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MATERIALS ACCOUNTING AS A TOOL FOR DECISION MAKING IN ENVIRONMENTAL POLICY (MAC TEMPO)

SUMMARY FINAL REPORT

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I. OBJECTIVES

Regions have a metabolism like a biological organism or an ecosystem. Sustainable development implies among other things, that this metabolism is directed towards optimum use and conservation of available resources, and long-term environmental protection. Hence, methods are needed to analyse, evaluate and control this regional metabolism.

Materials accounting comprises the analysis of flows and stocks of materials ("Material Flow Analysis MFA") in a given region in a systematic, rigid and comparable way. MFA is a complementary tool to traditional environmental and resource management approaches. It provides the necessary links between anthropogenic activities and their impacts on the environment. MFA is based on a holistic approach. It examines the total material flow into a given system such as a private household, company, city, region etc., the stocks and flows within this system, and the resulting outputs from the system to other regions and to the environment.

The five partners engaged in MAc TEmPo decided to share and expand their individual experience in materials accounting in order to:

- improve the MFA methodology,
- apply MFA methods in the field of sustainable development, namely resource conservation and environmental protection in highly urbanised areas,
- investigate the use of MFA as a base for policy decisions regarding anthropogenic metabolism.

The main objective of MAc TEmPo was to supply tools for decision makers in environmental protection and resources conservation. Previous work of the partners indicated, that MFA can be successfully used for: Early recognition of future problems of environmental loadings and resource depletion, to set priorities and to define measures for efficient environmental protection and resources utilization, and to analyse and improve the effect of measures taken in environmental policy. Based on this experience, MFA can be seen as a key instrument for the transition from today's "filter-strategy" to the next generation of source oriented environmental measures, focusing on *the total regional metabolism and not on wastes and emissions alone*.

Additional objectives were: to develop and improve existing and new computer based models for MFA, to share MFA experiences by the partners in four workshops and by the exchange of personnel, and to increase the number of experts in the field of MFA by involving additional research groups in the project. Also, the capacity to use statistics in support of environmental policy was to be improved. A more specific project aim was to look into early recognition of future risks of certain material flows by identifying long-term accumulations and depletion. *Measurable objectives* include the goals reached in the case studies (national and urban metabolism of metals, chlorine and other materials; MFA models) and to give first proposals of how to use MFA for decision making in environmental protection and resource conservation. In relation to this task, it should be noted, that the MAc TEmPo team included only one expert from the field of political science.

II. METHODOLOGY

In order to reach the above mentioned objectives, an *empirical* research approach was taken. Original research work was carried out in the following three areas:

1. case studies of material flows on various levels
2. development and improvement of models to describe regional material balances
3. initial investigations into the use of MFA in the policy decision making process

In addition, four workshops were held to co-ordinate, discuss and evaluate MFA case studies and modelling approaches, to share and unify the methodology, and to derive common results concerning tools for decision making in environmental policy.

The four case studies selected for this project, which are summarised in Table II.1, were carried out in four different countries at various levels (local, regional, national, European). The main reason to establish four different case studies was to learn more about the anthropogenic metabolism and the means to control it, and to find similarities/differences in the metabolic behaviour of different anthropogenic systems. All case studies

focused on urbanised areas, investigated the *total* flow of the substances selected and included transboundary and sometimes hinterland problems. Three of the case studies were mainly oriented towards substances (iron, zinc, carbon, chlorine etc.), and the other one was oriented more towards goods (biomass, water) and functions (construction). The case studies covered a wide array of specific regional metabolic systems: two studies dealt with the urban metabolism, one with both national and European substance flows and stocks, and one with a region including both urban and rural (agricultural) issues. Since the research questions and methods/models of the individual groups were complementary, general conclusions could be drawn from the individual results and applications.

The case studies focused on materials for which it was anticipated that data was comparatively easily available (metals), and on others such as carbon and chlorine which are more tedious to assess because of their very many different organic compounds. The materials investigated included those which are not in the public debate (iron), not yet in the debate (zinc) and those already in the centre of controversies (chlorine). This spectrum was relevant to the derivation of policy related conclusions.

