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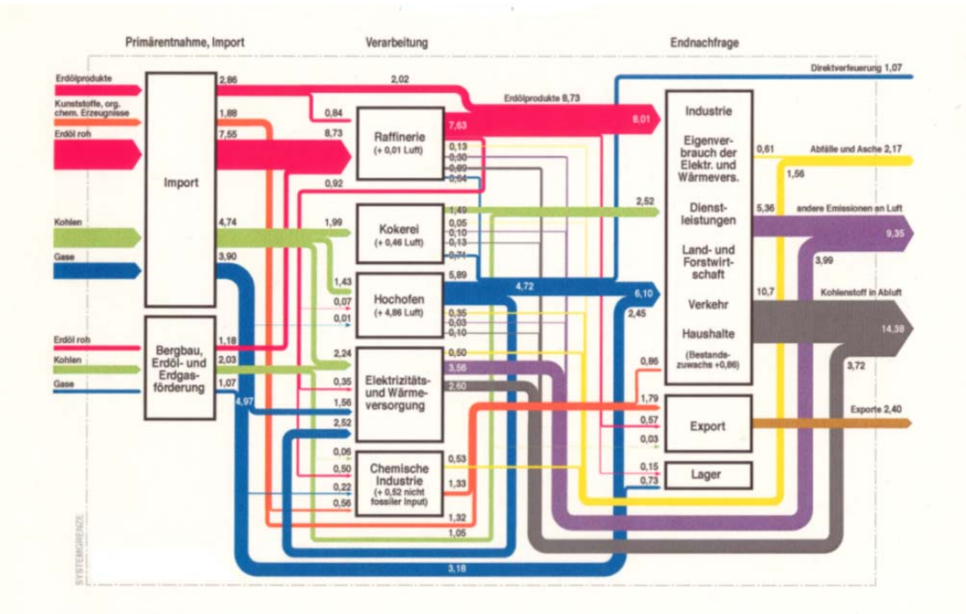
Handbook of Physical Accounting
Measuring bio-physical dimensions of socio-economic activities
MFA – EFA - HANPP



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1. INTRODUCTION

As the notion of sustainability, around 1990, has gained influence in the environmental discourse, the features of this discourse have changed remarkably. Under the notion of sustainability it was no longer the toxicity of some dangerous substances that was seen as the main problem of society's pressure upon the environment. The focus moved from the output side of the production system to a complete understanding of the physical dimension of the economy. From this point on, the economy was conceptualised as an activity, extracting materials from nature, transforming them, keeping them as society's stock for a certain amount of time and, in the end of the production-consumption chain, disposing of them again in nature. It has been recognised that environmental problems can arise at every step in this process. Furthermore, it has been understood that it is not only problematic substances but also problematic amounts of matter set in motion by society's activities that result in environmental problems.

These new insights have induced new approaches to environmental accounting focusing on the bio-physical dimensions of socio-economic activities in a comprehensive and integrative manner. The Department of Social Ecology at the Institute for Interdisciplinary Studies of Austrian Universities has been involved in the international process of developing methods for physical accounting as a basis of environmental indicators since about 10 years.

This involvement had three strands. Firstly, the participation in international projects where the social ecology team played an important role in pushing forward, together with others, the process of international harmonisation of the accounting methods. Important steps in this process were the European Union sponsored ConAccount project (Bringezu et al. 1997), the international cooperation on material flow accounting under the lead of the World Resources Institute (Adriaanse et al. 1997, Matthews et al. 2000) and the participation in the EUROSTAT taskforce to produce a guidebook on the state of the art in Material Flow Accounting (EUROSTAT 2001).

Within Austria, our efforts to play a major role in the establishment of MFA methods received substantial support. Not only had it been Steurer (1992) to produce the first comprehensive national material flow account worldwide; the Austrian Statistical Office was among the pioneer countries to introduce periodical national MFAs into its public statistics (Gerhold and Petrovic 2000, Schandl et al. 2000). The Department of Environmental Economics at the Federal Ministry of Environment (headed by Martina Schuster) considered MFA as a promising tool for accounting for pressures upon the environment and sustainability and supported the development of this tool both politically (see Pesendorfer 2002, Weisz et al. 2000) and financially. These efforts were complemented by support from the Austrian Ministry of Science and the Department for Energy and Environmental Technology of the Federal Ministry for Traffic, Innovation and Technology. Without such substantial support this handbook could not have been produced.

