# Parallel Session C:
# MFA for Regional and Local Materials Management

# Material Flow Accounting and Information for Environmental Policies in the City of Stockholm

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## Abstract

This paper presents some thoughts on the use of material flow accounting (MFA) as a tool for providing information to the environmental policy making and management in a city. Examples are given from the early approaches to MFA made by the Environment and Health Protection Administration in Stockholm. Further, some results and experiences from a current research project on MFA and environmental information management at the municipal level are presented.

The different MFA-studies carried out in Stockholm were able to clarify a number of questions regarding the magnitudes of various nitrogen, phosphorus and metal related problems in Stockholm. Further, connections between economic activities in Stockholm on the one hand, and emissions and environmental pressure on the other hand, are to some extent identified and quantified. Thus, better opportunities for setting proper goals and priorities in local environmental management have been, and will be further achieved. This will also make it easier to adopt a more pro-active approach in local environmental management. The studies, especially the most recent, have provided information to allow a more fruitful discussion between different stakeholders in the city. This is of great importance since local Agenda 21 work started in Stockholm and elsewhere is needed in order to cope with those problems that, regarding nitrogen and phosphorus, are identified as the most important.

Keywords: Environmental Information; Local; Material Flow Accounting; Policy; Stockholm

## Introduction

The Swedish capital Stockholm is situated on the Swedish east coast, just at the outlet of Lake Mälaren to the Baltic Sea (Figure 1). In 1995, the number of residents in the city was just above 700 000. The number of residents in greater Stockholm, which consists of the city, the suburbs and the surrounding municipalities, was more than 1.5 millions. The main socio-economic activities in the city of Stockholm are finance, trade and other services. There is no agriculture and hardly any large industries.

Considering local environmental management in Stockholm, several tasks are assigned to the Environment and Health Protection Administration in Stockholm (EHPAS). In short, the assignment is to monitor and control the environmental and human health situation in Stockholm. According to Swedish environmental and health legislation, EHPAS supervises the handling of food, residence hygiene, public premises, and environmentally hazardous activities (e.g. industries). Since 1986, EHPAS is the supervising authority for all environmentally hazardous activities in Stockholm. This means that EHPAS is assigned with a task usually assigned to the County Administration Board, a regional state authority. Other tasks are air quality monitoring, noise controlling, prevention of cruelty against animals, and, last but not least, planning and co-ordinating the local environmental management work. It should be mentioned that water quality monitoring is not a task of EHPAS, but of the municipal water supply and treatment company.

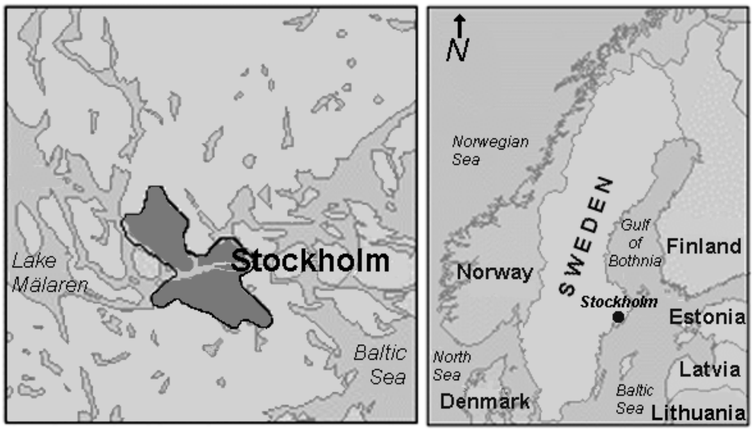


*Figure 1: The City of Stockholm.*

When the supervision of industries was delegated from the County Administration Board, EHPAS developed a data base for information on emissions from industries in Stockholm. Because of that, EPHAS has got a relatively good knowledge of emissions from industries.

Today there are, with some exceptions, no direct discharges of waste water to water recipients from households, industries or other activities in Stockholm. The waste water is led to municipal sewage treatment plants (STPs). Likewise, about half of the storm water is led to and treated in STPs. Because of this, the sewage sludge and outgoing water from STPs to a great extent mirrors the ‘leakage’ of different materials from the city.

## Early Approaches to MFA in the City of Stockholm

A comparison in the late 1980’s of the amounts of pollutants in waste water from the industries and the total load on the STPs revealed that the contribution from the industries was very small. This lead to the question: "Which are the most important contributing sources for pollutants to STPs? " The answer to this question is of great importance for the possibility to reduce e.g. the amount of metals in sewage sludge, and thus make it acceptable for application on arable land. Since the existing monitoring and control programmes could not answer the question, a new approach had to be taken in order to answer the question.

In 1989, some analyses of the sewage water from private households were made. They showed that private households was responsible for 10-50% of the total load of metals on the STPs. Also for several organic substances, the contribution from private households were significant. Analyses of storm water and studies on material corrosion also indicated that significant parts of the loads on the STPs were due to diffuse emissions. To compile the data and make a deeper analysis of the new information, EHPAS accomplished some rough material flow analyses for Cu, Cd, Cr, Pb, Hg, Zn and PCB in Stockholm. In Table 1 some interesting results from the flow analyses are listed.

Table 1: Some results from analyses of metals and PCB in Stockholm.

| Element | Results |
|---|---|
| | |
| Cu | Large releases of Cu from fresh water piping and copper roofs on buildings in the city. |
| | |
| Zn | Galvanised roofs and faces of houses, constructions, street furniture, electric pylons and wires are significant sources for releases of Zn. |
| | |
| Hg | Amalgam fillings of the inhabitants are a significant source for Hg-loads on the STPs and for Hg-emissions to the atmosphere. |
| | |
| Cd | The main inflow of Cd to Stockholm is the import of rechargeable batteries. |
| | |
| PCB | The main source for PCB emissions to the atmosphere and soils is the joint adhesive composition in houses made of concrete. |

These studies have clearly showed that private households, buildings and structures contribute to the greatest extent to the environmental pressure of metals and PCB in the Stockholm area. It was also concluded that for many substances of high priority in different plans-for-action, the most important sources to emissions were not the ones under control.

### Influencing Environmental Policies and Management in the City of Stockholm

The results from these 'early' material flow analyses have in different ways supported the environmental policy making in Stockholm:

- On basis of the results from the metal studies, some long and short-term goals on the issue 'chemical products and goods' in Stockholm's 4th environmental programme, 'Environment 2000', were formulated.
- A policy on local storm water treatment was adopted by several municipal administrations and companies. This policy contains e.g. requirements of storm water purifying equipment on copper roofs greater than 1000 m2. A comprehensive storm water policy is now being compiled.
- The city administration is soon to ratify a 'Programme on resource effective and environmentally adapted building', to be applied to all new building of dwellings on land owned by the city administration and companies (which is the greater part of the available land to build upon). The 'catalogue-of-action' of this programme contains several criteria to meet if one is to get land assignments for building. As examples of criteria could be mentioned that copper and zinc may not be used in roofs or faces unless the rainwater is treated, and that copper may not be used in piping.
- The PCB-analysis brought about further studies on leakage of PCB from joint composition in buildings made of concrete. Those studies indicated emissions of PCB from the joints to the soil and the atmosphere. Today, EHPAS is making inventories of buildings with PCB in joint adhesive composition.
- Results from the flow studies have also served as a basis for environmental criteria on some goods and products as a part of environmental guidelines for purchase by municipal administrations and companies.

## Environmental Management, Environmental Monitoring and Environmental Information Management in Stockholm

In September 1995, the Local Government adopted 'Environment 2000' as the 4th environmental programme for the city of Stockholm. It says that the local environmental management work in Stockholm is to be committed to the environmental goals proposed. Hence it is an important task to audit the fulfilment of environmental goals and to continuously review the environmental policies of the city. It is further mentioned that the control of material and energy flows, and the conservation of forests, green open spaces and fresh water are the fundaments for the future community planning. These fundaments are in different ways comprised in the local environmental goals, and will thus be the basis for the goal-oriented environmental management work.

In ‘Environment 2000’, environmental monitoring is identified as a key tool for providing the information necessary for auditing the fulfilment of environmental goals, and reviewing the environmental policies of the city. A recent study on the environmental monitoring system in Stockholm (Burström et al., 1997a) did however indicate shortages in the present monitoring system and the management of environmental information, such that a lot of information necessary for audits and reviews could not be provided. This is mainly due to lack of systems approach in the overall environmental management and monitoring. These problems are identified in other Swedish municipalities too (Brandt & Frostell, 1995; Brandt et al., 1997). As a consequence, there is a risk of sub-optimising actions on different environmental issues taken in Stockholm as well as in other Swedish municipalities.

To overcome these problems, local environmental monitoring and information management (i.e. collection, storage, analysis/interpretation, and presentation of data) has to be further developed. It has to be changed in character, especially with respect to goals, structure and parameters investigated, as the local environmental management work develops and changes in character. In order to cope with the environmental issues of today, which could also be seen as important sustainability issues, the entire metabolism of society and nature will have to be considered from a systems point of view in environmental management (cf. Ayres & Simonis, 1994). Thus, flows of matter and energy become increasingly important to monitor. As we see it, a system for regular material flow accounts could be a useful tool for the local environmental management, environmental monitoring and environmental information management, and thus needs to be developed.

## ComBox: A Model for Municipal Material Flow Accounting

From the experiences of the early approaches to material flow accounting in Stockholm, and the identified need of systems approach to environmental monitoring, a joint research project on local material flow accounting and environmental information management was launched in the beginning of 1996. One of the aims is to establish improved methods for monitoring and control of material and energy flows in the city of Stockholm, as a decision basis for planning and investments. The project is to a great extent based on the concept of the so called ComBox model, developed at the Royal Institute of Technology in Stockholm.

### The ComBox Model

The ComBox model, further described by Frostell et al. (1994 & 1997), has been established as to create an intellectual basis for further work and discussions on collection and dissemination of environmental information at the local political/administrative level. In the approach, traditional state-of-the-environment monitoring is combined with material flow accounting. To this date, only the flow part of the model is considered.

The model represents an open system which exchanges material, energy and information with its surroundings through the three sub-systems: air, society and water. The spatial system boundary consists of the geographical border of the local political and administrative unit, e.g. the municipality. This border is extrapolated into the atmosphere and the earth crust, thus forming a fictive box – a Community Box.

As mentioned, the in- and outflows to the system takes place in any of three interacting sub-systems. Of these, the sub-system society is further divided, and is represented as 12 sectors:

- Agriculture & Fishery
- Forestry
- Mining & Extraction
- Industry
- Food Supply
- Energy Supply
- Service
- Infrastructure
- Real Estate
- Transport
- Households
- Waste Management

The selection of sectors has been influenced by the Swedish Environmental Accounts. The reason to this is to contribute to the discussion on how to create a common structure for municipal material flow accounting in Sweden. This would facilitate comparisons between different municipalities, as well as making aggregation of information from the municipal level to the provincial and national level possible. The latter would be of great importance for the information supply to the Swedish Environmental Accounts.

Besides the three sub-systems in the ComBox model, there are two important storages included, namely land (incl. soil and vegetation) and sediments. The reason why these parts are not included as sub-systems in the overall model, is because no transport occurs in them. But as they serve as important sources and sinks for various flows, they are accounted for in the overall model.

## The Metabolism of Nitrogen and Phosphorus in the City of Stockholm

In connection to the work on developing a system for material flow accounting in Stockholm, we have analysed the metabolism of nitrogen and phosphorus in the city of Stockholm. One aim of the study was to present a comprehensive picture of the nitrogen and phosphorus flows in the city of Stockholm for one year (1995) as to give valuable information for the local management of nitrogen and phosphorus related environmental issues in the city Stockholm. The knowledge of the overall metabolism of these substances in Stockholm is of great importance for the city to take action against nitrogen and phosphorus related problems, and thus for the possibility to reach some of the goals in the local environmental programme. Despite heavy reductions of the discharges of nitrogen and phosphorus to the water recipient (Baltic Sea) from sources in Stockholm, the concentration of these substances in the inner parts of the eutrophication sensitive Stockholm archipelago are high according to the classifications from the Swedish EPA (EPHAS, 1997). Further, emissions of nitrogen to the atmosphere contribute to the deposition of nitrogen on land in Stockholm, that in several areas exceed the critical load level, and thus contributes to acidification of soils and lakes. The resource aspect of nitrogen and phosphorus is also relevant, as they are nutrients that can be used in agriculture. For relevant policies and priorities to be made on issues related to nitrogen and phosphorus, as well as other substances, in local environmental management, major and minor problems as well as responsibilities has to be identified. To do this, we assert that local environmental monitoring and information management have to give an answer to questions like the ones below.