Table 0.1: Comparison of MAc TEmPo members and their case studies

Topic	**Scale**		**Materials**	**Method of Investigation**	**Policy Link**
	Spatial	**Temporal**			
Metabolism of Vienna (Massgoods, C, N, Metals)	Urban region - city of Vienna	1 year	Carbon, Nitrogen, Iron, Aluminium, Zinc, Lead	Analysis and comparison of flows and stocks with respect to the ratio of anthropogenic and geogenic	City of Vienna - Planning and Environment Department
Metal metabolism of Stockholm	Urban region - city of Stockholm	95 years	Cadmium, Chromium, Copper, Lead, Mercury, Nickel Zinc	Historical reconstruction and modelling of material flow and stock analysis, sediment cores	Local Environment Government in Stockholm, Swedish Environmental Protection Agency
Chlorine flows in Europe and European countries	European and national	lifespan of product	Chlorine, chlorinated compounds, mainly organic	Analysis, evaluation and modelling of material flow and stocks	Dutch Ministry of the Environment, European Union
Development of models, policy simulation		-		origin and control analysis for modelling of material flows and stocks	
Material balances for a Swiss Lowland region	Region - Swiss Lowland Synoikos	two generations (approx. 60 years)	Water, biomass, construction materials	Analysis and modelling of material flows and stocks, economic modelling, scenario development for resource use	21 Municipalities and 2 Cantons

In the MAc TEmPo case studies, several examples for static and dynamic models for materials management were presented. Based on existing material accounting methods, a new modelling approach was developed

which incorporated the noise structure of the data. The objective was to exploit the potential of systems identification to improve MFA.

An attempt was made in the case studies to evaluate the use of materials accounting to support policy decisions. A comprehensive, social science investigation into this topic was not attempted because most of the Mac TEmPo team consisted of natural scientists and engineers. Hence, the conclusions presented here were drawn mainly from a technicians perspective.

The four *workshops* held in each participating country were instrumental for the exchange of information about methods, data, modelling and results. The workshops served as valuable platforms to present the case studies and to facilitate feedback discussions. While the early workshops were more dedicated to the case studies, the last two workshops focused primarily on policy related issues.

Four *National Advisory Boards* (Austrian, Dutch, Swedish, Swiss) consisting of both policy makers and scientists were established to provide the linkage between the project research activities and environmental policy. Their feedback was incorporated into the project in each phase.

Research personnel were exchanged for short term periods in order to enhance the exchange of expertise concerning methods, data acquisition and data treatment. This exchange also stimulated discussion and resolution of specific questions relating to the metal metabolism of urban regions.

III. MAIN RESULTS

The results fell into two main categories: those related to methodology developments and those related to material accounting case studies.

III.1 Methodology Developments

MFA Methodology : The objective of materials management is to firstly analyse, secondly to evaluate and thirdly to control material flows in view of certain goals such as sustainable development. The MAc TEmPo case studies confirmed, that MFA is an excellent tool for the first objective and is well suited to generate a base for the other two objectives. In itself, MFA does not allow to evaluate or control materials flows; additional methodologies, such as toxicology, environmental impact assessment (EIA), the concepts of Material Intensity Per unit Service (MIPS) or ecological footprints techniques (Sustainable Process Index SPI) are necessary for evaluation. Within MAc TEmPo, methods for these steps have not been explicitly discussed. However, each group has used its own criteria for evaluation and control of the flows and stocks. For example, the concept of "regional self sufficiency" was used in the case of the SYNOIKOS study. Just by analysing the material regime of a region, important characteristics of the regional metabolism can become apparent. A striking example is the strong accumulation of materials in urban anthropospheres, which was observed in all case studies. This finding implies significant consequences for future environmental protection and resource utilisation (see Materials Accounting Studies).

The methodology used in each case study was not identical. It appeared, that a certain minimum in standardisation was necessary for a mutual understanding of the systems investigated. In each case study a system was used comprising of a system boundary in time and space, of processes (transports, transformations and stocks), and of flows of goods and substances. It was agreed to apply the term "substance" as defined in chemistry (a substance is an entity of identical atoms or molecules, that is an element or a defined chemical compound), and to use the term "good" for matter (substances as well as mixtures of substances) with a positive or negative economic value such as construction materials or wastes. The term "material" comprises both substances and goods. In addition to this minimum set of definitions, each group used its own terms according to their needs, such as „Hibernation" for materials not in use, or „Hinterland" to show the dependency on neighbouring systems etc. The work of the MAc TEmPo team confirmed that the methodology for materials accounting can be applied on all levels and scales, such as households, cities, regions, and nations. For future studies and research in the field of materials accounting, it is recommended to follow this common set of definitions and to gradually enlarge it by a consensus process before establishing normalised standards.

Data Collection: To date, there exist no standardised methods or databases which allow simple, routine collection of data about flows and stocks of goods and substances. Thus, information needed for MFA was measured/assessed on an individual basis. It appeared that the necessary statistical data to establish balances for mass goods is available in all countries. Regionalised information is more difficult to obtain, and information about the flows and stocks of specific substances in general is not readily available from official statistical sources. In general, statistics focus on goods with an economical value. Substances, which are often hidden in goods, are rarely assessed. A main drawback of present data collection is, that the requirements of MFA are not yet taken into account, that is, that the information which is collected about the use of substances on one level (e.g. mining) is not yet linked to the next levels (production, trade, consumption, waste management, emissions).