In Germany, the Wuppertal Institute for Climate, Environment and Energy was a major player to promote this methodology worldwide. Much of the methodological advice laid down in this handbook is owed to their path breaking efforts (Schmidt-Bleek and Bierter 1998, Weizsäcker et al. 1997) and the long-standing collaborations between the research institutions involved (see Bringezu 1993, Bringezu et al. 1997). Concerning national MFA, there exist some minor methodological differences between the Wuppertal approach and the approach laid down in this handbook. While the Wuppertal Institute has strongly promoted "Total Material Requirement" (TMR) as a headline indicator from MFA, we still have some doubts as to the reliable measurability of so-called "hidden flows" and tend to stress more the indicators based upon "direct material flows" that can be linked to economic activities and data at each stage of the economic process. These methodological differences have been resolved within the process leading to the abovementioned methods guidebook issued by EUROSTAT in 2001. The information there, particularly the technical parts, should be used to complement the information spelled out in chapter 2 of this handbook.

In its approach to physical accounting, this handbook extends beyond the methods of national MFA, though. It presents a broader approach to physical accounting by offering a methodology of energy flow accounting in analogue to MFA (EFA, chapter 3) and for accounting for the human appropriation of net primary production (HANPP, chapter 4). These two methods, while not as well established internationally, provide valuable tools for describing other environmentally relevant bio-physical dimensions of socio-economic activities. Finally, the focus shifts from the national to the local level (chapter 5). This chapter pays tribute to the experiences accumulated in several attempts to apply the above methods in developing countries. For developing countries, national data on MFA, EFA and HANPP tell only part of the truth. Within such countries, there exist extreme differences between industrialized and capitalized parts of the economy concentrated in certain regions, and other parts of the country where the population lives on subsistence economy, more or less. These subsistence economy segments usually are hardly reflected in national economic data, and escape MFA and EFA based upon them. Chapter 5 is devoted to methods that allow to measure MFA and EFA indicators in local communities in a way compatible to the MFA and EFA model by field studies and direct measurement. These methods have been successfully applied in eight field studies in seven different countries so far, financed by the European Union (Amazonia 21, http://www.amazonia21.org , South East Asia in Transition, http://www.seatrans.net).

This handbook has served as a guidebook in several international workshops so far. It helped to shape training processes both within projects (see above) and in the context of educating communities of researchers in the application of these innovative methods. It deserves continuous improvements from all those who try to apply these methods, and it will grow further with training exercises and examples. We are grateful to all who wish to contribute.

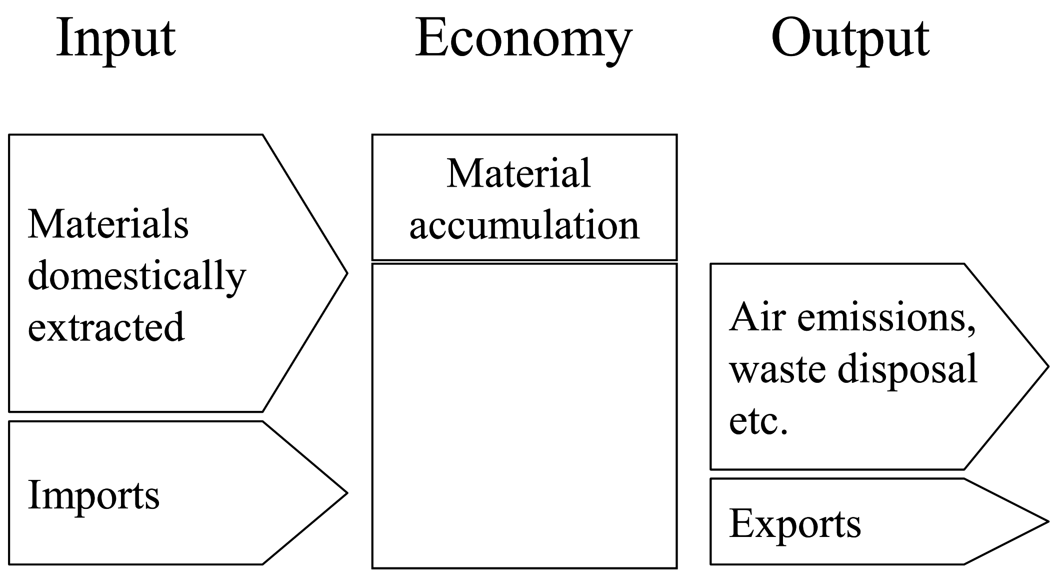
2. ECONOMY-WIDE MATERIAL FLOW ACCOUNTING