- Which are the main sources and underlying causes of emissions today?
- Which are the possible sources for emissions tomorrow?
- Which are the main sinks for material flows, and how much is accumulated in the municipality?
- To what extent does activities in the municipality contribute to environmental pressures in the municipality?

- Does the municipality put more environmental pressure on its surroundings than the surroundings put on the municipality?
- What material flows may directly be influenced by the local community itself?

Our hypothesis is that questions like these can be answered by means of analysing the metabolism of the local community.

## Methods and Data

The quantification of nitrogen and phosphorus flows is made in the same way as in a study of the nitrogen metabolism of a Swedish rural municipality (Burström et al., 1997b). The assessment of the metabolism is to some extent based on available data for nitrogen and phosphorus flows in Stockholm 1995, i.e. data from existing environmental monitoring at the local, regional or national level with connection to Stockholm. The existing monitoring provides information on discharges to air from different sources, on discharges to water from large point sources, and on transportation within some watercourses. All other flows have been estimated by using different calculation models. The information needed as input to these models, e.g. food consumption and waste generation, was not provided by existing environmental monitoring programmes, and thus had to be collected from other sources. This information has been obtained from official statistics and scientific reports, by comparison with similar studies performed elsewhere, and to a great extent by personal communication with different companies, business organisations, experts, and employees at local, regional and national authorities.

## Some Results

The total turnover of fixed nitrogen in the city of Stockholm 1995 was app. 11600 tons (Figure 2), while the total turnover of phosphorus was app. 1100 tons (Figure 3). For both elements, the most significant inflows entered the society system. The flows entering the water and air systems were considerably lower, especially much lower for the air system. A significant import (and export) route for both nitrogen and phosphorus is the water system through Stockholm in the form of lake Mälaren, emptying into the Baltic Sea through the river Strömmen. App. half of Stockholm's nitrogen and phosphorus discharge to the Baltic Sea is imported through the lake Mälaren.

The flow charts (Figures 2 and 3) also show that for both nitrogen and phosphorus, the principal function of Stockholm is to import these substances with goods, foods and energy carriers and to spread them into the air and water systems. This is since the export of nitrogen and phosphorus through the air and water systems are considerably larger than the imports.

An important result of the study is that it identifies the most important sources and sinks for nitrogen and phosphorus in the city of Stockholm 1995. For nitrogen they were:

- the food consumption in private households and restaurants resulting in large nitrogen emissions to water;
- the transport sector causing nitrogen emissions to air through the combustion of fuels;
- the infrastructure sector with discharges of nitrogen to air from various types of combustion engines in work machines and vehicles;
- the energy supply sector by converting nitrogen in fuels to inert nitrogen gas.

and for phosphorus:

- the food consumption resulting in an export of phosphorus in municipal sludge;
- the service sector via import of phosphorus in detergents that end up in sewage sludge.

Further, the study have identified the dominant pathways for nitrogen and phosphorus flows through Stockholm. For both elements they were import -> food supply -> households -> waste management. From waste management and on, the fate of nitrogen and phosphorus differs.

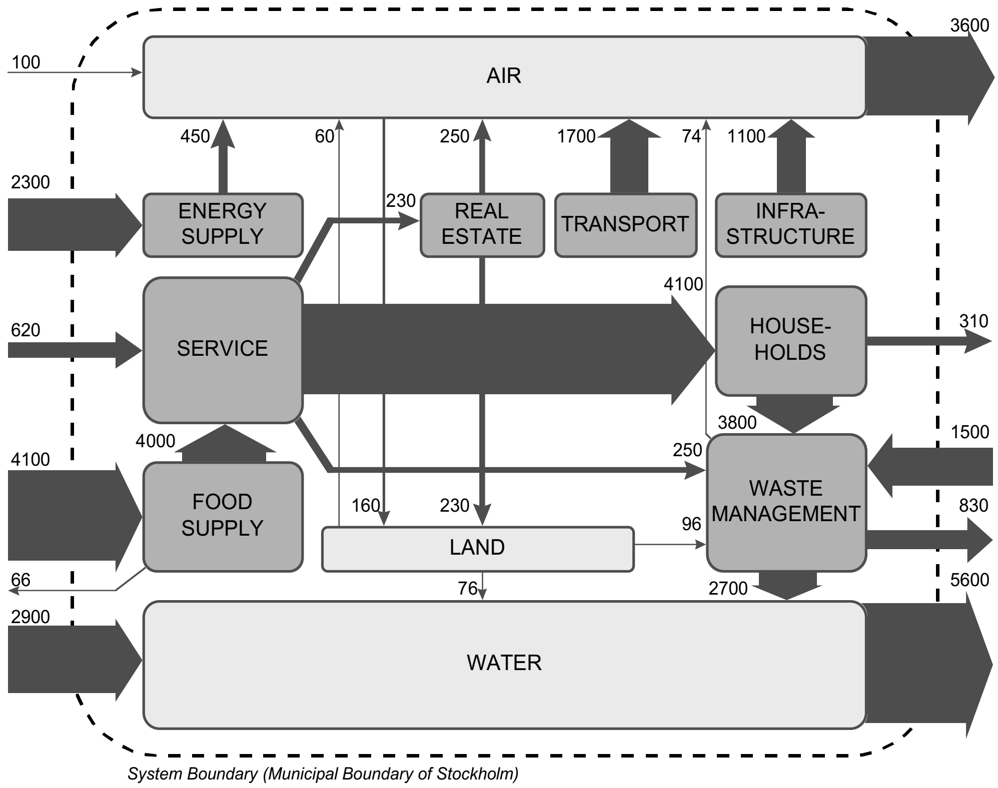


*Figure 2: Nitrogen Metabolism of the City of Stockholm 1995. Only flows >0.5% of the total turnover are shown, in tons N per year.*

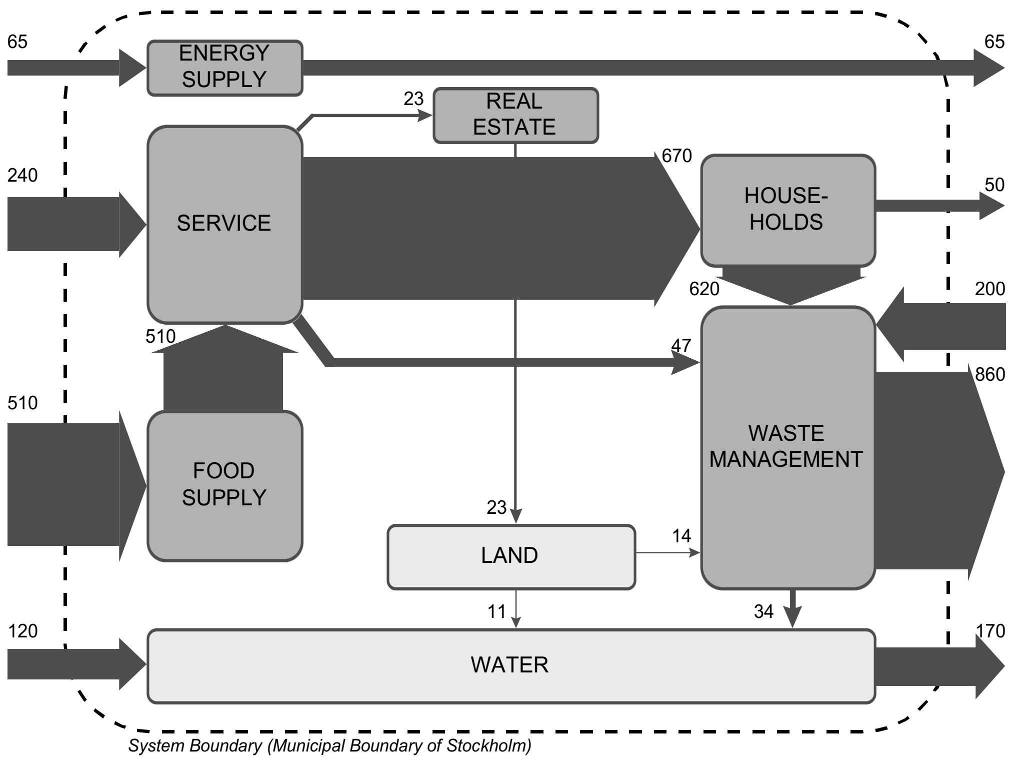


*Figure 3: Phosphorus Metabolism of the City of Stockholm 1995. Only flows >1% of the total turnover are shown, in tons P per year.*

The major part of the nitrogen flow, 84%, leaves the households in the municipal sewage water. Despite very modern treatment plants and a governmental bill from 1991 to install nitrification in coastal STPs, the assessments show that the overall nitrogen reduction in Stockholm was only 38% in 1995. This means that for every kg of food nitrogen, 0.62 kg is discharged to the Baltic Sea, contributing to eutrophication.

The dominant part of the phosphorus was precipitated with iron- and aluminium salts in the STPs and exported as sewage sludge. The overall phosphorus reduction in Stockholm in 1995 was app. 95%. The further fate of the phosphorus is an app. 60% application on farmland and 40% landfilling.

On the export side, the transport and infrastructure sectors are very important as sources for nitrogen emissions besides the above discussed food -> household -> waste management route. Here, NOX formation in combustion engines is the dominating pollution mechanism.

### Influencing Environmental Policies and Management in the City of Stockholm

Since these analyses are just completed, it is too early to tell how the results will influence the environmental policies and management in Stockholm. The analyses have however revealed a lot of information of great importance for the future environmental management, such that policy makers have to take it into account.

According to the flow analysis, the food supply system was the most significant import route for both nitrogen and phosphorus. This finding is of great significance, since the hidden nitrogen and phosphorus turnover are significantly higher. The losses of nitrogen and phosphorus in food production are app. 80% and 90% respectively (cf. Isermann, 1991). This means that dietary habits in Stockholm will be important to discuss with respect to an increased control of nitrogen and phosphorus flows in Stockholm as well as in other areas, where the food consumed in Stockholm is produced.

The flows analysed here are the direct ñ or primary ñ flows through Stockholm in 1995. For all activities in the city there are large secondary flows. A very good example is the food chain mentioned above, where food production represents a much higher turnover of nitrogen and phosphorus than does food consumption. Of great importance is that the city administration has only a limited decisive power over the primary flows and only very limited decisive power over the secondary flows. The principal areas where the city has a direct influence is the energy supply and waste management. In all other areas, the city has a more limited decisive power to exert. Our analysis emphasises the fact that the most important flows of nitrogen and phosphorus in Stockholm are determined by the life-style of the inhabitants, namely food habits and travel habits. This finding is of great importance for the city administration, since these flows may not be directly controlled by the city. Changes in life-styles may not be achieved by law, regulations, fees and taxes only. Discharge limitations for industrial enterprises and vehicles as well as various taxes and fees may be introduced, but to our opinion not efficient ones controlling driving and food consumption habits. Likewise, our investigation indicates that changes in these two areas are the most important measures to decrease the flows of nitrogen and phosphorus through the city of Stockholm and thus ultimately the load on the environment. Such changes will depend on life-style choices of the individuals. This in turn means that the local Agenda 21 work in Stockholm and elsewhere is very important. Thus, our study suggests that material flow accounting, e.g. according to the ComBox model, may also develop into an important instrument for the local Agenda 21 work.

## Conclusions from Studies on Material Flows in Stockholm

The different studies on material flows in Stockholm have revealed a lot of information of great importance for the local environmental management in Stockholm. By further analysis of the results, the following conclusions have been drawn.

- For several substances, the society sub-system of Stockholm works as a dissipator. This means that significant amounts of the substance in question dissipates from the system , i.e. the city.
- Diffuse sources are very important as sources for emissions to the environment.
- Private households and the personal life styles are important as the origin and source to emissions and environmental pressure of nitrogen and phosphorus.
- Different structures in Stockholm (i.e. buildings, roads etc.) are important as sources to emissions and environmental pressure of metals and PCB.
- The societal activities identified as most important origins to environmental pressure are to a great extent uncontrolled by present legislation or unsupervised by the environmental administration.