A systematic development of an accounting system for selected substances could greatly facilitate the use of MFA and hence improve efficient materials management. A sound methodological approach over the full range of scales (households to countries), such as a national materials accounting system, could finally yield a comprehensive data set for many substances. Before official statistics are engaged in such data collection, it is important to define the exact goals, and to agree on the purpose as well as on the methodology of data collection and use.

Within the MAc TEmPo case studies, it was indispensable to engage experts with a profound knowledge of the method of MFA and of data about the flows and stocks of substances in anthropogenic systems. The main challenges in applying MFA involve establishing an appropriate material management system and selecting the critical data from all levels, including public and private sources covering production, supply, consumption and waste management.

The substance flows of different MAc TEmPo case study regions proved to be often quite similar. Nevertheless, some figures determined by the teams showed considerable deviations. The question remains open, as to whether these variations are due to data collection and treatment factors, or if they are a result of real differences between the anthropogenic metabolism of regions.

Modelling: All case studies presented have a common basis with respect to the physical principles applied, namely the laws of conservation of energy and matter. The first important and most creative step in each project is the choice of a combination of processes or subsystems, for which specific material and energy accounts have to be determined. The defined material management system can be described by a mathematical model. These mathematical models are used to understand the functioning of the whole system.

Models are based either on *a priori* assumptions or on the determination of unknown model parameters by available measurements. In the first approach, error propagation for a given system is calculated. The latter approach is a system identification approach. Both have been successfully applied in case studies. In the system identification approach the following problems have been solved: data reconciliation based on the precision of the measurements available, estimation of unmeasured flows, estimation of the model parameters corresponding to the subsystems, origins analysis and policy simulation (control analysis)

There are several software packages that are available to handle MFA (e.g. SFINX, SIMBOX). Within MAC TEmPo, each team has developed their own computer aided tools for calculating and visualising serving their specific purpose. However, in each case the methodological basis of SFA was the same (similar physical concepts). Eventually the best software should be selected by market mechanisms (user demands).

III.2. Materials Accounting Case Studies

Main messages: MFA of urban regions revealed two typical characteristics of the anthropogenic metabolism:

- The flow of most mass goods through urban areas is, compared to geogenic flows, large and predominantly linear (few cycles).
- The stocks of goods and substances in urban regions are large and increasing.

These observations are important for both future environmental protection and resource utilisation. During relatively short consumption phases, large amounts of materials are being accumulated in the infrastructure and in households. In one respect, these materials are valuable resources and can be used for reconstruction of the

anthroposphere. This holds true if information about its concentrations and locations are available, and if the substances can be viably collected and recovered economically. For many substances used today, these prerequisites are not fulfilled yet. In contrast, large stocks of materials which are no longer in use ("Hibernating materials") may pose a future threat to the environment a long time after they have entered the market. The MAc TEmPo case studies have shown, that the amount of many materials in use or in „Hibernation" is larger than the total amount of substances in landfills or in emissions.

Since urban metabolism is characterised by large linear flows and increasing stocks, a shift in the strategy for environmental protection is necessary. The main focus in the future should be the analysis and control of the anthroposphere. In order to use materials efficiently and in an environmentally sound manner, the urban metabolism must be understood. MFA, comprising of the systematic analysis of substance flows and stocks, has proven to be an excellent means to facilitate this shift of focus from the environment to the anthroposphere. It enables decision makers to abate environmental impacts by the most efficient means along the pathway of materials from the sources to the sinks. The MAc TEmPo case studies also confirmed, that MFA is a useful tool for synthesis, too, e.g. to design future scenarios of goal oriented resource utilisation.

Case study results: Three types of MFA case studies were performed: The substance metabolism of cities was investigated; the flows and stocks of chlorine and chlorinated compounds in Western Europe was assessed; and scenarios for the management of mass goods such as water, biomass, and construction materials were studied in view of sustainable development. The main results of the case studies are summarised below.

Metal metabolism of cities: The main objective of the two case studies on Stockholm and Vienna was to examine the flows and stocks of selected materials (i.e. Al, C, Cd, Cr, Cu, Fe, Hg, N, Ni, Pb, and Zn) through the anthroposphere of these cities. The MFA studies from both cities allowed one to compare anthropogenic substance flows and stocks with geogenic flows and stocks. This served for early recognition of future environmental loadings and to set priorities/ define measures to protect the environment in urban areas. For the first time, metal inputs and stocks in a city (Stockholm) were analysed and modelled for a long period (95 years), an approach which required new assessment methods. The stocks were divided into sectors of use, degree of exposure to corrosion and in areas of responsibility for the goods. The study in Stockholm, which was performed in close co-operation with the Local Environmental Government and the Swedish Environmental Protection Agency, revealed high concentrations of cadmium, lead and mercury in sediments, soil and ground waters. The model used in Stockholm included responsibilities for the management of materials, and thus served to find actors and operators. It was also suited to include value analysis, which is important when evaluating the shift of a material from "In Use" to "Hibernation"".