by Heinz Schandl and Helga Weisz

2.1. Introduction

A large amount of empirical research was stimulated by notions such as "industrial metabolism" (Ayres and Simonis 1994) or "society's metabolism" (Fischer-Kowalski and Haberl 1993), which imply a new conceptualisation of society's pressures on the environment. The basic idea is that the economy is physically embedded into the environment, i.e. the economy is an open system with regard to matter and energy (see figure 1).

Figure 1: Scope of economy-wide material flow accounts



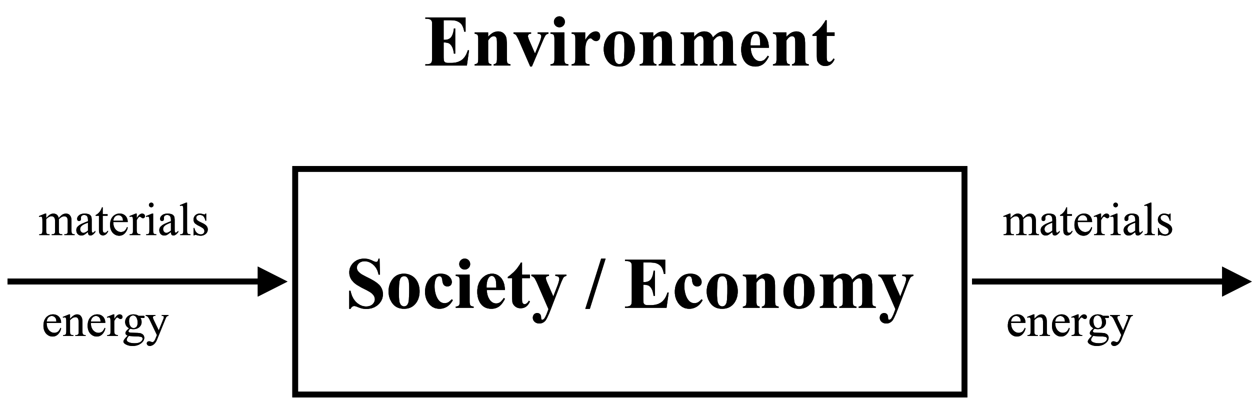
The empirical work appears under the heading of Material Flow Accounting (MFA)[1] and Energy Flow Accounting (EFA) respectively. The aim of both is to give an overall picture of the physical dimension of socio-economic systems.[2]

Economy-wide Material Flow Accounts, which are the topic of this chapter, show the amounts of all materials entering the economy, material accumulation in the

[1] Within the MFA community there are primarily two, at first sight different, approaches, material flow accounting (MFA) concentrating on materials and substance flow accounting (SFA) concentrating on chemical substances like for instance carbon, nitrogen, lead, chlorine and so on. Despite these differences, both approaches result in rather similar methodological assumptions. Moreover, due to methodological correspondence MFA can be linked to SFA rather easily.
[2] EFA will be described in detail in chapter 3.

economy and material outputs back to nature and to other economies (EUROSTAT 2001).

Figure 2: The economy/environment system



Unlike other methods of physical accounting MFA methods have already reached a reasonable level of international standardisation. Important steps in this process were the European Commission funded ConAccount project (1996-1997), two international projects coordinated by the World Resources Institute leading to the widely recognised publications of "Resource Flows: the material basis of industrial economies" (Adriaanse et al. 1997) and "The Weight of Nations: material outflows from industrial economies" (Matthews et al. 2000). Finally, with the publication of a methodological guide "Economy-wide material flow accounts and derived indicators" by the European Statistical Office (EUROSTAT 2001), an officially approved harmonised standard was reached.

National material flow accounts are readily available for a number of national economies yet. Two comparative reports published by World Resource Institute represent a certain degree of harmonisation. Adriaanse et al. 1997 represents comparative data on inputs for four countries (USA, Germany, Japan and the Netherlands), Matthews et al. 2000 resembles data on the output side for five countries (USA, Germany, Japan, Austria and the Netherlands).