A great problem in the analyses carried out has been the scarcity of relevant information suitable for these types of analyses. This finding supports the conclusions about shortages in the present system for environmental monitoring and information management in Stockholm, mention earlier. It seems quite obvious that important changes in routines for collection, storage and processing of environmental information will be necessary in the city of Stockholm to accommodate regular analyses of this type. As is obvious from the nitrogen and phosphorus study, the society system is the most important import channel for nitrogen and phosphorus. This holds true also for metals and PCB. Information on these flows are at present not available on a routine basis. The establishment of improved collection routines for such statistical data would therefore be of much help.

### Contributions of MFA and the ComBox Model to Environmental Information Management in Stockholm

Our concerted experience of analysing material flows have made us see several advantages of MFA in general and the ComBox model in particular as a tool in local environmental monitoring and information management. Among the advantages to previous approaches to monitoring the following were realised in the analyses:

- The analyses carried out was able to clarify a number of questions regarding the magnitudes of various nitrogen, phosphorus and metal related problems in Stockholm. Thus, better opportunities for setting proper goals and priorities will be achieved.
- The connections between economic activities in Stockholm on the one hand, and emissions and environmental pressure on the other hand, are to some extent identified and quantified. This will make it easier to adopt a more pro-active approach to environmental management and to take action at the origins to the problems.
- The establishment of a concerted picture of the environmental problems in the municipality provides information to allow a more fruitful discussion between different stakeholders in the city (e.g. decision makers and citizens) as they will get the same information and the same picture of the overall situation.
- The specific information achieved through this type of analysis forms an excellent platform for further environmental work in the city, where more detailed analyses can be carried out with respect to composition of different flows and their environmental impact.

- The ComBox model provides a systematic structure to MFA and further to the management of environmental information. This will facilitate auditing of the city's environmental performance, and reviewing of the environmental policies of the city.

Another, very important experience from our work is the importance of a close co-operation between researchers and practitioners. We believe that this cross-breeding of practical experience and theoretical approach is necessary for the successful development and implementation of material flow accounting methods into the practical environmental management work.

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# Resource Management in the Federal State of Brandenburg

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The Brandenburg Ministry for Environment has carried out a research programme into strategies for sustainable development of areas typical for Brandenburg. The characteristics of the Land Brandenburg are:

- More lakes than all other states with a great variety of biotopes and species.
- Very low population density with 88 inhabitants/km2 - federal average 223 inhabitants/km2.
- Highest share of formerly military areas, comprising 8% of the total land surface.
- Grave changes in economic and scientific structures (unemployment July 1997: 17.7%; rosion of industrial research and develop up to 90%).

In July 1996 an invitation for tender of a research program on ”Concepts and approaches for a sustainable development of former military areas and underdeveloped rural regions in the Land Brandenburg was done by the Environmental Ministry together with the Ministries of Economics and Science. In these areas the need for employment creation is recognised as also being of central importance. 11 case-studies are being carried out. This specific regional knowledge will also inform the implementation of the State´s general technological strategy drawn up in 1994. The research programme - first results of which were presented in 1996 - explores a wide range of research areas:

- Sustainable resource use and creation of exemplary closed production cycles.
- Sustainable regional development, especially development of reference projects for conversion of military areas and structurally underdeveloped regions.
- Evaluation the transferability of concepts of sustainable development already implemented elsewhere.
- Analysis of necessary change of legal and other framework conditions.
- Encouragement of environmentally conscious production, consumption and lifestyles.
- Methodological work to evaluate sustainability.

In one of these projects the environmental Technology Reseach Group of the University of Potsdam has explored the starting points for sustainable material flow management in the district of Ostprignitz-Ruppin (Fig.1), a district almost as big as Saarland, with only 115 000 inhabitants, that means 46 inhabitants/km2, and a predominantly agricultural economic structure.

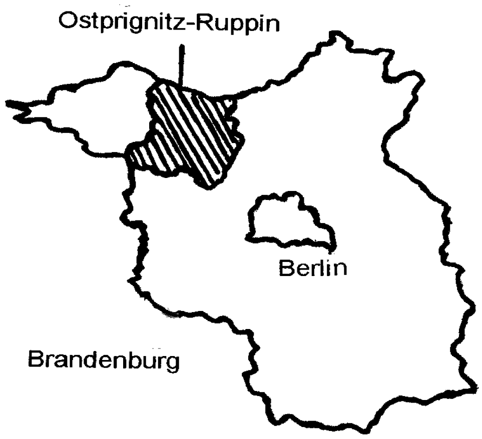


*Figure 1: The District Ostprignitz - Ruppin*

## Why did we chose this Methodology?

Concerning the idea of sustainable development we wanted to explore the possibility of developing a closed cycle supply for the needs of the region with the aim of reducing the global material flow and developing more economic activity in the region. Therefore it was necessary to measure the regional material flow. That is to say:

- production, recycling and consumption (term of transformation)
- disposal (term of reservoir)
- import and export of material and emissions (term of transport)

This methodology has many advantages, which have already been demonstarded in the previous chapters. One additional aspect seems to be very important in relation to regional studies: The results do not depend on incidental engagement and individual priorities, as we often find in Local Agenda 21 processes and they also do not depend on political targets, which influence the concepts of regional planing.

Advantages of Regional Material Flow Management for the Sustainable Development:

- Full description of the area
- Comparability of different regions
- Foundation to formulate and control targets of sustainability
- Results are less influenced by incidental engagement and individual priorities
- Proposals for action do not depend on political targets, which influence the concepts of regional planing

Open Questions:

- How to take into consideration the lack of data?
- How to find the “right size” of the area?
- How to deal with distortions caused by the integration into the national economy?

*Figure 2: Advantages of Regional Material Flow Management and Open Questions*

On the other hand there are some special problems of the regional material flow account which are not yet solved:

- Lots of data, especially production and consumption data is only available at national or state level.
- The "right" size of areas for material flow management can not be established independently but one has to take into consideration the goal, the methodology along with other sociological and geographical conditions. But to get any kind of data in fixing the size of an area one is dependant upon administrative boundaries.
- When doing material flow management on a smaller scale than that of the national, there is the risk of distortion, because the regions are not autarc: They are integrated into the national economy, so that processes that at the national level are sustainable may not recognised as such at the regional level. On the other hand, the fact of their economic weakness makes structurally weak regions appear to be sustainable managers of their resource base simply because the absence of economic activities. However, this neglects the hidden use of resources brought about by government transfers from richer regions with higher level of economic activity.

## So what did we find out about the Material Flow Account in Ostprignitz-Ruppin?

For a first evaluation we made up a strength-weakness-profile of the region from the available structure data. Some essential aspects are shown in figure 3. The German average is set at 100 and shown is data from Ostprignitz-Ruppin and from the average of the State of Brandenburg. There is:

- an obsolete structure of apartment buildings;
- high activities in construction on useful areas, especially in commission of public authorities;
- lots of employees in agriculture and forestry, average activities in trade, transport and services and few employees in manufacturing;
- low soil fertility and usability;
- average number of cars.

All in all the district “Ostprignitz-Ruppin” shows a typical structure for the State of Brandenburg with extremely obsolete apartment buildings, with a vacancy rate of 6%, especially high activity in public works and a very rural economic structure, which struggle with the bad conditions caused by the climate and the soil.

The structure of heating should also be mentioned (figure 4): A majority of one-familiy houses is still heated by coal. We expect that they will be renovated during the next few years.

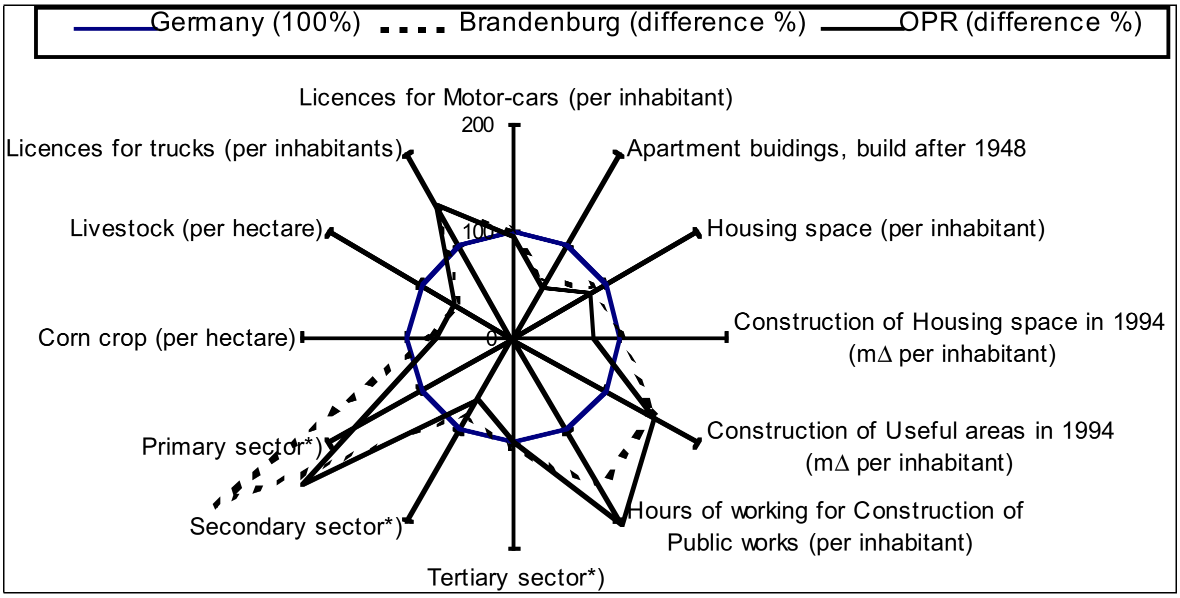


*Figure 3: Strength-Weakness-Profile of Ostprignitz-Ruppin*

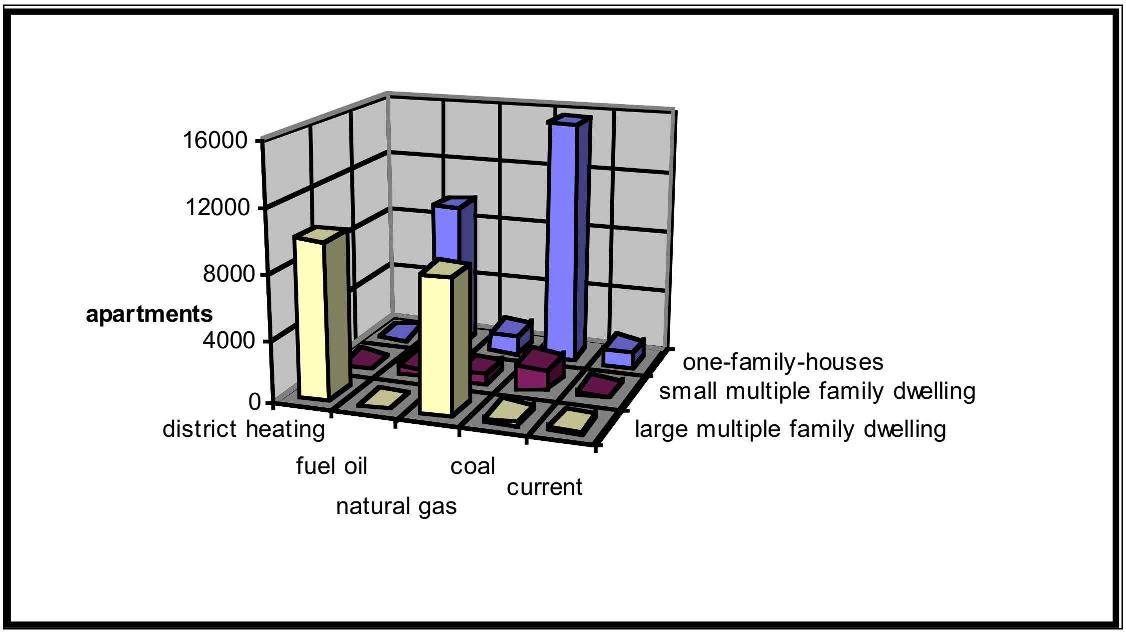


*Figure 4: Heating structure in Ostprignitz-Ruppin*

| | Consumption of private households | Production |
|---|---|---|
| Meat products | 5 400 | no data |
| Fish products | 150 | 300 |
| Eggs | 590 | 26 000 |
| Dairy Products | 4 900 | 65 000 |
| Friuts | 5 700 | 0 |
| Vegetables | 4 000 | (200 ha cultivation area) |
| Potatos | 3 600 | 52 000 |
| Crop and crop products | 5 700 | 147 000 |
| Exotic food | 3 000 | 0 |
| Textiles | 2 700 | 0 |
| Useful articles of high value | 6 600 | Few |
| Timber | No data | 118 000 |
| Coal | 65 000 | 0 |
| Natural Gas | 10 | 0 |
| Fuel oil and petrol | 80 000 | 0 |

