Can sustainability be achieved by conserving the Urban Structure?

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1 Introduction

The concept of sustainability implies a long-term perspective. But long-term development of complex systems – e.g. an urban structure – is difficult to predict and plan. We therefor need (a) indicators for early recognition and (b) parameters to influence future development of resource consumption and emissions.

In this paper we show that information on magnitude and composition of the current material stock in urban systems (e.g. the building mass) can be used as indicators for early recognition. It allows for predicting material fluxes in the time period of approximately the average life-span of the materials which are analyzed (e.g. 50 years for residential buildings).

If we further understand management of material stocks as an important task in an overall resource management, stock change rates become key parameters to influence future development. As stock change rates are determined by technological, economic and social changes (and their interaction) management strategies should be determined an interdisciplinary discussion.

Both information and management aspects will be illustrated in a case study on the development of residential areas. In a first step we will demonstrate how future requirements of energy and construction materials can be estimated based on data of today’s building mass and how this information can be used to evaluate management strategies. In a second step we will discuss implications of economic and social findings on the development of residential areas in choosing the appropriate management strategy.

2 MFA as a method for assessing resource consumption trends

Human resource consumption is shaped by society’s material and energy metabolism. It includes the basic processes “extraction” of natural resources, “production” and distribution of commodities, “consumption” of goods and services, and “waste treatment”. Any metabolism can be described by assessing the magnitude and dynamics of (i) the involved material fluxes between the processes (e.g. from production to consumption), (ii) the material stocks (e.g. buildings or durable goods), and (iii) the exchange of materials with neighboring systems. A suitable method for describing and analyzing metabolic processes is Material Flux Analysis (MFA) [1]. Since a decade or so, the method is increasingly used to analyze large-scale metabolic processes of the

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anthroposphere including associated emissions (e.g. pathways of single substances through a nation or a region).

What information on the evolution of resource consumption does such analysis provide? Most relevant and inspiring is information about the links between material stocks and material flows because this interdependency shapes the system's dynamics [2] [3] [4] [5] [6] . In general terms, the interdependency can be described as follows (see figure 1):

1) Most material stocks in anthropogenic processes are used to produce commodities, goods or services (stock operation). Their operation requires material and energy and produces waste. These input and output flows can be roughly estimated on the basis of the technological properties of the material stock (e.g. energy requirements for heating of buildings) and data on its expected output (e.g. used floor space).

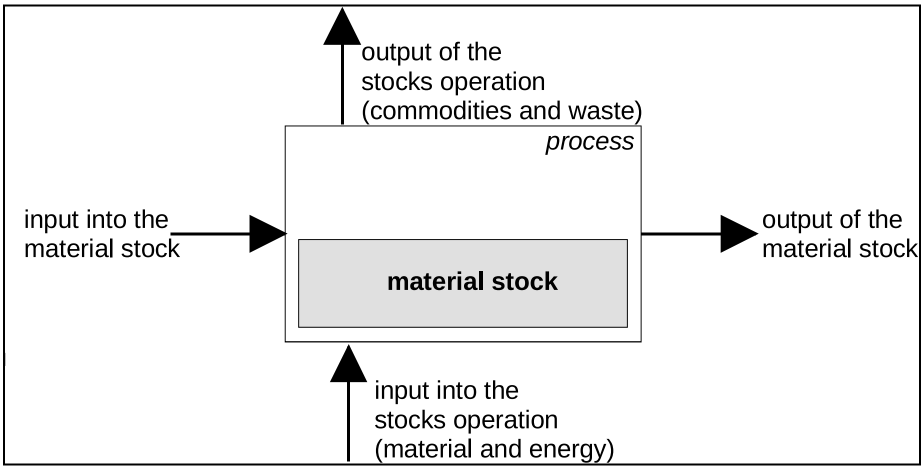

Fig. 1. The development of material turnover of a process can be described as dependent of the evolution of its material stock. Material fluxes stem from the stock operation (e.g. production) or its maintenance and growth.

2) Material flows into the process are also used to increase the stock or to replace parts of it which leave the process as waste. These changes depend on the entry time of material in the stock and their expected residence time. The residence time can be explained by technical properties of the involved material (e.g. the technically determined average lifetime of building material) and by consumption habits.