Regarding European Countries, Denmark, Finland, Italy, Sweden, the United Kingdom and Poland are the countries that so far compiled MFA data. For non European Countries data is available for Japan, Australia and the USA as well as Bolivia, Brazil, Venezuela, and China. Other countries, for example from the region of Southeast Asia are following. Recently, a report for the EU 15 has been compiled (Bringezu and Schütz 2001).

One summary indicator derived from Material Flow Accounting, what is known as Direct Material Input, is discussed as a physical pendant to the overall GDP of an economy. Interestingly, some countries have already implemented this indicator within official statistics reporting systems.

The significance of the chapter at issue therefore differs from the significance of the following ones. Complementary to the EUROSTAT guide it focuses on the conceptual foundations such as the concept of society's metabolism and its methodological implementation in the form of an accounting framework on material flows. Further, it gives some practical information how an economy-wide material flow account can be established. The technical part is elaborated to a degree, which ensures easy use of both references, which in fact is what we recommend.

2.2. The concept of societies' metabolism

Metabolism is a concept adopted from biology in which scientific context it refers to the physiological processes within living beings that describe the energy turnover connected to the conversion of matter, an intrinsic feature in the reproduction of any organism.

What are the underlying assumptions of the concept of society's metabolism? First, societies must organise a permanent throughput of matter and energy at or above the level of their population's biological minimum. This can be regarded as a minimum condition for any society. Second, different from all other living beings, societies organise this resource throughput purposively, by even changing parameters of natural processes to gain better access to natures resource supply. This entails a wide range of purposive interventions in natural systems, where society's activities do not concentrate on extraction and transformation of resources but do intentionally change natural conditions. Further, resource throughput is mobilised by labour. It is through labour, that raw materials are transformed to use values and are given a specific exchange value due to their capacity to be exchanged. Without inputs of concrete labour (or energy to drive machines to replace concrete labour) their would be (reservedly) no metabolism.

In this understanding we conceive of societies, besides many other features, as systems extracting raw materials from their domestic nature (or buying materials form other socio-economies), subsequently transforming these materials within the economic process to provide material goods for domestic demand (and also for foreign demand). A number of materials stay within the socio-economy forming societies materials stock (like for instance buildings, roads, machines, etc.) whereas other materials are released to the domestic environment in the form of wastes and emissions rather immediately. In the view of metabolism, societies mainly have to face two problems, the ones of resource scarcity on the input side and the override of the absorbing capacity of domestic ecosystems on the output side.

Historically, problems of resource scarcity often have been addressed to technological advance where the argument was, that as long as enough energy is available resource scarcity problems always can be solved by technological solutions. Consequently, societal development and energetic resource use have been seen as linked for a considerably long time and also contributed to social theory formulation. The material aspect of societies metabolism appeared in the discussion more recently. Only in the 1970ies, when certain substances showed to be responsible for environmental pollution, substances and materials appeared in society's consciousness. Around 1990, alongside a paradigmatically shift in the environmental discourse the physical dimension of economic activities became more and more important. Subsequently, this inspires a number of conceptual works dealing with the industrial metabolism (Ayres and Simonis 1994) and societies metabolism as a historical notion (Fischer-Kowalski and Haberl 1998). Nevertheless, apart from some exceptions, sociology as a discipline ignores the feedback's between the social realities and the material realities until today.[3]

However, two important scientific communities have acknowledged the physical accounting framework to be a major tool to address societies environmental problems. These are the International Society for Industrial Ecology and the International Society for Ecological Economics. In both contexts it is shared, that the economy has to be seen as a sub-system of the environment, being embedded into natural processes. The main argument is, that any economic activity has to rely on a certain exchange of material and energy between nature and the economy or within the economy.

2.3. Criteria for Material Flow Accounting[4]

Like any complex accounting system, MFA requires a guiding theoretical framework to ensure the consistency of the numerous decisions to be made. We refer to this as the criteria of **theoretical soundness**.

The guiding theoretical concept for explaining the physical interrelation of society and nature is *socio-economic metabolism*, a concept applied to investigate the interactions between social and natural systems. It is the socio-economic metabolism (see Fischer-Kowalski 1997) that exerts pressures upon the environment. The socio-economic metabolism comprises the extraction of materials and energy, their transformation in the processes of production, consumption, and transport and their eventual release into the environment. Framed like this, MFA accounts for the overall material throughout, i.e. the overall metabolism, of a given socio-economic system. According to this concept we must have a systematic idea of the interaction of the two systems, society and nature and guidelines, of which elements of the material world belong to society and which to nature. That refers to a clear understanding and definition of the boundaries of the system under investigation. We will operationalize these requirements by applying systems theory and natural science considerations.