*Figure 5: Material Flows in Ostprignitz-Ruppin (tonne per year)*

Additionally, we tried to estimate the material flow of the region. It was possible to compare the consumption of private households with that of production for a lot of materials. (figure 5). It shows that:

- the production of foodstuff is much higher than consumption – by approximately a factor of 10 to 30;
- figures relating to the consumption of wood are not available, but the amount of wood that was currently felled equals only approximately 40% of the yearly growth;
- the amount of fossil fuels was comparable with the felled wood;
- for consumer durables with high value and textiles only data from the state of Brandenburg was available, 70% of the mass of consumer durables with high value are motor-cars;
- the very low level of industrial production is also visible by the small amount of hazardous waste, which are only 17 kg per inhabitant, what is 20% of the average of the Brandenburg;
- material for construction and masses of buildings are not estimated but we are compiling data on this;
- the consumption of private households lead to 25,000 tonnes of municipal solid waste and 20,000 tonnes material for recycling.

All in all the district is characterised by a high biomass turnover and big imports of fossil fuels. The high activities in construction and the import of consumer durables lead to another use of resources from outside of the region.

## What does it mean for the Material Flow Management in Ostprignitz-Ruppin?

In order to come to some useful early conclusions a more thorough investigation is being undertaken on a specific material flow. It was chosen by the following criteria:

The Material Flow should ...

- be substantial in quantity and quality,
- have influence on the use of resources and area,
- be regarded as important by the local people,

- offer possibilities of economic development for the local people,
- contain the potential for co-operation with developing countries and not reduce the possibilities of development in other regions.

Because of the relevance in land use, energy supply and construction the material flow of wood was selected. Study of this material flow began in April 1997. This investigated the amount and source of wood burnt as fuel, the amount and source of wood used in construction, and the amount and source of wood employed in other activities. It further explored how the wood is used, and through which means a circulation oriented supply system in combination with a rational energy plan could be achieved.

There are a lot of interdependencies in the region:

- The area of forestry is so large per head of population that forestry waste wood alone could supply 60% of the private households with heating energy if the buildings were constructed according to the German Heat Insulation Act.
- The amount of wood which is currently felled equals approximately 40 % of the yearly wood growth.
- There is an high potential of wood waste in the obsolete buildings which may be demolished during the next years. The demolition of a pre 1918 three-storey-apartment building would deliver 100 tonne of waste wood.
- It would be possible to implement a regulation which would encourage the use of local materials in public construction projects.
- There are 120 small business for wood working in the district which could work together to close material cycles in the region.
- The expected replacement of coal fuelled heating systems offers an exceptional possibility for change.

The implementation of this switch should build on existing local activities. In addition to the material flow account of wood, we currently are in discussion with local people and organisations on practical ways to develop and implement a sustainable wood management system. The Ministry of Environment expects important insights for new and sustainable ways of producing added value and strategic recommendations of the Brandenburg Energy Concept with the reference to the use of biomass to the amount of 3% by the year 2010.

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# Planning Future Handling of Biodegradable Waste in the City of Stockholm Using MFA Combined with LCA

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## Abstract

Future treatment of biodegradable waste in the City of Stockholm has been analysed. We have used the approach of systems analysis. A static material/substance flow model, ORWARE, was used for calculating the studied system's outputs of emissions, residual products and energy, as well as necessary inputs of energy and other resources. Three future scenarios with emphasis on nutrients recycling were evaluated against the present situation. LCA technique was adopted for evaluating model results by aggregating substance flows to environmental impact categories.

Transports have shown to be of relatively low importance to the overall environmental impact, which is remarkable considering the geographical circumstances. Certain technical details, such as removal of NOx from combustion of landfill gas and biogas from anaerobic digestion, or utilisation of biogas for combined power and heating or heating only, are of significant importance. Adjacent systems, such as electric supply and district heating, are in some aspects crucial for the overall outcome of the study. The potential future impact of landfilling can not be ignored in comparison with more immediate impacts. Results from the study are however not unambiguous, and conclusions drawn will depend on prioritised goals.

The general experience from this project is that modelling of material flows can be a useful tool for decision support. The co-operation of different interested stakeholders brought about valuable exchange of information, and has been developing for those involved in the project.

Keywords: municipal waste management, organic waste, static modelling, material flow accounting, life cycle assessment, nutrient recycling, energy, environmental impact

## 1 Introduction

In agreement with national goals and goals set up in the work with Agenda 21, the Environment and Health Protection Administration in the City of Stockholm (EHPAS) has set up goals to increase the recycling of nutrients contained in biodegradable waste. Biodegradable waste is here defined as the biodegradable fraction in municipal and industrial waste and sewage. Aiming at a holistic perspective, the objective is to optimise the waste management system, taking into account regional structures for farming, energy support, sewage treatment, transports and environmental effects.

At present, the major part of the solid biodegradable waste generated in Stockholm is incinerated as a part of mixed municipal waste. Waste incineration with heat recovery delivers 500 to 600 GWh per year in Stockholm, mainly as district heating. Sewage sludge is, as far possible, spread as fertiliser on arable land. Because of quality limits and market limitations, only about 50% of the sludge is used for this purpose, the rest is landfilled.

There are no general solutions to meet the goal of increased recycling of nutrients, since the solutions must largely depend on local conditions. Being the largest city in Sweden, Stockholm will have to consider specific circumstances such as large amounts of organic waste generated, shortage of farmland suitable for recycling nutrients within its near surroundings and interdependencies between the waste management system and the energy system.

In early 1996, a joint research project was started to find guiding principles for the treatment of biodegradable waste in Stockholm. Participating institutions have been the Swedish Environmental Research Institute (IVL), the Royal Institute of Technology (KTH), the Swedish University of Agricultural Sciences (SLU) and the Swedish Institute for Agricultural Engineering (JTI). In addition, the EHPAS and companies engaged in waste management took active part in the work.

To avoid suboptimisations, it was essential to carry out a systematic analysis, which rendered possible a comparative assessment of various approaches to reach the goal of increased nutrient recycling. Static modelling of substance and material flows was used as a means to systematise the information. LCA-methodology was applied in the process of defining system boundaries and for environmental evaluation.

In this paper we summarise the most important results from the simulations of three future scenarios for handling biodegradable waste in Stockholm and discuss the policy relevance of the results obtained.

## 2 Methods

Two methods have been combined in this study, material flow analysis (MFA) and life cycle assessment (LCA). The ORWARE model (ORganic WAste REsearch) is a static material flow model, for simulating future scenarios of biodegradable waste management (Dalemo et al, 1997), Figure 1.

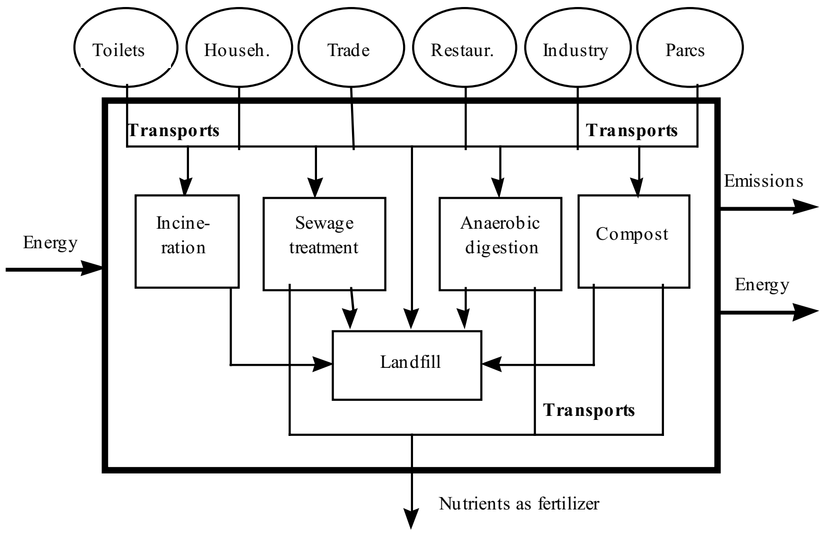


*Figure 1: Activities and system boundaries of the ORWARE-model.*

All physical flows within the system are described by the same vector, containing substances and materials that either cause environmental impact, or that are necessary for modelling the various waste treatment processes. The model calculates emissions to air, water and soil, energy turnover and resource consumption. The information generated by the ORWARE model can be viewed as corresponding to the inventory made in an LCA, although more detailed. Emissions from the system are classified and characterised according LCA methodology (Linfors et al, 1995). Another LCA concept which has been adopted is the one of functional units. Each functional unit should be fulfilled to the same extent in all scenarios to make them comparable. This has been a criterion when defining system boundaries.

### 2.1 Applying the ORWARE-Model to Stockholm

Four functional units were defined in this study. They are based on the benefits provided by the waste treatment system in Stockholm:

- An acceptable treatment of the biodegradable waste and sewage produced within the borders of the Stockholm municipality
- A certain amount of district heating produced
- A certain amount of bioavailable phosphorus spread on arable land
- A certain amount of bioavailable nitrogen spread on arable land

The system boundary of the ORWARE model is indicated by the inner boundary in Figure 2. Due to the chosen functional units, the system boundary was expanded to include some additional processes. This expansion is illustrated by the outer boundary in Figure 2.

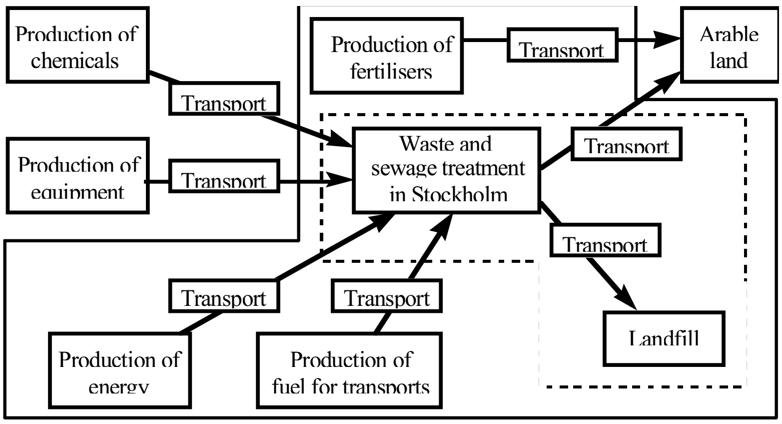


*Figure 2: System boundaries of the ORWARE model (inner dashed line) and the expanded boundary in this study (outer solid line).*

Additionally, the waste incineration facility in Stockholm should be utilised at its maximum capacity in all scenarios. This may be a rather short-term constraint of the system, but never the less a very interesting issue for the municipality of Stockholm. We assume 85% of the biodegradable fraction of the incinerated household waste to be source separated, leaving a certain capacity free to be used for incinerating other types of waste. If Stockholm decides to source separate its biodegradable waste, it is likely that the surrounding municipalities will act similarly. Therefore there will be a surplus of a so called residual household fraction in the near region of Stockholm, a drier fraction with higher energy content than the biodegradable fraction. This residual household fraction will be used in the simulations to fill in the extra capacity.