To elaborate forecasts or scenarios for future resource consumption based on these interdependencies, we need data on stock magnitude and composition (e.g. life span distribution). Additionally, we have to make assumptions about other factors influencing change rates (e.g. stock growth due to economic growth) and the expected output of the stocks operation (e.g. production of commodities or services).

How such an MFA can be performed is shown in an EU-funded research project which was accomplished recently [7] [8]. Several case studies were defined in order to demonstrate the benefits of material flow modeling for a better understanding of a society's metabolic dynamics.

(a) Worldwide emissions of CFC's [9]: Emissions of chlorinated fluorocarbons (CFC's) are an important issue in environmental policy. Some applications immediately lead to emissions (e.g. propellants and solvents), others store CFC's e.g. refrigerators or insulation material in the building sector. In latter case, CFC emissions will be largely delayed and will occur during waste processing. Such delayed emissions were calculated based on a dynamic MFA model, which used data on the current stocks of products which contain CFCs. The results show, that we may expect a CFC emission peak in about 40 years. These emissions stem from insulation foams that will be replaced during building conservation or demolition.

(b) *Consumption of construction material and energy in the Swiss Lowlands* [10]: The settlement area of the Swiss Lowlands has assembled a large amount of construction material in buildings and infrastructure. An important share of the current energy demand in Switzerland is required for operating this building stock (mostly heating energy). Today, the stock grows with a rate of approximately 1.5 percent, and the corresponding material and energy flows grow accordingly. Successful sustainable management of the building stock should contribute to a reduction of both energy and material demand. Such strategy, however, is not evident because increasing the energy efficiency of existing buildings requires further input of construction material. In order to assess and discuss possible management strategies, the project used a dynamic MFA model that evaluated the maximum gains in energy efficiency and conservation of construction material (see 3.1).

Example (a) illustrates how the current material stock determines material fluxes which represent outputs of this stock (see figure 1). Example (b) illustrates the interaction between the material stock and material fluxes into the stock (construction material) as well as into the stock operation (heating energy). We will take a more detailed look into the interaction between these three variables in the following case study.

3 Management pf material stocks - case study “residential areas”

A widely used hypothesis about reducing resource consumption is based on a life-span argument: longer life spans of products increase residence time and, hence, reduce resource demand [11].

However, this hypothesis is not generally true. Looking at the resource demand patterns of products throughout their life span, two important classes of products can be distinguished.

- Category A: Resource consumption is most accentuated during production (e.g. furniture, paper, etc.).
- Category B: Resource consumption is highest during usage of the product (e.g. cars, bulbs, houses, etc.).

For category A products, it is evident that enhancing life spans will lower resource consumption. If such products are used for a longer period of time, demand for the products will decrease and eventually lower resource input into the production of these goods. With regard to the material stock formed during the use-phase of these products, this management strategy brings about slower change in the stocks' composition. Thus, changes in resource consumption during the stocks operation will be retarded. But as resource consumption during production is predominant, the overall effect will be positive. We will refer to the strategy of prolonging product life spans as "conservation-strategy".

For category B products, however, the life-span argument does not hold because prolonging life spans might impede the implementation of newer, more resource efficient products and technologies. This can be well illustrated with figure 1: if net energy input for changing the material stock is smaller than the realized energy savings for operating the stock, high replacement rates which contribute to a quick change of the stock's composition, are favorable. To evaluate the strategy of encouraging replacement we introduce the term “substitution-strategy”.

In the following case study we will compare these two strategies in the development of residential areas in the Swiss Lowlands. In the current discussion on sustainable development in Europe the management of residential areas is widely recognized as key issue [12] [13] for the following reasons:

- Residential areas cover a large portion of today's settlement area (approx. 40% in Switzerland) and are still growing.
- Residential buildings are responsible for a large share of the private households' energy consumption. In Switzerland for approx. 30% of the private households direct energy requirements is needed for heating.

It is generally accepted that the continuous growth of residential areas should be halted. It is not obvious, however, how the existing material stock should be managed.

In this paper, we will evaluate resource trends in residential buildings if stock growth is set to zero and management focuses on changes in stock composition. As we consider products with a long life span (residential buildings), we will allow for technical improvements in the “conservation strategy” during maintenance and repair and consider their effect on resource consumption.