The usefulness of the MFA approach for informing sustainability strategies will also depend on how the linkage between environmental degradation and socio-

[3] This argument is true for mainstream sociology, especially for the German speaking tradition.
[4] The considerations for this section on criteria for MFA stem from a presentation made by Helga Weisz and Heinz Schandl at the Industrial Ecology Conference at Troyes, France, 1999.

economic activities is conceptualised. The mutual interrelationships between economic, political and environmental processes, available information, the judgement of experts and public awareness is highly complex. The criterion of **political relevance** refers to a well-chosen reduction of this complexity rather than to a full understanding. Policy relevance, then, refers to the strength of the concept to provide information for policy decision and public discourse. Therefore the information must be available relatively quickly and must successfully reduce complexity. Only if this is achieved, can MFA be a tool to operationalize the overall goal of future sustainability.

We propose the following sub-criteria: link to SNA, international comparability, indicating major trends in the ecological performance of societies, application for various levels of intervention, the possibility of time series and scenarios, and compatibility to established environmental information systems.

The application of these criteria would result in the conception of MFA as an umbrella environmental information system that is linked to the SNA, an approach that has sometimes been called "green accounting system".

Finally, like any approach that addresses "real world problems", the criteria of **feasibility** must be applied. This criterion refers to the availability of accurate data sets, which can be used for the MFA account. Further, MFA has to concentrate on a strictly top-down approach such as not to get lost in too many, though interesting, details.

2.4. Theoretical preconditions: system definitions and boundaries

The question raised here is what would theoretically be needed to follow the idea of society's production and reproduction by means of a natural resource background?

First of all it needs a concept of society that does not reduce society to a merely symbolic or cultural system of meanings and beliefs. As has been argued elsewhere (Catton and Dunlap 1978, Benton 1989, Fischer-Kowalski 1997)' society also contains or consists of material elements further on addressed as the physical components of a socio-economic system.

2.4.1. Physical components of socio-economic systems

We identify certain material elements to be physical components of a socio-economic system by using the concept of labour as a starting point. In this understanding, we consider every part of the material world that is produced by, or is periodically maintained by, human labour as being material components' of society. This argument of labour investment for maintenance is first of all true for humans (or human bodies). It also accounts for livestock and, even more widely shared, for the wide range of what we call artefacts. With the notion of artefacts, we try to subsume the whole man-made infrastructure, such as, for example buildings, roads, dams and sewers, machinery, vehicles, furniture and so forth. We argue that everything that is used by society for a period longer than a year should be considered as part of these physical components of society.

This implies that the complete metabolism of humans and of animal livestock has to be included in society's metabolism. It comprises nutrition, intake of oxygen and water, excretion, output of carbon dioxide and water, and also the deposition of dead bodies. One consequence of considering livestock as a physical component of the socio-economic system is that products from livestock like meat and milk, and so on are not treated as inputs from the environment into the socio-economic system. They have to be looked upon as transfers within the socio-economic system.

Theoretical considerations have been raised about whether to include plants as a component of the socio-economic system insofar as they are maintained by labour in agriculture and forestry. Here we suggest for pragmatic reasons that plants should not be considered as a component of the socio-economic system (Fischer-Kowalski 1997). Therefore, in the same way as they appear in agricultural statistics, plant harvest can be seen as an input to the socio-economic system whereas manure and fertilisers are an output to nature. If agricultural plants were considered as part of the socio-economic system, the boundary between this system and its natural environment would be pushed outward, to the mineral level, expect for fishing, hunting and gathering. Although there can also be reasonable arguments for the consideration of agricultural plants as part of society, this would not correspond to the economic logic of the System of National Accounts (SNA) or to any economic statistics, which we consider as the most important criteria for policy relevance.[5]

Finally, we consider artefacts, the man-made and maintained technical structures as physical components of the socio-economic system. This recognises powers of re-naturalisation, which are valid for all artefacts. Once society suspends further maintenance the process of naturalisation unavoidably starts and we not longer regard an object to be part of society's material components.[6]

According to convention two, all materials that serve to produce or reproduce (maintain) the physical components of the socio-economic system belong to its metabolism and therefore are counted as inputs res. outputs within material flow accounting. This draws our attention to the differentiation between stocks and flows.