The following conclusions were drawn: it is possible to determine the stock of goods and substances in urban centres even over long time periods. Concerning mass goods such as water, air and fuels, today's cities are linear flow through reactors i.e. materials flow directly through the city and from a bulk material perspective recycling does not exist. There is an ever increasing stock of construction materials and consumer goods stored in cities. The accumulation of metals in cities is large, while the emissions so far are small in relation to the stock. Stock emissions are not well known. Thus, most environmental concern should be directed to manage the stock in order to minimise future impacts. Older domains of use often dominate the stock. Some of the goods, i.e. "dead electrical cables", are no longer in use and are forgotten "resources". The responsibility for managing these forgotten materials is unclear. MFA enables one to detect such hibernating materials. MFA can serve as a base for environmental indicators. Such indicators should be based on the anthroposphere (use of materials) rather than on the environment (concentrations in air, water and soil).

Chlorine compounds in the EU: The main objective of this study was to give an overview of the flows and stocks of chlorine and chlorinated compounds within the Western Europe. In particular, the project identified hazardous flows, described trends and explored various control measures. A number of flows, which were methodologically difficult to determine were studied in detail, such as emissions and wastes from stocks of PVC and CFCs, and emissions of chlorinated micropollutants.

The following results were obtained: There is a large stock of PVC in the anthroposphere. Hence, if the use of PVC is phased out within the next 10 years, PVC waste flows will still be generated over the next two centuries. This can be shown with simple models. From the study of world-wide CFC stocks, it can be concluded that there will be emissions of CFCs for the next 50 years from accumulated stocks, even if the use in developing countries would decrease just as fast as in the developed countries.

The study of chlorinated compounds in the Netherlands reveals, that there is an important gap in the current knowledge about emissions of chlorinated micropollutants. A number of ways to improve the understanding of these emissions have been identified. For example, a comprehensive monitoring program could be carried out to identify individual compounds in these emissions. This research could be coupled with research to determine the persistency and bioaccumulative potential and toxicity of these compounds. Alternatively one could bypass identification and focus more on the total emissions. In both the Dutch Chlorine Chain study and in the MAc TEmPo case study of flows of chlorinated compounds in Western Europe, it was found that MFA can be a powerful decision supporting tool: MFA can be an important aid to focus discussions and to help reduce uncertainties by providing structured data.

SYNOIKOS: This project is part of the large programme called SYNOIKOS investigating the restructuring of a region in the Swiss Lowlands in view of sustainable development. The main objective was to elaborate material management models for water, biomass and construction materials, and to develop long term scenarios with regard to concrete goals of regional development, such as " sustainability" and regional self-sufficiency. The results of SYNOIKOS have been implemented into regional policy through workshops with local leaders (political, economic, social). A new project titled: „Stadt der Wigger“ has begun leading into the development and management of regional action plans by regional enterprises (public and private).

The following conclusions from SYNOIKOS were drawn:

Water regime: In the Synoikos region, systems for water supply as well as waste water collection and treatment are highly developed. The region depends on ground water as a source of drinking water. The quality of this source is gradually decreasing mainly due to agricultural activities. An appropriate hydrological model for regional water management is still lacking. Such a model is indispensable to evaluate scenarios regarding the sustainable use of water resources. Nitrate concentrations in the groundwater are still increasing (very slowly). If no additional measures in agricultural practice are taken, then drinking water quality limits on a long-term scale could be exceeded. This regional metabolic process does not fulfil the criteria of sustainability.

Biomass: The case study focuses on wood and shows, that today, wood is not a scarce resource anymore in this region. Even at a high consumption rate of about 0.5 t/c.y, the degree of self sufficiency in the study region amounts to 85 %. Scenarios were developed to get a better understanding of the future role of wood as a renewable resource. The project revealed, that regional forestry should be directed towards the production of timber rather than paper. Sustainable forestry practice alone is insufficient to attain sustainable regional management of wood. In addition, production, processing, consumption, and disposal of wood have to be well balanced.

Construction materials: Flows and stocks of construction materials and construction wastes were analysed, and the effects of control measures on material and energy flows were investigated by modelling three scenarios. It was found, that for sustainable management of residential buildings, the key factor is the energy demand for the building’s operation, and not the amount or kind of construction materials used. Thus, energy policy concepts focusing on sustainable development must also take into account the long-term goals of settlement policy. As the existing stock of residential buildings determines the energy demand of the system, its future development depends upon the change in the settlement area. A significant reduction of energy consumption can only be reached, if the stock of residential buildings stops growing and the existing buildings are raised to the highest available standard of energy conservation.