3.1 Substitution versus Conservation

In the life cycle of a single residential building, the consumption of different resources follows contrasting patterns. For construction materials (e.g. gravel and sand) the bulk of resources is consumed during the construction period whereas for energy demand the operation of residential buildings is dominant. Looking at the overall resource consumption of a residential area in Switzerland the importance of the operation of residential buildings becomes even more obvious, because in general only a small portion of the building stock is under construction (see figure 2).

In the categorization that was previously introduced, residential buildings figure as products of category A as far as the consumption of construction materials is concerned. Thus, the conservation strategy is appropriate here. For energy demand, however, the existing residential buildings can be regarded as products of category B and should be replaced by more energy efficient substitutes.

The implications for regional resource management are evaluated with a dynamic MFA model that is based on system analysis and data presented in figure 2 [6] [10] [14]. Two additional measures in both strategies are considered (a) recycling of demolition waste (with a recycling rate of 80%) and (b) increase of energy efficiency of existing residential buildings by renovation. The renovation rate is tripled and renovated (optimized) buildings require only approx. 40% of their original energy demand.

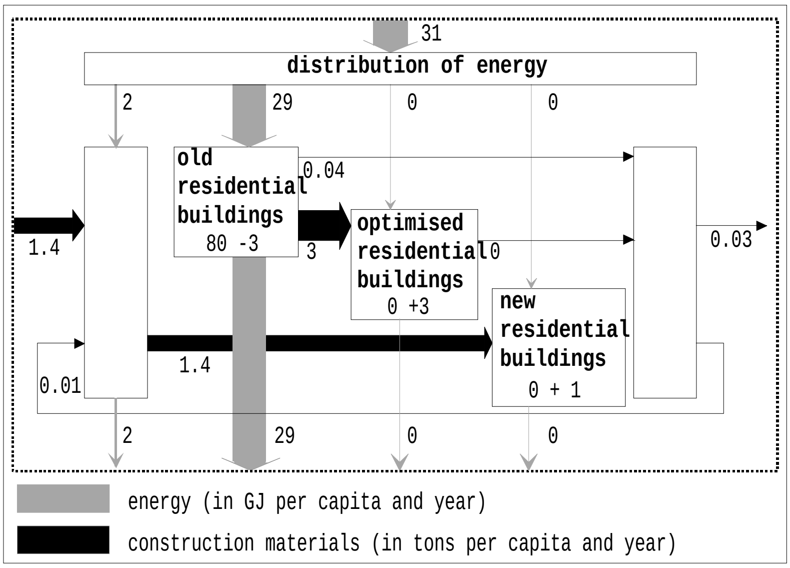

Fig. 2. Fluxes of energy and construction materials (gravel and sand) estimated for the year 2000 in the study region. The flux units are expressed in Giga-Joule (energy) and tons (construction materials) per capita and year. The stock units are expressed in tons per capita. The process “old buildings” describes operation and maintenance of buildings that were constructed before 2000. The process “optimized residential buildings” comprises renovation, operation and maintenance of buildings that are renovated in 2000. The process “new residential buildings” includes construction, maintenance and operation of low energy houses that are build in 2000. Source: [10].

Two scenarios were calculated which describe developments in resource consumption in the next five decades if either management strategy is applied.

In the scenario "conservation" the volume of newly constructed buildings is reduced to the extent of the current demolition volume (0.1 m^3 per capita and year). The scenario calculation shows, that after a short time of very intense optimization, the saving potential is exhausted as all the old residential buildings are optimized according to the latest technological standards (see Figure 3). In 2050 all residential buildings will have been renovated, consuming only 40 % of the current energy demand. All material fluxes will be reduced to almost zero.

The scenario "substitution" aims at minimizing the energy demand for heating by replacing the entire residential building volume with new ("solar") low-energy housings over the next 50 years. Thus, demolition and construction volumes will have to be raised significantly (20 m^3 per capita and year). In 2050 all old buildings during the study period will have been demolished (Fig. 3 at the bottom). Energy demand is reduced to about 15 % of its current consumption. Only 2,100 MJ per capita and year is required for heating. This demand is five times lower than the energy demand in the scenario "conservation" and equals the energy demand for construction (about 2800 MJ per capita and year).