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[5] However, Stahmer et al. (1998) treated agricultural plants as component of the socio-economic system in their physical input-output analysis for the German economy for 1990. On the contrary, but alongside our own argumentation here, the physical input/output tables for Denmark treat agricultural harvest as input into the economy and livestock as being produced within the economy (Pedersen 1999).

[6] Undoubtedly, this idea could activate criticism regarding the correspondence of the introduced concept of 'belonging to a society' with other categories like property rights. We acknowledge here that this problem of correspondence has to be discussed in future research.

2.4.2. Stocks and flows

Once these components are recognised (human bodies, livestock and artefacts) every material flow that produces or reproduces these components is considered to be an input to society's metabolism. These material flows are set in motion via society's activities to produce and maintain society's material stock (equating the material components). A reliable distinction between stocks and flows is a prerequisite for determining whether a socio-economic system is still growing in physical terms, is in a steady state, or is shrinking. This should refer to the size of the population, the size of the livestock and the weight of the artefacts (the infrastructure). Accordingly, an operational distinction between size and metabolic rate, between the growth rate and the energetic/material turnover of the socio-economic system can be drawn. Clearly, there is a close link between stocks and flows and also a positive feedback. The bigger the material stocks are, the bigger the future material flows needed to reproduce the material stock will be. This positive feedback can also be stated for future use of energy resources, labour investments, and monetary expenditures.

2.4.3. The law of "conservation of mass"

One basic idea of MFA should be the attempt to reach a full balance integrating the input and the output side. This idea of a mass balance is one of the most powerful features of the MFA approach. In terms of policy, this approach allows for the development of integrated resource and waste/emission strategies. Balancing is also a methodological tool, as it provides a framework for consistency checks and estimation of data gaps. For material balances the first law of thermodynamics, the "law of conservation of mass" applies, which is also a leading theoretical criterion for material accounting. The law of conservation of mass attributed to MFA results in the following equation:

The sum of material inputs into a system = the sum of outputs corrected by changes in stocks.

This equation applies not only to the system as a whole but also to all its sub-systems to which we refer as components of the system.

The metabolism of the socio-economic system can be broken down into the metabolisms of its physical components. For each component, the law of conservation of mass applies.

This convention follows a systems approach that has so far been applied in a variety of disciplines. Biology, for example, conceives of an organism as an integrated entity, which is composed of interdependent components like organs or cells. Likewise, economics, especially in input/output analyses, conceives of a national economy as an integrated system composed of interdependent sectors. In both biology and economics the components or sectors are considered as entities which operate their own metabolism or input/output relationships respectively. According to this, we look at the metabolism of socio-economic systems as being composed of interdependent self-organising components that maintain their own metabolism, rather than being just an assembly of "material flows".

Due to the problem of double accounting, the sum of all material inputs and outputs of the components of a system does not equal the total material inputs and outputs of the system. The recently published physical input output table for Denmark (Pedersen 1999) discusses this for animal and vegetable products. The sum total of the weight of the intermediate consumption of these materials exceeds the amount of primary input to a large extent. This can be traced back to the disaggregation into components (sectors), as the metabolism of a component also records the processing of materials within the system. In highly functional differentiated economies, the output of one sector typically serves as input into others. Treating components as systems with their own metabolism emphasises, increasing with the degree of disaggregation, flows within the economy. The material interdependencies between the components/sectors of an economy become visible.

2.4.4. Water, air and "materials"

We distinguish between three main groups of input materials: water, air and all the other materials. The latter, the heterogeneous group of the non-air non-water fraction, consists of raw materials, semi-manufactured materials and final goods. Raw materials can further be differentiated into biomass, mineral materials and fossil materials. Such a differentiation is not appropriate for semi-manufactured materials and final goods as they appear as a material mix.