IV: SCIENTIFIC INTEREST

The MAc TEmPo project indicated clearly the need to shift the focus in environmental protection research from the analysis of the environment to the understanding and control of the anthroposphere. It is suggested that a new research agenda be established in order to further the discipline of the "metabolism of the anthroposphere". This agenda must include several disciplines from natural sciences to engineering to social sciences. The ultimate goal of this agenda is to supply the necessary tools to design future anthropogenic systems in view of long-term environmental protection and resource conservation.

The MAc TEmPo group has demonstrated, that MFA is a well developed and readily available, rigid method for the analysis of metabolic processes of regions. It can be used to simplify the complex system "regional me-

tabolism" so that the important flows and stocks of materials become clear. It is an indispensable tool to assess the flows and stocks of materials in the anthroposphere. Together with mathematical modelling, MFA serves as a strong base for the management of resources and the environment. The case studies have shown comprehensibly, that MFA scenario modelling can yield new solutions with regard to the sustainable management of resources.

The methodology of MFA has been further developed and clarified. Terms such as goods, processes, materials and substances, have been discussed, and new terms such as Hibernation and Hinterland have been introduced. It is up to the applied community now to use and eventually further develop the present set of terms and definitions. With respect to modelling, four partners have elaborated their own products, which they present now intend to market. The ultimate goal of a dynamic model for the anthropogenic metabolism will be further pursued.

Innovative work within the MAc TEmPo project comprises also the historic and systematic treatment of the accumulation of materials in urban systems ("stock problem"), and the link of several disciplines (MFA, regional planning, statistics and economics) in order to design future resource management scenarios.

The propose research agenda involves:

- collecting more data, comparing the material flows and stocks of cities and their Hinterlands in several European regions.
- creating a data base system which allows data collection and treatment in a systematic “cradle to grave” manner.
- developing a methodology for evaluating stocks in terms of environmental loadings and future resources.
- developing design tools for urban metabolism which are capable of incorporating MFA methodology data and results.
- creating new computer based models to treat the dynamic case of material management systems.
- constantly evaluating the use of MFA in the political decision making process

V. POLICY RELEVANCE

The first experience with MFA in Europe dates back to the beginning of the 1980´s. The early projects focused mainly on methodological development. Case studies well suited for evaluating the use of MFA as a tool for policy decisions are still rare. In addition, as stated before, the MAc TEmPo project included only one policy science expert. Hence, the following findings are to be regarded as first assessments. They are based on the experience of the case studies, and have been collected by a questionnaire elaborated within the framework of this project. In general, the case studies showed that MFA is a useful tool for policy decisions regarding the management of resources.

MFA is well suited to visualise the complex regional metabolism. It is based on the principle of the conservation of mass (input equals output), and thus is easily understood by decision makers (“what goes in must come out”). It is a highly transparent tool, and provides a good basis for comparing a set of scenarios. MFA systematises and integrates information coming from different disciplines. If all assumptions about system boundaries and the selection of processes and goods are known and documented, an MFA research permits an objective discussion of environmental and resource policy measures.

Arguments from different stakeholders in the political debate can be formulated and tested against the information provided by MFA. The common language of MFA allows one to systematise and integrate information from different disciplines. Thus, MFA improves the ability of the actors to define a common platform with regard to the current situation, and to participate in the development of future scenarios by visualising the consequences of certain measures at an early stage. Hence, “operators” and their clients should use both this new and efficient tool together to find a common platform and to reach effective decisions. “Operators” could include decision makers on all levels, such as entrepreneurs, city officials, Ministries of the Environment etc.

The formation of stocks and subsequent material flows from stocks can, on the one hand, reduce the effects of source (consumption) related policy measures. Thus, policy decisions regulating environmental protection must always be based on a complete set of data, including all major flows and stocks. MFA can provide such a complete set of information. On the other hand, knowledge about the formation of stocks allows one to design new resource utilisation strategies such as an “urban mining” strategy. Anthropogenic materials built into the city

may become the main source of raw materials. If resource conservation policies are directed towards the new goal of urban mining, new tools are necessary, e.g. in the field of information (material databases) and technology (design for urban mining).

Often, public awareness for an environmental problem is a vital promoter for the MFA approach. In many cases, MFA provides the basic information needed to solve a specific problem. Up to now, only in a few cases has public interest arisen by an MFA research, e.g. CFC stocks in construction materials or diffusive emissions from metal stocks in cities. One reason for this shortcoming might be that MFA is still primarily used and discussed among scientists and experts. Another drawback of MFA is, that the results sometimes cannot be immediately translated into action, because the system in question cannot be directly influenced by the particular decision maker.