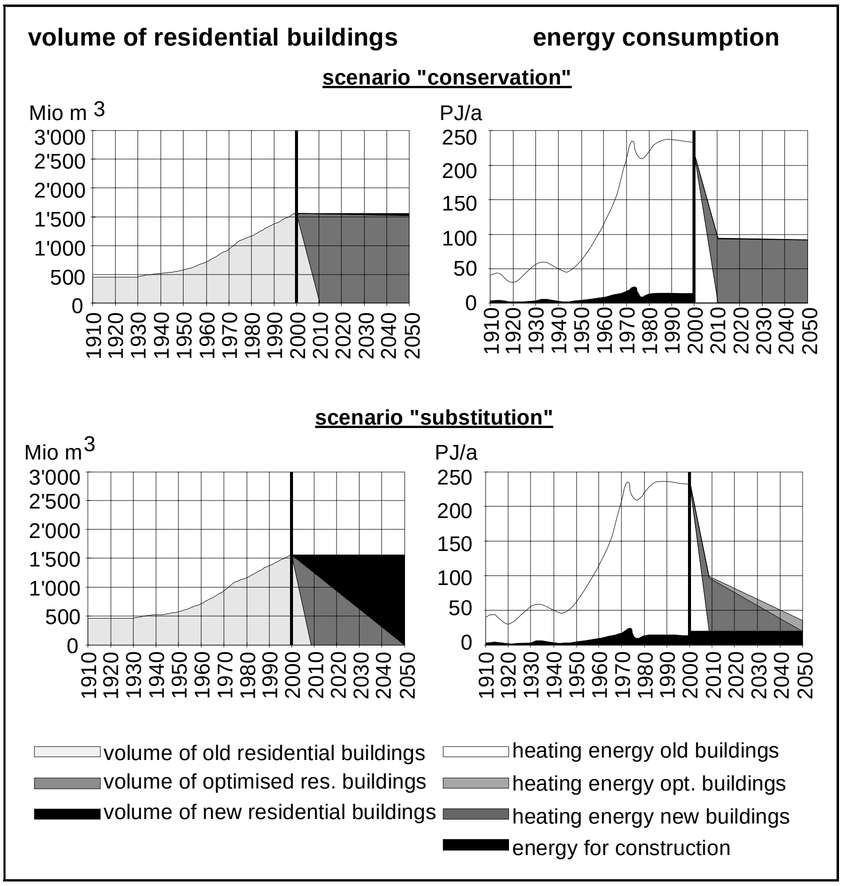

Fig. 3. Volume of residential buildings and energy consumption in the scenarios “conservation” and “substitution”. Source: [10].

These results show that minimizing energy or material consumption in residential areas represent conflicting goals. But if we give preference to energy conservation, the substitution strategy is clearly favorable.

Any management strategy, however, has to take into account that stock dynamics are highly influenced by socio-economic developments (e.g. economic growth). As their effects might counteract or foster our efforts in resource management, we have to better understand social and economic driving forces and their effects on a system's metabolism.

3.2 Influence of economic properties of residential areas

Basically, resource consumption in residential areas is determined by decisions of two groups of economic actors: owners and tenants of residential buildings. From an economic point of view, they aim at maximizing the difference between benefits and costs of owning and living in residential buildings. How do costs and benefits arise?

1) *costs of residential buildings*: An evaluation of life-cycle-costs of a residential building reveals that most of the costs are determined in the period of "construction" but realized in the period of "operation" (see figure 4). 63% of the overall costs are rendered by construction. Approximately half of this amount can be directly accounted to capital costs. Heating costs (18% of the overall costs) are related to decisions which are taken during the construction period but can be still influenced throughout the buildings life-time by renovation (see 3.1). The same is true for the costs of maintenance and renovation. Here, especially renovation costs vary according to the owners willingness to prohibit decay and adjust the building to changing needs.