Water, air and materials should not be summed up. This has to do with the common-sense idea of not literally "drowning" economically valued raw materials and commodities in water and air.[7] However, this distinction does not hold up on closer examination, as the non-water non-air fraction is not free of water and air. Even worse, the content of water and air of the various materials changes due to natural processes (like evaporation, oxidation) and due to technical processes within the socio-economic system. Therefore, a consistent distinction between the three groups needs practical agreements. They are the following:

(a) Water and air that serve as a transport medium are reported as an important part of socio-economic metabolism but are not included in sum indicators like "direct materials input". (b) Inputs of the non-air-non-water fraction are counted, including water and air content, when they cross the border into the socio-economic system under investigation, that is usually when they are marketed. Therefore, all inputs are accounted for as market weights, with the important exception of timber, which is counted with standardised water content of 14 %. (c) Water and air that become part of a material good during the production process are considered as part of the mass balance. These amounts

[7] A case study on Austria's economy wide Material Flow Analysis shows that water and air together account for 95 % of the total weight of materials input (Schandl et al. 1999).

of water are referred to as additional inputs of water and air. (d) Inputs that are not marketed like green fodder grazed by cattle are also accounted for with standardised water content of 14 %.

2.4.5. Direct materials input and hidden flows

We defined all flows that pass through at least one of the physical components of the socio-economic system as input flows. Yet these economically used flows don't tell the whole story when it comes to evaluating society's natural performance. There exist two different kinds of "hidden flows" that also contribute to society's impact on the environment. One is related to domestic material extraction, the other to trade flows. The first, unused domestic extraction, refers to materials intentionally mobilized but not foreseen for later use, such as overburden from mining, by-products from agricultural harvest, and by-catch from fishing.[8] This group of hidden flows portrays additional impact occurring domestically.

Trade-related hidden flows tell a different story. They describe environmental impacts that are connected to the international division of labor. Accounting for hidden flows that occur in relation to imports and exports, respectively, allows us to estimate the shifting of environmental impact from one economy to another. This group of hidden flows still offers an array of methodological difficulties, since trade flows consist of raw materials, semi-manufactured goods, and final products, where each group has to be treated differently regarding their hidden flows. Essentially, when accounting for hidden trade flows, one has to be careful not to undermine the systems perspective of MFA (the underlying logic of input and output) by introducing a life-cycle approach (which does not ascribe material use to any particular system).[9] For traded raw materials it seems appropriate to consider related foreign unused extraction as hidden flow. For semi-manufactured or final products one could recalculate the traded flows into their raw material equivalents and consider then the appropriate relevant hidden flows.[10]

Especially hidden flows related to foreign trade are of crucial political importance when dealing with questions of globalization, uneven development, or the international division of environmental impact. Hence, accounting for an accurate and politically relevant indicator is a crucial need. However, the Total Material

[8] Especially the Wuppertal Institute has promoted the idea that soil erosion be seen as part of unused domestic extraction. We differentiate unused (not economically used but intentionally mobilized) from all side effects of economic activities which appear in natural systems, such as soil erosion or even loss of biodiversity. Whereas the first can be part of an account of hidden flows the latter should not be.

[9] Nonetheless, Life Cycle Analysis (LCA) offers a useful policy tool and an information tool for consumers (see Schmidt-Bleek 1993).

[10] Still, serious problems remain. Whereas for raw materials one can assume that the related unused extraction appears in the country of origin, this is not true for intermediate and final products. The necessary raw materials might have been extracted in a third country, and even the country that imports the final product might have been the domestic extractor of the preceding raw material. Such difficulties represent an unassessable source of double counting.

Requirement (TMR) approach (see Bringezu 1993, Adriaanse et al. 1997) does not represent the accuracy and reliability such an indicator would deserve.

2.5. Sub-accounts and data sources

From a more technical point of view Material Flow Accounting can be broken down into different sub-accounts. We differentiate between the input side (input account) and the output side (output account) of the socio-economic metabolism. These two sides of accounting should be linked within a material balance. In bringing together inputs and outputs, the idea of a material balance focuses on the economic processes between inputs and outputs. Therefore, the material balance opens the black box of an economic system.[11]

Table 1 A Categorization of Material Flow Accounting

Internal Flows Production – distribution – consumption (serves to produce and reproduce the material components of a society)	**Material Outputs** Waste and emissions on a domestic territory Material exports to other socio-economic units
Material Inputs Material extraction on a domestic territory Material imports from other socio-economic units	

Basically, we distinguish two empirical approaches. One approach is a full balance of inputs and outputs within an input-output framework for one year (usually in the near past). The other approach concentrates on time series for inputs and outputs but does not take the relation between them into account. Both approaches deserve different methodological treatment. The full balance for a year (material balance) should necessarily be based on an input/output accounting framework comparable to economic input/output tables (Weisz et al. 1999) and hence should take all available sources of evidence (like detailed case studies for certain sectors or materials) into account. Unlike this, a time series for inputs or outputs (material flow analysis) should restrict itself to periodically available data sets and should be reserved against data sources which are basically created for one specific point in time. Like material balances, time series analysis can largely profit from the insights gained by a full balance, due to cross checks that strengthen the accuracy of the data set.