MFA is useful to forecast the effects of social and economic developments on materials management systems. This forecast must be based on data on the current material stocks, on an analysis of the materials management system, and on assumptions about the developments of technology, economy and human behaviour. In a decision making process MFA provides information about possible future "problem shifts" and thus serves as a base for long term planning. If MFA is applied repeatedly to the same system ("materials accounting"), it can be used to evaluate the success of policy measures, and to create and enhance awareness of future problems.

As stated in the Results - Materials accounting Case Studies (III.2), a major conclusion of MAc TEmPo is to shift the focus from the environment to the anthroposphere. In order to start this change, decision makers must become familiar with the idea of urban metabolism and the accompanying tool MFA. This implies continuous efforts to build new capacities in the MFA field and to widely disperse the results. In the first place, these new tools must be provided and integrated into the fields of planning and development. Producers of investment goods (e.g. infrastructure) and mass products (e.g. consumer goods) with long residence times should also be addressed. Continuous education curriculum in the field of sustainable development must include the methodology of MFA on all levels.

Another important shift revealed by the results of MAc TEmPo is the need to design certain measures for environmental protection and resources conservation on a regional level, too. The geogenic as well as the anthropogenic conditions (e.g. dilution potential in water and air, population density) can vary from region to region, thus posing different problems and solutions for individual regions. In the future, it is important to find an appropriate mix of regional, national and global measures for resources protection based on MFA.

The shift of emphasis from the environment to the anthroposphere mentioned above requires new instruments on the administrative and policy level. Traditional administrative bodies are directed towards environmental protection, focusing on administering the flows of emissions and wastes on the one hand and the materials supply on the other hand. Today, there are a few administrative bodies which concentrate primarily on materials management in view of sustainable development. Thus, it is important to establish offices for materials management on regional, national and European levels, which eventually may replace current environmental protection positions. Such a change seems possible only if new policy strategies are established which focus more on efficient and total resource management rather than on singular *ad hoc* forms of environmental protection.

Today, a general data base for MFA does not yet exist. Future collection of statistical data should also be directed towards MFA. This means, that not only information about goods should be compiled, but also about substances contained in these goods. In the first place, a data base system should be developed in order to systematise the collection and treatment of data on all levels. Case study examples could highlight for decision makers how MFA can be used and how corresponding databases permit efficient materials management. Ultimately, a system for materials accounting could be established similar to financial accounting systems. In view of the MAc TEmPo team, the information developed within this project is not sufficient yet to prescribe a procedure for data collection to be followed by statistical offices. The question of how national and European statistical offices should collect and treat goal oriented data for MFA purposes requires further consideration.

VI. LIST OF PUBLICATIONS

In preparation

Bergbäck, B., Brunner, P.H., Lohm, U. & Obernosterer, R. "Urban Metabolism - Growing stocks and unknown emissions", *Water, Soil and Air Pollution,* to be published in 1999.

Brolin, P.; Lindstrˆm, M.; HÂkansson, L.; Jonsson, A. Modelling the dispersion of heavy metals from Stockholm. *Water, Soil and Air Pollution,* to be published in 1999.

Hedbrant, J. Modelling of metal metabolism in Stockholm. *Water, Soil and Air Pollution,* to be published 1999.

Hendriks,C., Müller, D., Obernosterer, R. & Brunner, P.H. "Material Flow Analysis (MFA) - a tool for regional environmental and resource management", *Local Environment*, To be published June 1999.

Jonsson, A.; SvidÈn, J. The use of mercury in Stockholm during the 20th century. *Water, Soil and Air Pollution,* to be published 1999.

Kleijn R., E. van der Voet en R. Huele (1998) ìDynamic Substance Flow Analysis: the delaying mechanism of stocks, with the case of PVC in Sweden". Submitted to Ecological Economics.

Müller D. (1998). *Stoffhaushaltsmodell zur regionalen Bewirtschaftung von Holz*. Dissertation, PhD-thesis, to be published in 1998. (ETH Zürich)

Redle M. (1998). *Energie- und Stoffhaushaltsmodell zur regionalen Bewirtschaftung von Kies und Sand*. Dissertation, PhD-thesis, to be published in 1998. (ETH Zürich)

Real, M. (1998). *Stoffhaushaltsmodelle zur Bewirtschaftung photovoltaischer Energiesysteme,* PhD-thesis, to be published in 1998. (ETH Zürich)

Sˆrme, L.; Hedbrant, J. Metal metabolism - Stockholm. *Water, Soil and Air Pollution,* to be published 1999.

In press

Bergbäck B & Jonsson A. (YEAR) ìCadmium in goods - contribution to environmental exposure". *The Swedish National Chemicals Inspectorate*.