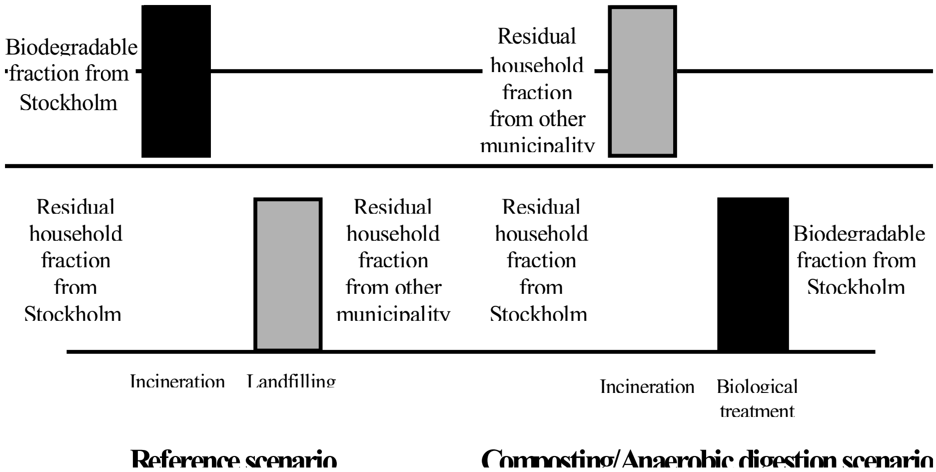


*Figure 3: Illustration of the effect of separating a certain amount of the biodegradable household waste from the incineration plant.*

### 2.2 Scenarios in the Stockholm Study

Four main scenarios have been simulated and evaluated. These are:

- Reference scenario, which illustrates the situation of today.
- Composting scenario, where suitable fractions are composted in a large scale reactor compost. The compost is spread as fertiliser.
- Anaerobic digestion, where suitable fractions are anaerobically treated with recovery of biogas. The digester sludge is spread as fertiliser.
- Urine separation, where human urine is collected separately and spread as fertiliser.

Scenario 2 and 3 illustrate alternative ways of treating the biodegradable fraction of solid waste. Scenario 4 illustrates an alternative to conventional sewage treatment.

In addition to the four main scenarios, several sub-scenarios, or variations of the main scenarios, have been run in order to investigate some of the assumptions made when designing the scenarios.

The model has been adjusted to local conditions in Stockholm concerning waste amounts and the performance of the existing treatment plants. This was done in co-operation with technical personnel, by interviews with companies, stakeholders and the municipality.

## 3 Results

The results are presented as to what degree the functional units are fulfilled within the waste management system, potential environmental impact, spreading of metals, resource consumption and quality of the residual products.

The results are better understood if some important circumstances in the scenarios are first explained.

i) The waste incineration facility is utilised at its maximum permitted capacity in all scenarios. In the composting and anaerobic digestion scenarios, a so called residual household fraction is incinerated in place of the out sorted biodegradable fraction, generating more district heating, electricity and emissions than in the reference scenario. The residual household fraction is landfilled in the reference and urine separation scenarios, generating landfill emissions.

ii) In the anaerobic digestion scenario, the produced biogas will further increase generation of district heating.

iii) Increased nutrients recycling in all future scenarios results in less need for industrial production of fertiliser.

## 3.1 Functional Units

Each functional unit is dimensioned by the scenario providing the biggest amount of that utility within the waste management system. All other scenarios will provide less than 100% of that functional unit, and are complemented by activities external to the waste management system to fulfil the functional units.

Table 1: Extent of functional units that are provided by the waste management system (WMS). 100% corresponds to: phosphorus, 410 ton/year; nitrogen, 1 980 ton/year; district heating, 11(108 MJ/year. Net electricity consumption is not a functional unit, and is therefore reported in absolute amounts.

| Scenario | Phosphorus | Nitrogen | District heating | Net electricity consumption |
|---|---|---|---|---|
| | % of functional unit produced within WMS | | | MJ/year |
| Reference | 71 | 9 | 31 | 3.2*106 |
| Compost | 90 | 16 | 98 | 1.2*108 |
| Anaerobic digestion | 88 | 23 | 100 | 3.7*102 |
| Urine separation | 100 | 100 | 32 | 1.1*103 |

## 3.2 Resource Consumption

Use of primary energy resources, material, water and land should be included in an LCA. The extended ORWARE-model includes use of primary energy resources, water and direct consumption of chemicals, but not land, production of chemicals and material in equipment. Here, we only report primary energy resource consumption.

Table 2: Primary energy resource consumption (total amount of resource extracted from the earth's crust) as compared to the reference scenario.

| | Scenario | | |
|---|---|---|---|
| Primary resource type | Compost | Anaerobic digestion | Urine separation |
| Non-renewable | | | |
| Coal | 0 | - - | - |
| Oil | - - | - - | 0 |
| Natural gas | 0 | - | - - |
| Uranium | 0 | - - | - |
| Peat | 0 | - - | - |
| Renewable | | | |
| Water power | 0 | - - | - |
| Biofuel | 0 | - - | - |

| | |
|---|---|
| 0 | 0 to 10% increase or decrease in primary energy resource consumption |
| + or - | 10 to 50% increase or decrease in primary energy resource consumption |
| ++ or - - | 50% or more increase or decrease in primary energy resource consumption |

Electricity and district heating is partly delivered from waste incineration, biogas and landfill gas. When there is a need for extra delivery, electricity is produced using the Swedish average mix of oil, natural gas, coal, uranium, peat, water power and biofuel (Brännström-Norberg, 1996 and Dethlefsen, 1997). District heating is produced by incineration of oil.

### 3.3 Environmental Impacts

Ecotoxicity is excluded in Table 3. Today there is no robust method for calculating this environmental impact (Linfors, 1997). There are also data gaps in the modelling of hazardous organic compounds in the ORWARE-model. In our view, it is therefore more relevant to evaluate only the fate of specific heavy metals, instead of aggregated measures of ecotoxicity. The impact category "human health effects" is considered sufficiently robust for comparisons between scenarios, whereas absolute values should be treated with care. Human health effects from air emissions outweigh those from water and soil emissions, which therefore are not reported either.

Long term effects comprise emissions from the landfilling, mainly leaching of heavy metals and nutrients and methane emissions. These are reported separately due to the uncertainty associated with the prediction of future landfill emissions.

Table 3: Potential environmental impact from the three main future scenarios as compared to the reference scenario. 1

| | Scenario | | | | | |
|---|---|---|---|---|---|---|
| Potential environmental | Composting | | Anaerobic digestion | | Urine separation | |
| impact | short term2 | long term3 | short term | long term | short term | long term |
| Acidification | 0 | n. e. 4 | + | n. e. | + | n. e. |
| Eutrophication | 0 | - | 0 | - | - - | - |
| Global warming | - | - - | - - | - - | - - | 0 |
| Photo-oxidants, org. comp. | - | - - | - | - - | + | 0 |
| Photo-oxidants, NOx | 0 | n. e. | + | n. e. | + | n. e. |
| Human health, air emissions | 0 | n. e. | + | n. e. | + | n. e. |

0 0 to 10% increase or decrease in potential environmental impact
+ or - 10 to 50% increase or decrease in potential environmental impact
++ or - - 50% or more increase or decrease in potential environmental impact
2potential effect from all activities within the extended system, and 100 years of landfill emissions
3potential effect from all activities within the extended system, including all future landfill emissions
4n. e. = no effect other than the short term perspective

Statements about increased or decreased environmental impacts are meant as compared to the reference scenario. As composting and anaerobic digestion are alternative means of treating solid biodegradable waste, these two scenarios can also be compared with one another. The urine separation scenario is not to be compared with the two former ones, as it deals with alternative means of treating liquid waste.

Note that the results in Table 3 are only a direct compilation of simulation results. They do not stand for themselves, but should be complemented with explanations of the underlying reasons and possible variations of each outcome, as well as the results obtained in the sub-scenarios. These aspects will not be illustrated in this text, as its intention is more to focus on conclusions than on analysis.

### 3.4 Metals

In all studied scenarios, heavy metals are spread by two main routes. They will end up either in the landfill, or as contaminants in the residual products. In Table 4 the total metal inflow in all scenarios and distribution in the reference scenario is described.

Table 4: Total inflow of heavy metals in all scenarios (kg/year) and distribution of heavy metals to different media in the reference scenario (% of total inflow) 1.

| | All scenarios | Reference scenario | | | |
|---|---|---|---|---|---|
| Metal | Total inflow | Landfill | Air, incineration | Water, sewage treatment | Soil, sewage sludge |
| | kg/year | % | % | % | % |
| Pb | 34000 | 98 | 0 | 0.2 | 1.6 |
| Ni | 7000 | 75 | 0 | 22 | 3.3 |
| Cu | 40000 | 89 | 0 | 2 | 8.5 |
| Zn | 110000 | 91 | 0 | 5 | 4.7 |
| Cd | 720 | 97 | 0 | 0.3 | 2.2 |
| Cr | 7700 | 93 | 0.03 | 2.5 | 4.7 |
| Hg | 100 | 75 | 0.03 | 5.7 | 19 |

1 A minor part of all metals end up in compost from local composting of park waste included in the reference scenario. This is excluded because of its minor importance.

The major part of the metals entering the system do not originate from the biodegradable waste fractions, but from the residual household fraction. Therefore, there are no major differences in the distribution of metals in the future scenarios. The metals in the residual household fraction are landfilled either as a part of slag and flyash, or as untreated waste. There is however one new type of residual product in each scenario. Compost and digester sludge contain 0.6-3.5% of all metals entering the system. Urine contains only 0.02-0.4% of all metals entering the system.

### 3.5 Quality of Residual Products

The residual products obtained in the different scenarios are intended to be used as fertilisers. As such, they will contribute to the successive contamination of arable land, due to their metal content. In Table 5, each residual product is compared to quality standards set up by the Swedish EPA for sewage sludge for year 2000.

Table 5: Quality of the produced residual products in the different scenarios related to the future quality standard for sludge according to the Swedish EPA. The calculation is done based on a dosage of 20 kg P/ha.

| Metal | Sewage sludge, without urinesep. | Sewage sludge, with urinesep. | Reactor compost | Anaerobic digester sludge | Urine |
|---|---|---|---|---|---|
| | (% of maximum limit, at 20 kg P/hectare) | | | | |
| Pb | 150 | 230 | 550 | 560 | 2 |
| Ni | 60 | 100 | 128 | 110 | 10 |
| Cu | 77 | 120 | 120 | 120 | 1 |
| Zn | 60 | 90 | 70 | 60 | 2 |
| Cd | 140 | 220 | 180 | 160 | 5 |
| Cr | 62 | 94 | 126 | 100 | 2 |
| Hg | 90 | 138 | 10 | 7 | 1 |

# 4 Discussion

## 4.1 Fertilisers and Energy

Recycling of phosphorous is fairly large in the reference scenario, 42%, and does not increase much in any of the future scenarios, see Table 1. At most, 66% of is recycled in the urine separation scenario. Therefore, industrial production of phosphorous fertiliser causes very small changes of the emissions in all future scenarios. Recycling of nitrogen does not increase much in the composting and anaerobic digestion scenarios, but is significantly higher in the urine separation scenario. Therefore, industrial production of nitrogen fertilisers causes very small changes of the emissions in the composting and anaerobic digestion scenarios, but does influence emissions contributing to global warming, acidification, human health and photo oxidant formation in the urine separation scenario.

As none of the calculated environmental impacts are significantly influenced by industrial production of phosphorous fertilisers, recycling of phosphorous in biodegradable waste is mainly a question of saving a potentially scarce resource, and preventing environmental impact from leakage of phosphorous from landfills. Recycling nitrogen, on the other hand, is not a question of saving nitrogen as a resource, but avoiding unwanted leakage of nitrogen and avoiding impacts caused by industrial production of nitrogen fertiliser.

In the composting and anaerobic digestion scenarios, with the defined system boundaries, the total utilisation of energy in household waste is increased. Due to this, the results of these two scenarios in comparison to the reference scenario are largely influenced by energy supply systems. For example, using biofuel for producing district heating or introducing better technique for NOx-removal, may alter the results by changing the conditions in the reference scenario in a crucial way. The urine separation scenario has very little influence on energy supply.

## 4.2 Environmental Impact

As the environmental impact categories are only summarised in Table 3, but not discussed and explained, a lot of important information will not be revealed to the reader. Disregarding this, based on the results from the main scenarios and the sub-scenarios, we argue that increased recycling of nutrients in solid biodegradable waste can be introduced, giving positive effects on all environmental impacts considered in Table 3. On the other hand, urine separation can not yet be introduced without increasing environmental impact.