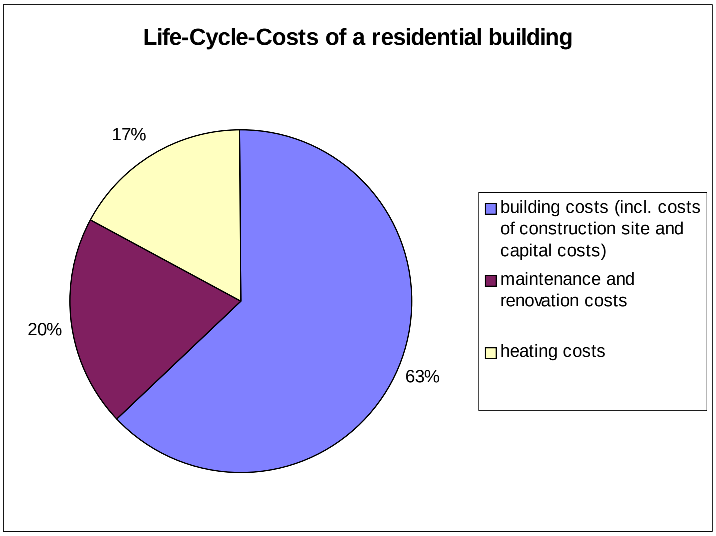

Fig. 4. Life-Cycle-Costs for a residential building estimated for a building with a living space of 150 m^2 on a building site of 300m^2 with an expected lifetime of 50 years assuming an annual inflation rate of 1.5% and an annual interest rate of 4%. For further assumptions see [15].

2) *Benefits of residential buildings*: The benefits of residential buildings depend on two factors (a) the extent to which they satisfy the tenants need for living space (in quantity and quality) and (b) changes of the value of buildings and sites. Beside the development of general economic parameters (e.g. household income or interest rates) (a) is determined by properties of the building itself (e.g. floor plans) and its location within the settlement area (e.g. distance to public transport) whereas (b) depends on the scarcity of construction sites.

We can transfer these findings to a description of the money flows and stocks which originate annually from the management of residential areas in a region in the Swiss Lowlands (see figure 5). It reveals that in residential areas with low growth rates major money fluxes are caused by the buildings' operation. These are capital costs and rents. The turnover of construction is comparatively low, because approx. only two percent of the entire building mass is under construction (renovation and maintenance).

Fehler! Kein Thema angegeben.

Fig.5. Monetary fluxes and stocks in the extended material management system for construction material in thousand Swiss Franks per capita and year based on data shown in figure 2 [16]. Owners and tenants of residential buildings are

introduced as processes. Monetary stocks (assets) are introduced by including the monetary value of residential buildings. Monetary flows (costs) occur in combination with flows of material and energy (e.g. construction or heating costs) or in combination with stocks (e.g. rents or capital costs). The benefits of tenants and owner are not represented, because they don't correspond to flows of money. Data for the city of Olten in 1990 is used to assess the fluxes and stocks. It is assumed that the renovation rate is equal to zero. Source: [10].

How will this economic system react on the management strategies of "substitution" or "conservation"?

The reaction pattern will probably be very similar to the evolution of the systems resource consumption, which was described in 3.1.

If we decide to maintain and renovate the existing building stock (*conservation strategy*), construction costs will decrease. However, they only represent a small share of the overall costs. The costs of operation will remain on a relatively high level because

(a) heating costs won't decrease significantly (see 3.1);
(b) maintenance costs increase with an aging building stock
(c) Capital costs won't decrease because the value of buildings and construction sites is not likely to fall when the settlement area is limited.

Choosing *the substitution strategy* will increase construction costs. But, we now get a chance to construct new buildings with lower operation costs. This will require further changes in building construction in order to reduce costs of capital and maintenance as well as heating costs. This development could be fostered by changes in urban planning or regulations in the capital market. On the long run, however, the overall costs of residential buildings might be reduced significantly.

Both strategies have an important effect on the economic system. As we stop growth of settlement areas, construction sites become scarce and the value of property in residential areas will increase. On the short run the current owners will profit, while on the long run the tenants will have to pay more rent. Thus, we will get an effect on distribution that has to be taken into account.

Distribution effects are clearly underestimated with the assumptions which we have choosen so far. In the next paragraph we will discuss how our system reacts if we discuss one key assumption: the assumption of a constant demand for floor space in residential areas.

3.3 Dynamics in floor space demand

In last decades the floor space demand in Switzerland grew significantly due to (a) growth of population (b) reduction of household size and (c) income growth. Ignoring technological change, all of these changes tend to fuel residential energy flows, direct (heating, hot water, electricity, etc.) as well as indirect (embodied energy in goods and services [17]).

Figure 6 shows orders of magnitude for future development in Switzerland. Population growth is estimated as rather moderate for the next 20 years. In contrast to that, the number of households will increase much faster. This implies that average household size will decrease, from currently 2.4 persons to approx. 2.2 persons in 2020. Taking into account the changes in household structure and in population growth, floor space dynamics largely correlates with household dynamics. Population development is of minor importance.