Gleiß, A., Matyus T., Bauer G., Deistler M., Glenck E., Lampert C., (1998) "Identification of Material Flow Systems - Extensions and Case Study", to appear in: Environ. Sci. & Pollut. Res. 5 (3). In press.

Kytzia S. (1997). "Wie kann man Stoffhaushaltssysteme mit ökonomischen Daten verknüpfen? Ein erster Ansatz am Beispiel der Wohngebäude", in: T. Lichtensteiger and P. Baccini (Eds.), *Ressourcen im Bau,* in press.

Müller D., Redle M. and Baccini P. (1997), "Der Einsatz erneuerbarer und nicht-erneuerbarer Baumaterialien. Die Beispiele Kies und Holz". in: T. Lichtensteiger and P. Baccini (Eds.), *Ressourcen im Bau,* in press.

Paumann, R., Obernosterer, R. & Brunner, P.H. (1997) *Wechselwirkung zwischen anthropogenem und natürlichem Stoffhaushalt der Stadt Wien am Beispiel von Kohlenstoff, Stickstoff und Blei*. Institut für Wassergüte und Abfallwirtschaft, Abteilung Abfallwirtschaft, TU-Wien, Wien.

Redle M. and Baccini, P. (1997). "Metabolische Modelle für den Umbau urbaner Siedlungen am Beispiel der Wohngebäude" (accepted for publication in *GAIA*, 1998/9).

Published

Bauer, G., Deistler M., Gleiß A., Glenck, E., Matyus T., (1997) "Identification of Material Flow Systems", Environ. Sci. & Pollut. Res. 4 (2) 105 - 112

Baccini P. and Oswald F. (eds.) (1998) *Netzstadt. Transdisziplinäre Methoden zum Umbau urbaner Systeme*, VDL Hochschulverlag AG, ETH Zürich.

Baccini P. and Bader H.-P. (1996) *Regionaler Stoffhaushalt*. Spektrum Akademischer Verlag, Heidelberg/Berlin.

Baccini, P. (1996) "Understanding Regional Metabolism for a Sustainable Development of Urban Systems", *Environ.Sci.& Pollut*. Res.3 (2): 108-111.

Baccini, P. (1996) "Carbon Management in Urban Systems: Present and Future Strategies", *Proc. of International Symposium on Global Environment*, Jan.22, 1996, 73-78, Sanjo Kaikan (The University of Tokyo) Japan.

Baccini P. (1997) "A City's Metabolism: Towards the Sustainable Development of Urban Systems", *Journal of Urban Technology*, Vol. 4(2) : 27-39.

Bader H.-P. and Baccini P. (1997) "System-Modelle und Simulations-Programme im Umweltmanagement - Eine kritische Analyse des Stands der Technik", *GAIA* 5 (6) : 263-274.

Bergbäck, B.; Johansson, K. (1996) *Metaller i stad och land. Lägesrapport 1996*. Report 4677, The Swedish Environmental Protection Agency. (In Swedish)

Bergbäck, B. & Lohm U., (1997) ìMetals in Society". In Brune, Chapman, Gwynne and Pacyna (Eds.): *The Global Environment*. Scandinavian Science Publisher, Wiley - VCH.

Binder, C.; (1996) *The Early Recognition of Environmental Impacts of Human Activities in Developing Countries*, Disseration ETH Nr. 11748. Zürich.

Binder C., Schertenleib R., Diaz J., Bader H.-P., Baccini, P. (1997) "Regional Water Balance as a Tool for Water Management in Developing Countries", *Water Research Review*, Vol. 13 (1): 5-20.

Brunner, P.H. (1997) "Material Flow Analysis - a Tool to Support Decision Making in Wastes and Resources Management". In: *Proceedings of ECO-INFORMA* '97. Hrsg. Alef, K. et al., Eco-Informa Press, Altendorf/Bamberg, Deutschland, p. 374-380.

Chassot, M.; Besson, J.-M.; Candinas, T.; Henseler, G.; Siegrist, H.; Baccini, P. (1996) "Modifications métaboliques-Détection avancée à l'aide des boues d'éepuration", *Gas-Wasser-Abwasser* 76 (5) : 409-415.

Daxbeck H., Lampert Ch., Morf L., Obernosterer R., Rechberger H., Reiner I. & Brunner P. H. (1997) "The Anthropogenic Metabolism of the City of Vienna", *Proceedings of the ConAccount Workshop Regional and National Material Flow Accounting: From Paradigm to Practice of Sustainability*, 21-23 January, 1997 Leiden. In: Wuppertal Special 4, Wuppertal Institute for Climate, Environment and Energy, Germany, ISBN 3-92 99 44-05-7.