## 4.3 Metals

As long as source separated biodegradable waste and sewage sludge are contaminated with metals, increased recycling of nutrients will inevitably increase spreading of metals on arable land. At present, the only residual product which will be accepted for spreading by the year 2000, is urine. If other residual products are to be recycled, something must be done to reduce their degree of contamination. Only if one believes this to be possible, evaluating the other impacts will be meaningful.

## 4.4 Relating to Total Emissions in Stockholm

The results can be viewed and discussed in different contexts with different aims. Either the small scale, finding what activities related to the management of biodegradable waste contribute the most to the different environmental impacts. Or the large scale, finding the system exerting the lowest overall environmental impact. In order to achieve the latter, it is not sufficient to consider the results as presented above, but one must somehow rank the importance of each category relative the others. To do this, the results from the simulations can be related to the amounts of emissions or material flows in Stockholm as a whole. Relating the results from the reference scenario to these total flows, will give a hint of what is important and what is not.

In order to make relevant comparisons, we analyse what substances contribute the most to the various impacts. These are then related to total flows/emissions. This summary also gives a good picture of the small scale context as described above.

Table 6: Major contributing emissions for each environmental impact and their major sources in the reference scenario; entire system and actual waste management system (WMS).

| | Actual WMS | | Entire reference scenario | |
|---|---|---|---|---|
| Environmental impact | Major contributing emission | Major contributing activity | Major contributing emission | Major contributing activity |
| Acidification | $NH_3$ | sludge storage | NOx | district heating |
| Eutrophication | $NO_3^-$, $NH_4^+$, P | sewage treatment | same as WMS | same as WMS |
| Global warming | VOC incl $CH_4$ | landfilling | fossil $CO_2$ | district heating |
| Photo-oxidants, org. comp. | VOC incl $CH_4$ | landfilling | same as WMS | same as WMS |
| Photo-oxidants, NOx | NOx | waste collection, transports, burning biogas | NOx | district heating |
| Human health, air emissions | SOx, NOx | burning landfill gas, transports | NOx, SOx | district heating, burning landfill gas |

This summary suggests that $NH_3$/ $NH_4^+$, $NO_3^-$, P, VOC including $CH_4$, NOx, SOx and fossil $CO_2$ should be examined further by relating to total emissions in Stockholm. It should be noticed that emissions of ecotoxicological importance are not examined.

The system boundary of total material flows through Stockholm does not correspond entirely with the system boundary in this study. Our analysis is not strictly limited to the geographical boundaries of Stockholm. Thus, emissions that partly occur outside Stockholm, can not be used to calculate to what extent the management of organic waste contributes to total emissions. Relating the two to each other will however give a good hint of its relative importance. Excluding all external activities in the comparison would give a false picture of waste related emissions. For clarity, emissions from the actual waste management system and external activities, are reported separately.

Table 7: Some examples of relating material flows from the waste management system to total flows from Stockholm.

| Emission | Total in Stockholm [tons] | External activities [tons] | Waste system, not landfill [tons] | Landfill, surveyable time [tons] | Landfill, infinite time [tons] | Total [tons] [3] | Importance [% of total in Stockholm] |
|---|---|---|---|---|---|---|---|
| P, total outflow | 1 145 [1] | 0 | 322 | 2 | 404 | 728 | 64 |
| N, total outflow | 10 390 [1] | 30 | 3 260 | 67 | 76 | 3 433 | 33 |
| fossil $CO_2$ | 2 500 000 [2] | 7 330 | 2 710 | 0 | 9 700 | 20 740 | 1 |

1 In 1997 (Burström et al., 1997)

2 In 1992 (EHPAS, 1995)

3 Emissions do not necessarily occur in Stockholm. The landfills are for example located outside Stockholm.

Total material flows are scarcely calculated in Stockholm. Therefore we so far only outline a possible way of structuring the data. The waste management system apparently plays a significant role in the metabolism of phosphorous and nitrogen in Stockholm. Emissions of fossil CO2, on the other hand, should be of very little importance when evaluating the waste management system. This comparison should however be done for all emissions that are to be prioritised according to Table 6.

### 4.5 Policy Relevance

The ORWARE-tool has been applied in a small town (Dalemo et al, 1997), a rural region (Oostra, 1996), and now a large city. Combining MFA and LCA methodology has proven to be a useful means to widen the basis for strategic decisions concerning management of biodegradable waste in communities or regions.

Specific results from a case study are not generally applicable, and the results from one region can not serve to guide in decisions for another. This becomes evident for example when realising the major influence of the existing waste incineration facility in Stockholm. Specific results from one region can however be used for understanding more of the complexity of management of biodegradable waste. Some general conclusions may possibly also be drawn about what parts are more or less important for different impacts.

Apart from specific results in the case study in Stockholm, the policy relevance of the ORWARE-model depends on how the results can be utilised and what side effects the project brings about. The approach systematises existing knowledge and helps to point out critical questions when discussing future waste and sewage treatment systems. Working with scenarios is also a good way to better understanding of yet untested solutions and systems. The modularity of the ORWARE-model, enabled by the MFA approach, makes scenario building rather straightforward. Close co-operation with different stakeholders and practitioners gave the benefits of combining research with practical experiences, as well as improving communication between different stakeholders in the municipality.

## Acknowledgements

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# Towards a Sustainable Company: Resource Management at the "Kambium Furniture Workshop Inc."

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## 1. Introduction

In appendix 1D of the EEC-Audit-Ordinance[1]"good management practices", both the direct environmental effects of running a business as well as the life cycle spanning burdens associated with the environmental effects of the products should be taken into consideration in an environmental management system. Which method should be employed in the assessment and analysis of the product line-wide environmental effects and how the results of such an analysis are to be integrated into an environmental management system is left open.

In light of the very high number of materials transformed in the context of production - or at one production site - a consideration of the life cycle wide view of the environmental stress intensities seems highly complex if not altogether impossible. The experiences of many firms and professional associations with product line derived environmental analyses (Schmitz et al. 1995, Mallay/Pfriem 1993, Umweltbundesamt 1992, Schmidt-Bleek/Liedtke 1995a, SETAC 1992) to date cause businesses to hesitate for reasons of both cost and time about considering this recommendation in the context of their EEC-audit procedures. It is becoming apparent that the rather weakly phrased requirement in the ordinance, to consider environmental aspects from the perspective of product lines, will often not take place in the environmental management procedures of businesses.

A prerequisite for the development of a sustainable economy is that wealth/well-being and social security can be provided with one tenth the level of resource consumption of today (Schmidt-Bleek 1994). For industrial production of goods and services, this does not mean that the resource productivity of every single process or every individual phase of the life cycle must be drastically increased (Liedtke/Schmidt-Bleek 1995b) but rather that the resource consumption in societies should be reduced by as much as possible across the board. In the big picture, it may turn out to be ecologically preferable to "invest" more resources at particular points in the life cycle of a product, in order to increase the resource productivity across the entire life cycle. This is most often the case with durable goods such as office furniture out of stainless steel or wood furniture in general, pipes, bridges or large architectural constructions. Besides exhausting the technical potential for efficiency increases, a fundamental "revisioning of our concept of use" (Bierter 1995, Hopfenbeck/Jasch 1995, Schmidt-Bleek/Tischner 1995, Sachs 1994) is in order: a deliberate and conscious shift toward a dematerialized consumer culture throughout all areas of life. The consideration of product line derived environmental aspects in environmental management systems of those firms participating in a given product line is decisive, as this is the only manner in which the potential for dematerialization can be fully utilized. For individual firms this is an injunction to undertake the greatest possible measures toward influencing how material and energy is used both upstream and downstream. This is the ecological equivalent of the familiar injunction to minimize the costs to the final consumer.

1 Verordnung (EWG) Nr. 1836/93 des Rates vom 29. Juni 1993 über die freiwillige Beteiligung gewerblicher Unternehmen an einem Gemeinschaftssystem für das Umweltmanagement und die Umweltbetriebsprüfung, Amtsblatt der Europäischen Gemeinschaften Nr. L 168/1. In the international discussion about the EU-Audit-Ordinance the abbreviation EMAS is commonly used, which stands for "Environmental Management and Audit Scheme."

Scientists estimate (International Factor-10-Club 1994) that the important changes to how we run our economies will have to have occurred by the middle of the next century, unless we are willing to run the risk of threatening human life as we know it beyond the point of no return. It is therefore imperative to ensure that in the development processes of industrialized nations the necessary improvements in resource productivity are begun as soon as possible. In the context of "developmental assistance," the development of dematerialized infrastructures for less industrialized nations should be made a central issue: not the materially intensive and resource wasting systems of the industrialized nations in the areas of construction, transport, communication and energy should be promoted as high tech; instead the ideas underlying service oriented, resource saving technologies are the market of the future, which, in regionalized market structures, can be utilized by countries as they need them. The earth won't be able to cope with another materially intensive industrial development as has occurred in the North over the past century.

In order to operationalize such an "environmental goal" it appears useful - in light of the multitude and diversity of the goods on today's markets and their complex chemical composition - to use a system like the "Chemikaliengesetz" (Germany's laws governing the use of chemicals) to arrange a step-process which would augment the environmental compatibility assessment of goods by a directionally stable procedure as a rough first approximation.

### 1.1 The MIPS Concept

The resource productivity can be defined as the amount of use (or service) associated with, or derived from, a given amount of energy and material, and with reference to the total life cycle of the "service delivery machines" (Schmidt-Bleek 1994) employed toward that end. In so doing, each raw material, intermediate, or end product that is employed is paired with an "ecological rucksack," consisting of the weighted sum of all matter and energy used for its production-from cradle to grave. In this manner the environmental quality (associated with the resource effort) of all functionally equivalent goods or production sites can be compared directly. Whatever knowledge about the human - or eco-toxicity of materials involved that is available is to be included in all decision making processes - which is generally already required by law.

The inverse of the resource productivity is the material input per service unit, or MIPS. The material input (including energy and transport intensities (Manstein 1995a, Stiller 1995a, 1995b)) reflects all the material displaced with the help of technology in nature in either kg or t, and with reference to a service provided. An example would be the sum total of all resources which were afforded on a life cycle wide basis for a person-kilometer in an automobile.

The material input is summarized in five different statistical categories.

- abiotic raw materials
- biotic raw materials
- earth movements in forestry and agriculture
- water, and
- air.

The material intensity in each respective category contains the material or resource input per t of material or specific product weight. Seven tons of abiotic raw materials, for instance, per t of sheet steel, or 88 t abiotic raw materials per 110 kV reinforced concrete power pole (Merten et al. 1995). The ecological rucksack, on the other hand, represents the resource consumption without the tare weight of the material or product in question. In the case of the sheet steel, (MIabiotic raw materials = 7t/t) the ecological rucksack of abiotic raw materials weighs 6 t (7 t abiotic resource consumption minus 1 t tare weight of abiotic raw materials).

MIPS can be used to analyze both durable and less durable goods and in principle it can also be used to examine complex facilities and infrastructures.

With the help of the indicator “resource productivity” it is possible to identify sustainable market niches for materials and products. In this context we use the term sustainable to denote a marriage between what is economically feasible and ecologically necessary.

### 1.2 Offensive Environmental Management and Competition

The concept of offensive environmental management is worthwhile for businesses in both an economic and an ecological sense, as it enables them to avoid negative environmental consequences in advance, where this is possible, and thereby seeks to reduce the costs of environmental protection.

How then is a sustainable economy to be conceptualized, which uses competition to cost effectively introduce and establish socially and ecologically sound products on the market?

Socially sound implies a product or system which is tailored to specifically meet the service demanded.

