are considered. The flow *land → water* shows the largest span due to higher uncertainty factor. Only when the general data used that gives twice as large a value for *land → water* (b) the domination of this flow remain even after considering the data uncertainties. How much larger the flow is remains uncertain.

For example ii) the results indicate the flow *infrastructure → air* could be either insignificant or as important as *transport → air* due to the high degree of uncertainty for the first mentioned flow.

	Flow	Tonnes N-eq./ year 1998	Calculated uncertainty factor	Uncertainty range
i)	*waste treatment → water*	420	*/1.1	380 - 460
	land → water	a) 510	a) */1.8	a) 280 - 940
		b) 880	b) */1.9	b) 480 - 1600
ii)	*transport → air*	590	*/1.3	460 - 760
	Infrastructure → air	170	*/3.1	57 - 530

Table 2: Results on uncertainties and MFA for priority setting

3.2 On uncertainties and MFA for follow-up

The analysis shows (see table 3) that for small flows (ten or so) with very low data uncertainty (*/l.1) a relative small change in the same magnitude, the change remains significant even when data uncertainty is considered, although the exact size of the change remains uncertain. But for flows with low data uncertainty (here */l.2 and */1.3) but one magnitude larger (hundred or so) no certain increase or decrease can be stated.

Flow	Tonnes N-eq./ year		Calculated uncertainty factor	Uncertainty range	
	1995	1998		1995	1998
Industry → air	71	46	*/1.1	65-78	43-51
air → land	660	830	*/1.3	510 - 850	640-1100
Transport → air	750	590	*/1.2 and */1.3	610-940	460 - 760

Table 3: Results on uncertainties and MFA for follow-up. The flow *transport → air* has different calculated uncertainty factor for 1995 and 1998.

4. Discussion

4.1 Can the results be trusted?

When the flows that constitute the nitrogen metabolism are analysed without consideration of data uncertainties, it appears that certain conclusions can be drawn concerning relative importance for sources to the total load on the environment. But when data uncertainty is considered, the conclusions are not so given.

In the situation when MFA is used as a tool for priority setting the following can happen: Two flows that earlier seemed to be of the same importance, can in extreme situations vary so that any one of the two flows are twice as large as the compared flow. Moreover flows that seemed to be very different in mass may turn out to be equal.

In the first case where the flows *waste treatment → water* and *land → water* where compared, two things influence the result; choice of general data for the diffuse flow from land to water and the calculated uncertainty. The calculated uncertainty where higher for the diffuse flow *land → water* independent of what general data was used. This gives that the span of this flow is larger than for the point source emissions *waste treatment → water* and that the diffuse source in its extreme can be either lower or three times larger than the point source. Clearly there could be an important difference between these two flows even if they at first seems to be of the same importance. One conclusion from this study is that there are difficulties when comparing emissions from point sources with emissions from diffuse sources since the difference in data uncertainty more or less hinders the comparison. We try to compare apples with pears. Although a relative domination of the emissions from the diffuse source *land → water* could be argued for even if the data uncertainty are not known and then only based on the different general values.

In the situation when MFA is used as a tool for following up the following can happen: For flows (here the magnitude hundred and up) recorded from data with an uncertainty factor of */1.2 or higher, the change is no longer certain. What can be argued is a possible trend. Only when the data have very low uncertainty (*/1.1) a change remains significant even when data uncertainty is considered. In this study the low data uncertainty applies to emissions from point sources while emissions from diffuse sources have higher levels of uncertainty. Thus the usefulness of MFA for follow up is very limited for diffuse sources.

4.2 Implications for future data collection

Even if this is a limited study concerning only the nitrogen metabolism in the municipality of Västerås, it is indicated that much of the data used in MFA studies is of low quality (high uncertainty). Given the intentions to use MFA in environmental accounting, and particularly as a tool for priority setting and regular follow-up in environmental policy and management, it is obvious that data of higher quality (less uncertainty) has to be collected.

From this study we can see a particular need for better and/or new measurement (monitoring) programmes in relation to diffuse emissions, *e.g.* leakage from agricultural soils, emissions from traffic and working machines from the infrastructure sector. Since the emissions are diffuse they are hard to measure directly, thus there is a need for better simulations models. But these models need data input from monitoring programmes if they are to be used in environmental accounting.

5. Conclusion

Based on the analysis of data uncertainty in relation to the case study presented in this paper, it is concluded that to use MFA as a tool for priority setting and follow-up is associated with considerable difficulties. However, MFA is still a useful tool for screening in order to identify areas for further and more detailed investigation.

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