Friedrich S., Kytzia S., Fischer C., Oswald F, Baccini P. (1997) "Umbau des Wohnens - Werkstattbericht aus einem transdisziplinären Forschungsprojekt". in: *Dokumente und Informationen zur Schweizerischen Orts-, Regional- und Landesplanung (DISP)*, Zürich, April 1997, p23-29.

Kleijn, R.; Tukker, A.; Voet, E. van der. (1997). "Chlorine in the Netherlands, Part I: an overview". *Journal of Industrial Ecology* 1(1) pp 91- 112

Hendriks, C., Müller, D., Obernosterer, R. & Brunner, P.H. (1998) Material Flow Analysis: A Tool to Support Environmental Policy Decision Making. *Proceedings to the Third International Expert Seminar on Environmental Management Instruments „New Public Management of Natural Resources"* in London, International Council for Local Environmental Initiatives (ICLEI), Freiburg.

Huele, R. and R. Kleijn. (1997) "Signal Processing: A Useful Mathematical Technique in SFA". *Proceedings of the ConAccount Workshop Regional and National Material Flow Accounting: From Paradigm to Practice of Sustainability*, 21-23 January, 1997 Leiden. In: Wuppertal Special 4, Wuppertal Institute for Climate, Environment and Energy, Germany, ISBN 3-92 99 44-05-7.

Huppes, G., Voet, E. van der & Huele, R. (1997) "Degrees of Immobilisation: a Matter of Time". *Proceedings of the ConAccount Workshop Regional and National Material Flow Accounting: From Paradigm to Practice of Sustainability*, 21-23 January, 1997 Leiden. In: Wuppertal Special 4, Wuppertal Institute for Climate, Environment and Energy, Germany, ISBN 3-92 99 44-05-7.

Imboden, D.; Baccini, P. (1996) "Konzepte für eine nachhaltige Schweiz: Mit welchen Ressourcen in welchen Siedlungen auf wessen Land?" in: Wehowsky St., Pieren K. (Hrsg.) *Nachhaltige Entwicklung oder hoher Lebensstandard?* CASS-Symposium 96, Konferenz der schweizerischen wissenschaftlichen Akademien, Postfach, 3001 Bern.

Lohm U., Bergb‰ck B., Hedbrant J., Jonsson A., SvidÈn J., Sˆrme L. & ÷stlund C., (1997) *Databasen Stockhome. Flˆden och ackumulation av metaller i Stockholms teknosf‰r*. Tema V Rapport 25. Linkˆpings Universitet. (In Swedish).

Lohm, U.; Bergbäck, B.; Hedbrant, J.; Jonsson, A.; Sörme, L. and Östlund, C. (1996) *Metallmetabolism - analys av ackumulerad miljöpåverkan i storstadsområden*. Report to the Swedish Environmental Protection Agency (In Swedish).

Möslinger J. (1998) *Stadtstrukturbezogene Analyse des Güter- und Stoffhaushaltes der Stadt Wien - Ein Beitrag zur Entwicklung eines Ressourcenkatasters.* Master Theses, Institut für Wassergüte und Abfallwirtschaft, Department of Waste Management, Technical University of Vienna. Vienna.

Müller, D., (1996) “Szenarien einer nachhaltigen regionalen Holzbewirtschaftung”, in: *Schweiz. Zeitschrift für Forstwesen*, Jhg. 147 (11) p 873-885.

Oswald F. and Baccini P. (1996) *Forschungsprojekt SYNOIKOS - Nachhaltigkeit und urbane Gestalt im Raum “Kreuzung Schweizer Mittelland*”. Zwischenbericht März 1996, Zürich 1996.

Palm, V.; Östlund, C. (1996) “Lead and zinc flows from technosphere to biosphere in a city region”. *The Science of Total Environment* 192: 95-109.

Tukker A., Kleijn R., van Oers, L., Smeets E., (1998). “Combining SFA and LCA: The Swedish PVC analysis”, *Journal of Industrial Ecology* 1(4) pp 93 - 113.

Tukker A., Kleijn R., Voet E. van der and Smeets E. (1998) “Chlorine in the Netherlands, Part II: The case of Risk Management in uncertainty for chlorine”. *Journal of Industrial Ecology* 1 (2) pp 91 - 110

Tukker, A.; Kleijn, R.; Oers, L. van; Smeets, E. (1996) *A PVC substance flow analysis for Sweden*. TNO report STB/96/48 I,II,III,IV.

Voet, E. van der; Oers, L. van. (1997) “Materials Management and Problem Shifting”. *Proceedings of the ConAccount Workshop Regional and National Material Flow Accounting: From Paradigm to Practice of Sustainability*, 21-23 January, 1997 Leiden. In: Wuppertal Special 4, Wuppertal Institute for Climate, Environment and Energy, Germany, ISBN 3-92 99 44-05-7.