In examining the ecological measures in a business, the emphasis should rest on performance. In contrast to the usual systematics (Porter 1989, 1990) of “cost drivers,” cost disadvantages and failure, it is necessary to identify “value drivers” that lead to competitive advantages-permitting firms to be both sustainable and successful. The ecological focus of management provides such a “value driver” (Zäpfel 1989). An early entry into a position of ecological leadership as a value driver enables a business to erect barriers to entry. In addition, legislative requirements are surpassed, giving the consumer an idea of what is ecologically feasible. Potential competitors, unable to meet the standards which result from such a performance are no longer a threat to the leader. Furthermore, it might be possible to identify customers particularly concerned about the environment among the clientele of the competition. In a focused strategy these consumers could then be wooed with exceptional ecologically sound products from the company discussed here. Under the right circumstances, this could even foster higher prices, justified by the increased utility to the consumer. Ecological production management can thus support both product differentiation and focusing strategies, making it an effective instrument in the context of competition. Such a strategy is being pursued by the Kambium Furniture Workshop, Inc., which is participating in this project. For this reason, this business and its production concept are particularly suited to the task of showing how a position of ecological leadership is both a factor in competition and a value driver.

In order to make a mark in the market of sustainable products and environmentally sound production, businesses must first show that they are able to effectively and successfully implement such a strategy. Besides the already mentioned procedure for determining the life cycle wide resource productivity of products and services as an ecological indicator, businesses require information on how they can set up a cost and eco-efficient environmental management system at their site.

With the ordinance (EWG) No. 1836/93 of June 29, 1993 on the voluntary participation of commercial enterprises in a joint system for environmental management and environmental audits (the EEC-Audit-Ordinance) the EEC commission has created an instrument, evolved through political negotiation, which, despite all the criticism, has successfully delivered on its promise of an offensive environmental management which doubles as a strategic performance factor.

As the first such instrument on a European scale, the ordinance provides the opportunity of developing a management system that attempts, through the use of preventative policy measures and strategies, to avoid cumulative environmental costs, while improving, or at least stabilizing, the profitability of a business.

The objective of this study is to find evidence of this by way of the environmental audit of a small business, the Kambium Furniture Workshop, Inc.

The resource management program developed at the Wuppertal Institut on the basis of the MIPS concept of Prof. F. Schmidt-Bleek represents the foundational instrument for a product line derived and site specific environmental analysis. It combines the firm's input-output analysis with a product line spanning analysis of resource demands as well as with a firm's cost accounting procedures. Consequently the study contains - on the basis of the MIPS concept - both a delineation of the operational as well as of the product-centered analysis of the environmental consequences associated with the production spheres.

The goals are,

- to test on site the degree to which the aforementioned ecological assessment instrument MIPS is operationalizable and whether it satisfies the product line and firm specific demands of the ordinance;
- to figure out ways for small and medium sized firms to minimize the costs of obtaining the desired certification while gaining the highest possible level of information about the environmental management system that is to be installed as well as about the environmental stress intensity of their products;
- to specify a resource management strategy for the Kambium company that permits the determination of specific methods for firm specific material flow management and ecological design, incorporating alternative modes of product use, as well as of firm specific environmental management, and
- to compile possible improvement suggestions for revisioning the EEC-Audit-Ordinance 1998.

## 2. Eco-Audit & Resource Management at the Kambium Furniture Workshop, Inc.

Kambium-a company presents itself

The Kambium Furniture Workshop, Inc. is a small to medium sized business with a payroll of about 35 and a fairly horizontal organizational structure, typical for a business of this size. In 1994, roughly 120 kitchens, as well as a few other pieces of furniture, were produced, yielding a turnover of 5.5 million DM. The kitchens are made of solid wood, and are produced and marketed with the highest standards of environmental compatibility in mind.

The choice of a site suitable for the use of wind energy as well as the architectural and energy concepts employed in the company structures (wind turbine, cogeneration, ecologically mindful construction methods) and the approaches to product and production methods and direct marketing (local markets within a 100km radius and the avoidance of transport packaging) all point to a deep commitment to principles of environmental compatibility.

Kambium kitchens are situated at the high end of the market in every respect. The use of modern computer technologies (CAD and CNC) facilitates the production of very individual kitchens, tailored to the customer's specifications.The primary material is wood from European sources (shorter transport routes).

The methods employed in the assembly is a derivation of the traditional "Hirnleistenbauweise" which guarantees integral structural stability, despite the characteristic of solid wood to shrink and swell over time.

Kambium kitchen

The use of paint is avoided entirely - the furniture surfaces are impregnated with natural oils.

Kambium kitchens are particularly durable. Obsolescence does not figure into the company's scheme, i.e., as long as the company is in business, reorders, repairs as well as conversions and modifications always remain possible. When one day a piece of such kitchen furniture should no longer fulfill the service needs it was purchased to meet, it can easily be returned to natural cycles, as it is free of all pollutants.

## 2.1 The Environmental Management System at Kambium

As a first step toward obtaining certification under the EEC-Audit-Ordinance the Kambium Furniture Workshop, Inc. put together an ten point environmental policy document which allies environmental protection with its primary business objectives besides featuring the elements required by the EEC-Audit-Ordinance. In addition, the document contains ambitious demands such as an examination of the environmental effects of the products spanning the entire product line, the regional focus of the firm, as well as their resource saving energy supply. The document is made available to employees, business partners, the community, governmental authorities and customers, as well as to the public, in order to inform all relevant groups about the environmentally based precepts of this business.

Parallel to the formulation of environmental policy guidelines, the first environmental audit was carried out at Kambium. It consisted of the following five categories:

iv) Registration of all relevant mass and energy flows in the in-house mass-survey.

5. Identification of ecological problem areas through the use of check lists.
6. Registration of the intra-firm material flows and comparison of the building construction with the planning and construction blue prints in the course of a plant inspection.
7. Questioning of the employees in two workshops.
8. The search for dematerialization potentials through an examination of Kambium products according to the criteria for ecological design.

All the problem areas and savings potentials identified in the course of the environmental audit are combined into a catalogue of measures, from which management-after having made preliminary ecological, economic and legal assessments-selects those areas which are to be included in the environmental program. In order to achieve a steady implementation of the environmental program, every measure is tabulated on a form, on which the responsibilities, deadlines, budgets and any possibly necessary incremental steps toward implementation are enumerated.

In the next step, the environmental management system is established, which constitutes one of the focal points of the eco-audit concept. This facilitates the creation of structures which aid in the continual improvement of in-house environmental protection. Organizational structures are to be determined at this stage, as well as the responsibilities, behavioral patterns, formal procedures, sequences and means. These explicitly enumerated ambitious demands from the EEC-Audit-Ordinance constitute the greatest hurdle for small to medium sized businesses, which generally do not have ready access to a sophisticated management system, on the road to certification.

## 2.2 Operational and Material Flow Analyses

In the operational and material flow analyses all relevant material and energy flows at the Kambium Furniture Workshop, Inc. for the reference year 1994 are recorded. The uniform system of mass accounts, which was developed for the in-house mass tabulation constitutes a comprehensive environmental information system which is simultaneously a core component of the environmental management system yet to be installed.

Alongside the basic objective of tabulating all relevant in-house material and energy flows, the uniform system of mass accounts has the additional task of ensuring a parallel sequence of cost and mass accounting (Preimesberger 1994) as well as facilitating a direct linking of the firm to a product line spanning material flow analysis. An important parameter in this context is the compatibility of the data collection framework of the uniform system of mass accounts and the computer based material flow analysis of the product line.. The expressed objective is thus to standardize all accounts to mass units (kg or t). The conceptual and methodological delineations are based on the MIPS concept and its tabulation criteria.

The basic structure reflects an hierarchical tabulation framework, that is organized according to useful categories. By analogy to national accounting, the basic structure includes both input (I) and output (O), as well as asset accounts (A). The additional category inventory or store (S) was also formed (Fig. 1).

| | | |
|---|---|---|
| I. | | input |
| I. | 1. | raw materials |
| I. | 2. | energy |
| I. | 3. | water |
| I. | 4. | air |
| I. | 5. | products |
| I. | 6. | merchandise |
| I. | 7. | communication |
| I. | 8. | services |
| I. | 9. | transport |

| | | |
|---|---|---|
| O. | | output |
| O. | 1. | products |
| O. | 2. | energy |
| O. | 3. | waste water |
| O. | 4. | vitiated air |
| O. | 5. | waste |
| O. | 6. | merchandise |
| O. | 7. | communication |
| O. | 8. | services |
| O. | 9. | noise |

| | | |
|---|---|---|
| S. | | store |
| S. | 1. | raw materials |
| S. | 2. | energy |
| S. | 3. | water |
| S. | 4. | products |
| S. | 5. | merchandise |
| S. | 6. | communication |

| | | |
|---|---|---|
| A. | | assets |
| A. | 1. | land areas |
| A. | 2. | structures |
| A. | 3. | plant and equipment |
| A. | 4. | vehicle fleet |

*Figure 1: Structure of the account framework*

The various areas are divided into accounts and subsidiary accounts, all of which are assigned a specific index. With the continual tabulation of all environmentally relevant data it becomes possible to regularly collate the results, providing a basis for assessing the environmental situation and its development. On the basis of the multi-levelled interconnections between product lines and firm specific (economic zone specific (Bringezu 1995)) analyses, improvements and cost saving potentialities on all important levels and in all areas can be shown. Outside the firm, the uniform system of mass accounts can serve as an important environmental information system in the context of the firm's environmental communication.

So as to interfere as little as possible with the operational production sequence, it is necessary that the in-house tabulation system – as represented by the uniform system of mass accounts and demanded by the EEC Audit Ordinance – be set up incrementally, and completed over time. Particular emphasis should be placed on the use of available informational and organizational structures, on computer aided material flow tabulation and evaluation, on offensive environmental communication as well as on active, participatory employee involvement and training.

## 2.3 The Kitchen – From "Cradle to Grave"

In light of the comprehensive ecological assessment of Kambium, the environmental effects associated with the product line "solid wood kitchens" were tabulated. These include all material flows attributable to production which were determined and evaluated using the MIPS concept. The material intensity analysis covers the entire life cycle of the kitchen, i.e. from raw material procurement/extraction, through the production of lumber, the assembly of the boards and assorted other parts, to the finished kitchen, the use phase and the recycling or disposal of the kitchen. The material intensity of a solid wood kitchen was computed both for the individual life stages (production, use, recycling/disposal) of the product line "kitchens" as well as for the entire life cycle (Fig. 2). This was compared to an equivalent kitchen constructed of Formica-covered particle board. Additionally the material intensity of a "second hand" Kambium kitchen was determined (see 2.4 Design), so as to be able to judge possibilities for environmentally sound kitchen recycling.

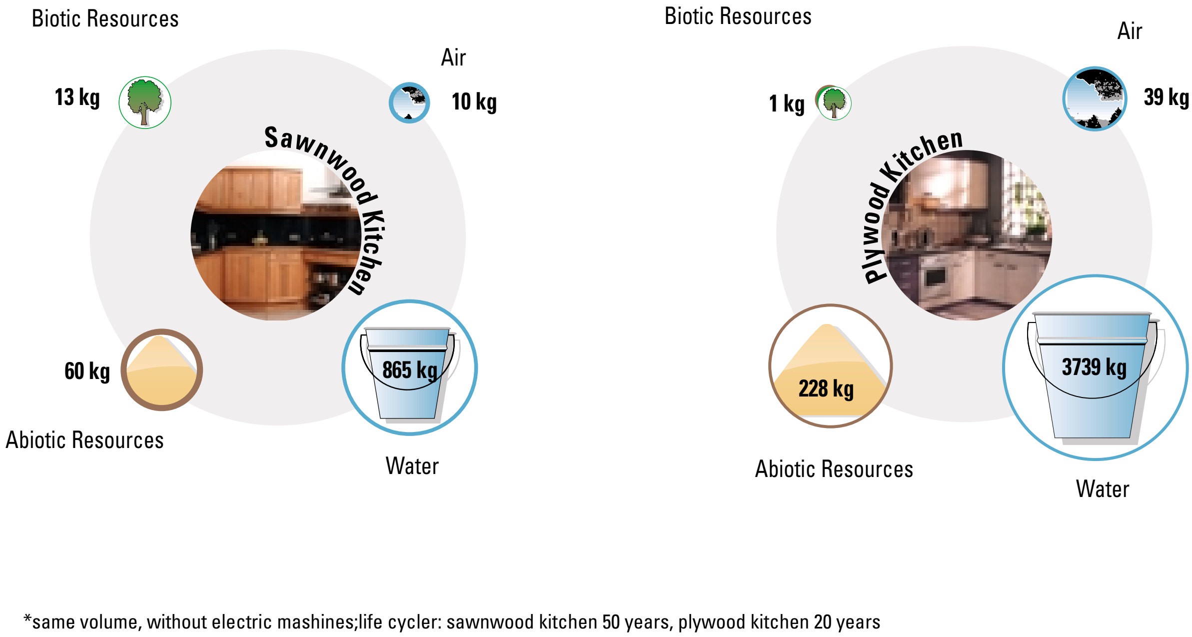


*Figure 2: Life cycle wide material intensity of a solid wood and a plywood kitchen in kg/l storage space*

The storage capacity of a kitchen according to DIN (German Industrial Standard, similar to ISO) 18022 was computed to be 2,061 liters/average kitchen1. In the case of the solid wood kitchen, a life span of 50 years was assumed, for the particle board kitchen, a life span of 20 years was imputed (Preimesberger 1996).