Apart from population and household growth, income contributes to floor space demand, too. With higher incomes, households can afford larger accommodations. The average size of an apartment rose from 88 to 93 square meters between 1980 and 1990. Taken into account all three effects, per capita floor space would increase by roughly 6% between 1990 and 2020. Overall floor space demand, however, will grow by 30%.

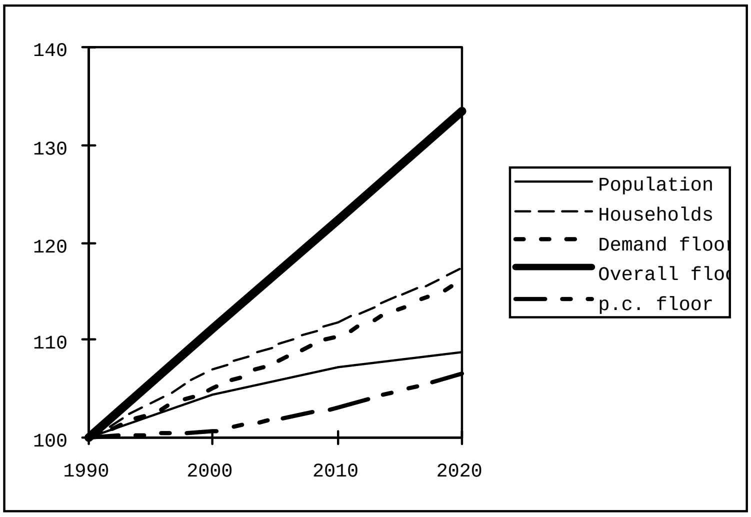

Fig. 6. Development of key figures in residential areas. Raw data stem from official Swiss statistics [18]. All data are indexed (1990=100)

In order to stabilize direct energy consumption for heating purposes, the overall energy efficiency of the residential building stock needs to be increased by 30% at least within the next two decades. Reductions would require even larger efficiency gains.

In the controversy “conservation versus substitution” this implies that

- energy reductions that stem from conservation investments are largely offset by an overall increase of floor space (see also [13]).
- gains in energy efficiency in the *substitution strategy* are sufficient to reduce the overall energy demand in residential areas. The reduction, however, will be smaller than shown in Figure 3.

Any strategy should therefor include measures to counteract this rebound effect. The substitution strategy is favorable in this respect because it allows for structural adjustment of the existing stock to the changing socio-demographic requirements, i.e. conversion of larger units into smaller ones.

Naturally, it is hard to predict how such adjustments in supply will affect demand. One example, however, illustrates the potential [20]. Elderly people, that are an increasingly important social stratum in Switzerland, contribute by 50% to all one-person households and by 40% to all two-person households. Their floor-space consumption amounts to roughly 55 square meters per capita compared to 37 square meters for persons younger than 65 years. If structural changes of the existing residential areas encourage people to adjust their floor space demand to changing living conditions throughout their life-time this difference might vanish.

4 Conclusions

Can sustainability be achieved by conserving the urban structure? Based on our argument we conclude that it can't be, because structural shortcomings of the existing residential areas can only be improved by replacing the existing material mass. These shortcomings are (a) low energy efficiency in heating existing residential buildings, (b) high operations costs of the existing residential buildings (especially capital costs) and (c) growing demand for floor space because demographic changes are not met by appropriate adjustments in supply.

Replacing the existing building mass must, therefor, be accompanied by changes in the economic structure of residential areas (e.g. property structure) as well as in the residents' life-styles e.g. the use of public or private space for individual recreation.

Our argument lead to several questions, which should be discussed further. The first concerns the distribution problem that is linked to zero-growth development. The second and third questions focus on possible incentives for substitution and zero-growth. It remained unanswered how the replacement of residential buildings could be encouraged by economic incentives and what changes in residential areas could convince residents to reduce floor space demand.

The investigation on the development of residential areas illustrated that dynamic MFA-models provide information on the future development of resource consumption. MFA-models can be used to evaluate strategies for the management of anthropogenic material stocks. However, MFA-models by themselves use given parameters that represent technological, economic and social dynamics and should be questioned in an interdisciplinary controversy. An evaluation of interactions between all three perspectives would require an integrated “techno-socio-economic” modelling. MFA looks like a promising basis for this further step.

References

[1] Baccini P. und Brunner P., Metabolism of the Anthroposphere, Springer Verlag 1991.