Fig. 2 identifies the solid wood kitchen as a significantly resource saving product. Looking at the life cycle spanning resource consumption, the input of biotic materials for the solid wood kitchen is thirteen times higher than in the case of the particle board kitchen. The input of abiotic materials, water and air on the other hand is about four times higher for the particle board kitchen than for the solid wood kitchen.

In the present study the electrical appliances were not considered, either in the resource intensity analysis of the product line or in the considerations about design.

While Kambium employees are not able to directly affect the design and installation of electrical appliances in the realm of the kitchen, they can affect the selection of the appliances through their consulting. When selling a kitchen built to very high environmental criteria specifications it makes sense to recommend those fixtures, which, from an environmental perspective, fair the best. The Low-Energy-Institute-in Detmold2 publishes an annual informational pamphlet on particularly conserving household appliances. In addition to mentioning total resource consumption, Kambium customers should consider this information in the selection of electrical appliances.

1 The average kitchen is defined according to the fictitious solid wood kitchen which Kambium conceived as a basis for determining the material intensity according to DIN 18022 („Küchen, Bäder und WC`s im Wohnungsbau", DIN Taschenbuch Nr.110, Wohnungsbau, Berlin 1991) This average kitchen was also conceptualized in four different variations with different materials.

2 Niedrig-Energie-Institut GbR, Michael & Scharping, Rosental 21, 32756 Detmold.

## 2.4 Design

An examination of the design had three objectives: to identify strengths and weaknesses of the present Kambium kitchen concept, to develop strategies for minimizing the material and energy throughput in production, use and disposal of Kambium kitchens, and to optimize the service performance.

This covers questions at the product level (i.e. materials used, principles of construction, aesthetics of durability), as well as at the system level, as in the marketing structures, product redemption and recycling options. Possibilities for expanding the resource-conserving Kambium concept onto other customer or user groups were also discussed.

Service

An optimal environmentally considerate design requires a careful definition of what we mean by service. The definition corresponds to the following categories:

- storing
- preparing
- cooking, roasting, baking, re-heating
- arranging/serving; (eating - only with a sufficiently large kitchen area)
- cleaning, dish-washing
- waste disposal.

The kitchen floor-plan and the number of users are important specifications for planning a kitchen which adequately meets the demands. As all the above service options cannot be captured in a functional unit, a service unit was defined with reference to the smallest common denominator: liters of storage space per year. In this manner the life cycle wide resource consumption of various kitchen variations can be compared with reference to a functional unit. The service options which can be met by the kitchen in question, and which go beyond this definition, can be ascertained from the description of expanded services, or, with reference to the level of the MI value. While this allows us to measure, we have not yet been able to fully grasp the service provided by a given kitchen. Only if two kitchens meet roughly the same service demands can they be compared using the formula above. If a kitchen supplies an expanded array of desired services, this kitchen is to be preferred over another providing fewer services, if the material and energy requirement were equal in both cases.

Analysis of strengths and weaknesses

With the help of a list, which enumerates the environmentally relevant product characteristics, the ecological qualities of the Kambium kitchen are to be examined.

Thoughts on the re-design of the product Kambium kitchens

A re-design considers constructive and design measures which can reduce the material or energy input into a Kambium kitchen beyond the previous levels while preserving its service functions, or, increasing the services at a constant level of material and energy input. Possibilities for variations on the concept of the "Hirnleistenbauweise" were drawn up, and the issue of a fitted kitchen vs. pieces of furniture was dealt with at length.

Thoughts on the re-design of the system Kambium kitchen

The Kambium company estimates the life expectancy of their fitted kitchens to be roughly 100 years. This appears to be a realistic time frame, as far as the material quality and the construction are concerned. At the same time this implies that the users of the kitchen (at least two generations) must agree to a long-term fixed kitchen installation. In many cases such a long use-period will not occur. Moving, changes in familial constellations, the death of the user are but a few examples of situations that could terminate the first use phase of a Kambium kitchen. What happens, though, when the next generation, or the successive renter is not interested in sticking with the installations? What happens in the case of a move? If the Kambium kitchen is to be kept, it must be adapted to the specifications of the new surroundings. The problem of every fitted kitchen is that they are quite inflexible when it comes to unanticipated changes. In the case of a kitchen that purports to last 100 years, the above situations can occur far more often over the course of the use phase.

It is therefore important to develop strategies which permit the use capacity potential to be utilized to the fullest extent. Among the many suggested options and ideas, the following are particularly noteworthy: product redemption concepts, the Kambium kitchen "light" (kitchens designed for single occupants, low budget kitchens) and variations such as renting instead of selling.

## 2.5 Building Analysis

The physical characteristics of the structures are significant in determining the energy demands of a building (heating, lighting, cooling). Thus aspects such as the use of sun light and radiant heat as well as the creation of a natural indoor climate were considered in the planning of the Kambium buildings (passive systems).

In the case of Kambium's production facility, the building is solid construction with the outer walls being of brick for the most part. The building concept included a concern for minimizing the demand for heating energy during the use phase. The passive energy systems, made possible because of the specific building concept, facilitated this. Climate control is provided by the 50 cm thick outer walls made of brick, the glass bricks in the outer walls (incident sunlight enters the building in winter, providing additional light and warmth; no direct sunlight in the summer, obviating the need for direct cooling), the extensive use of grasses on the Sedum-roof and the head block paving inside the building.

In the chapter on "building analysis" the repercussions of the construction physics peculiar to Kambium were examined with reference to the system-wide demand for energy as well as to the system-wide demand for resources of the building. These impressions were compared to a fictitious alternative structure, built according to conventional specifications (steel skeleton construction) providing equal services.

## 2.6 Energy Management

Energy management, energy conservation and the selection of energy sources comprise a substantial component of the ecological operations concept of Kambium Furniture Workshop, Inc. In the context of their environmental policy, Kambium commits itself to

- guarantee the least use of energy possible in the development of both products and processes,
- pursue continual improvements in the environmental compatibility of the use and generation of energy and
- to achieve 100% coverage of the energy needs through renewable energy sources.

In implementing these business objectives Kambium is engaging in energy management which relies on both active and passive systems. Besides various energy saving measures (passive systems), Kambium generates most of its energy itself. The demand for electricity is mostly covered through an in-house wind power facility as well as a block-type thermal power plant. To heat the buildings and cover the energy needs of drying the wood, both a natural gas fired heating system and the waste heat from the block-type themal power plant are used.

Part of the electricity demand in 1994 had to be obtained from the grid (is-situation). Due to control-technical problems, the wind power generator only produced 35% of the power guaranteed by the producer. Only at 100% performance of the wind power generator will the "ought-situation" occur at Kambium.

Compared to conventional energy management (standard situation: without in-house power generation) Kambium was already able to drastically reduce their energy-dependent resource consumption in 1994. Substantially reduced quantities of abiotic material, water and air were taken up system-wide for energy provision.

Table 1: Energy-dependent resource consumption-comparison of the is-situation (1994), the ought-situation and the standard situation.

| | abiotic materials [kg] | water [kg] | air [kg] |
|---|---|---|---|
| is-situation (1994) | 419.028 | 6.653.172 | 152.910 |
| ought-situation | 287.841 | 4.447.342 | 136.265 |
| standard situation | 914.394 | 15.791.580 | 180.234 |

In the case of the ought-situation, the system-wide resource consumption by Kambium are below the conventional energy supply system by a factor of 3.5 (with generally comparable use rates).

The resource savings on the input side necessarily lead to a reduced level of air pollution due to energy consumption on the output side. In 1994, for instance, roughly 52 t less CO2 were emitted into the atmosphere.

### 2.7 Transport

In the context of the study, transport management at Kambium was examined, both for "internal transport" - especially employee commuting - as well as the area of "external transport". "External transport" includes all transport induced directly by operational activity, i.e. delivery of merchandise.

The distributional boundary of the product Kambium kitchen of 100km contrasts with the supra-regional transport interconnections of the firm. The analysis shows that the material input for solid wood kitchens for abiotic and biotic materials, water and air, dependent upon transport comes to about 10% of the total inputs. In order to achieve the possible improvement potential, the supplier structure should be further optimized, similar to the way in which their own deliveries are. Kambium's self imposed limit on the delivery radius already saves resources today, while benefiting both humans and nature.

## 3. Summarizing discussion

The MIPS concept attempts to open up the possibility of using a screening procedure that considers the environmental relevance of the various life stages of a product to link an operational accounting with an estimation of the environmental stress intensity across the entire product line.

Preliminary promising points of departure were worked out at the Kambium Furniture Workshop:

- The material operational account can be adapted to the tabulational and computational system of the MIPS concept without any difficulty. The material flow survey for the reference year 1994 at Kambium was successfully implemented for all environmentally relevant areas. All the data gathered in the operational account can easily be converted into material intensities with the help of corresponding factors. For example, the consumption of gasoline - collected in units of liters in the operational account - can be directly converted to corresponding material intensities of the MIPS survey categories.
- The computer supported conversion of these data will introduce significant time savings in the future. As new data are entered for the operational account (for transport in the units t and km, energy in kWh or J) the software system CARA will be able to generate the ecological rucksacks in parallel.
- The results of the product line related material intensity analysis (energy management, selection of intermediate products with the least resource demands etc.) and, building on that,

of the ecological kitchen design ("Kambium light," use of other materials such as fabrics etc.) point to substantial potentials for improvement, even in the case here of a business like Kambium which is already set up according to environmental principles.

- An initial test of Kambium kitchens according to eco-design criteria generated suggestions about commercially sensible sales and leasing models which contribute to the protection of the environment across the entire life cycle, while keeping Kambium solvent.
- The qualitative and organizational demands made by parallel systems of material and operational accounting as well as mass accounting according to the MIPS system upon the business can be easily transformed into an environmental management system.
- Several catalogs of measures were developed for the various areas of analysis such as environmental management, operational accounting, product lines, energy management, ecological design etc. The suggested measures all take into account the objective of contributing to a reduction in resource flows across the entire life cycle. The catalogs of measures must be summarized in the ongoing EEC-Audit-Ordinance, evaluated and adopted into a program of measures with and by the employees of Kambium.
- In light of the present results, carrying out a comprehensive, product related life cycle analysis for Kambium's solid wood kitchens appears unnecessary. Continuing analyses for individual life phases of the product line wood should be undertaken, such as in the case of forestry. In order to ensure that Kambium could obtain wood from forestry operations devoting the greatest attention to natural and resource conserving methods, an environmentally considerate performance or tender specifications pamphlet was developed. It is more time and cost efficient to obtain environmentally relevant information with the help of tender specifications than to carry out individual process related life cycle analyses. For other product lines (i.e. the chemical industry) though, process related life cycle analyses can be highly recommended. The tender specifications mentioned can be conceptualized gradually for all upstream suppliers across the product line. Environmental information increases over the entire product line from inquiry to inquiry and the companies can act accordingly.

The results of the present study point to the necessity of itemizing the EEC-Audit-Ordinance in relation to the procedure for assessing the environmental stress intensity of products. A screening procedure based on the MIPS concept appears suited to surveying the environmental relevance of products across the entire life cycle in such a way that an environmental program and management system can be established (see below "screening"). The methodology of the material intensity analysis showed itself to be operationalizable in a company, and with the present concept it satisfies the demands of the EEC-Audit-Ordinance. In addition it was possible to develop a resource management plan spanning the entire life cycle for Kambium.

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