[2] Baccini P. und Bader H.-P., Regionaler Stoffhaushalt, Erfassung, Bewertung und Steuerung, Spektrum Verlag 1996.

[3] Binder, C., The Early Recognition of Environmental Impacts of Human Activities in Developing Countries, Disseration ETH Nr. 11748. Zürich 1996.

[4] Real, M., A methodology for evaluating the metabolism in the large scale introduction of renewable energy systems. Dissertation ETH No. 12937, Zürich 1998.

[5] Müller D., Modellierung, Simulation und Bewertung des regionalen Holzhaushaltes – Untersuchung zur Wald- und Forstbewirtschaftung in einer nachhaltigen Regionalentwicklung. Dissertation ETH No. 12990 Zürich 1999.

[6] Redle M., Energie- und Stoffhaushaltsmodell zur regionalen Bewirtschaftung von Kies und Sand. Dissertation, PhD-thesis, to be published in 1999. (ETH Zürich)

[7] Brunner P. et.al (Hrsg.), Materials Accounting as a tool for Decision Making in Environmental Policy (Mac TemPo). Summary Report. EC Environmental Research Programme. Research Area III – Economic and Social Aspects of the Environment. Vienna 1998.

[8] Hendriks,C., Müller, D., Kytzia, S. Obernosterer, R., Baccini, P. Brunner, P.H., Material Flow Analysis (MFA) - a tool for regional environmental and resource management. Local Environment, To be published June 1999.

[9] Van de Voet E., Kleijn R., Chlorine in Western Europe. in: Brunner P. et.al (Hrsg.), Materials Accounting as a tool for Decision Making in Environmental Policy (Mac TemPo). Summary Report. EC Environmental Research Programme. Research Area III – Economic and Social Aspects of the Environment. Vienna 1998.

[10] Kytzia S. et al., Synoikos. in: Brunner P. et.al (Hrsg.), Materials Accounting as a tool for Decision Making in Environmental Policy (Mac TemPo). Summary Report. EC Environmental Research Programme. Research Area III – Economic and Social Aspects of the Environment. Vienna 1998.

[11] Börlin M., Stahel W., Wirtschaftliche Strategien der Dauerhaftigkeit, Betrachtungen über die Verlängerung der Lebensdauer von Produkten als Beitrag zur Vermeidung von Abfällen. Schweizerischer Bankverein Heft Nr. 32, Basel 1987.

[12] Enquete-Kommission "Schutz des Menschen und der Umwelt" des Deutschen Bundestages (Hrsg.), Stoffströme und Kosten in den Bereichen Bauen und Wohnen. Entwurf (unveröffentlicht).

[13] Infras (Hrsg.), Nachhaltigkeit des Bauens in der Schweiz. Ein Diskussionsbeitrag. Koordinationsgruppe des Bundes für Energie- und Stoffbilanzen. Zürich 1996.

[14] Redle M., Baccini, P.. Stadt mit wenig Energie, viel Kies und neuer Identität. Metabolische Modelle für den Umbau urbaner Siedlungen am Beispiel der Wohngebäude. GAIA 7 (1998) no.3, p. 184-195.

[15] Kytzia S., Systemanalyse, Datenerfassung und Szenariorechnungen zum Modell Wohnen in Olten. Anhang zum 2. Zwischenbericht des Projektes Synoikos. EAWAG, Überlandstrasse 133, 8600 Dübendorf (unveröffentlicht).

[16] Kytzia S., “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, p. 69-79, vdf Hochschulverlag AG, ETH Zürich 1998.

[17] Dürrenberger G., Patzel N., Energy Metabolism of Swiss Households. Proceedings of the HOMES Symposium, June 3-4, 1999, p. 27-36, Groningen 1999.

[18] Bundesamt für Statistik, Wohnen in der Schweiz. Bern 1996.

[19] Bundesamt für Wohnungswesen,Siedlungswesen in der Schweiz. Schriftenreihe Wohnungswesen, 63. Bern 1996.

[20] Kytzia, S., Friedrich, S., Fischer, C., gewohntes verändern. Leitfaden für einen transdisziplinären Entwurf der Aktivität Wohnen, in: Baccini, P., Oswald, F., Netzstadt. Transdisziplinäre Methoden zu Umbau urbaner Systeme. Zürich 1998.