On the input side we principally distinguish inputs of water, air and materials. As has been acknowledged earlier, the metabolism of an industrial society consists of 85 % of water, about 8 % of air and 7 % all other materials (Schandl et al.

[11] Further considerations can be drawn from Weisz et al. (1999) which introduce a highly aggregated input/output table allowing for consistency checks and also for the derivation of physical environmental indicators. More importantly, the framework shows possibilities of linking different input factors like energy, materials and labour.

1999). However, many empirical works ignore water and air. Hence, they cover domestic extraction and harvest of materials and imported materials. These input categories will distinguish between biomass (agricultural harvest, timber harvest, fishing, hunting, collecting of wild vegetables, mushrooms and honey), mineral materials (ores, clay, industrial minerals, sand, gravel and crushed stone), and fossil materials (coal, natural gas, and crude oil). A fourth main category of input covers materials mainly manufactured as they appear via foreign trade. These materials are very often a mix of the above mentioned raw material categories and will, therefore, not be allocated to one of these categories.

The practicability of the data gathering process should be guided by several main principles. First of all, focussing on periodically available data supplied by official statistical bodies is advisable. Data collections, which could already provide a certain level of aggregation should be favoured. On the other hand, it should be a methodological guideline not to extensively use case studies, which could provide an in-depth picture on a specific problem, but could by no means help to establish sufficient time series data. This is due to the fact that the time series should end up with a summary aggregate, which will not change its magnitude permanently by embedding special knowledge of such, nevertheless important, case studies.

Data sources usually available as a basis for the empirical work and data quality are presented in table 2.

Table 2 Data sources and data quality

Internal Flows Production – distribution – consumption (serves to produce and reproduce the material components of a society) <u>Data quality usually high</u> Industry and Trade Statistics Economic Input Output Tables	**Material Outputs** Waste and emissions on a domestic territory <u>Data quality is varying</u> Environmental statistics, emission monitoring, waste statistics Material exports to other socio-economic units <u>Data quality usually high</u> Foreign trade statistics
Material Inputs Material extraction on a domestic territory <u>Data quality usually high</u> Agricultural-, forestry-, fishing- and hunting statistics Mining statistics Material imports from other socio-economic units <u>Data quality usually high</u> Foreign trade statistics	

Beside data compiled from national statistical offices data might be taken from international data sources, which already represent a certain degree of data comparability between different countries. However, for special problems more detailed information might only be available in national statistical compendia. Sometimes, it will prove to be useful to even gain expert information in a respective country to base estimates on reliable expert knowledge.

Following, we will review the most important international data sources for physical accounting:

2.6. The input side of a material flow account

For the input side of an Material Flow Account we distinguish between direct inputs entering a socio-economic unit and materials mobilized together with direct inputs but however do not enter the economy. Direct inputs stem form both domestic materials extraction and imported materials.

Direct (or used) material inputs contain water, air and materials (other than water and air). These materials are either solid, liquid or gaseous and enter the production – distribution – consumption chain. Material inputs of domestic origin (i.e. domestically extracted materials) are classified into three main groups of materials:

- fossil fuels (fossil energy carriers)
- mineral materials (metal ores, other industrial minerals, and construction minerals)
- biomass

Imports are classified according to their level of manufacturing at least into raw materials and products (both semi-manufactured and final goods). Raw material imports are further classified accordingly to domestically extracted raw materials into three subgroups, namely fossils, minerals, and biomass.

Unused domestic extraction refers to material flows that are mobilized in order gain certain materials for economic use or as a side-product of extraction. It comprises of three major groups.

Firstly, unused extraction from mining and quarrying activities, such as extraction wastes, overburden, and parting materials.

Secondly, unused extraction of biomass harvest, such as by products of agricultural and forestry harvest, by-catch from fishing, etc.

Thirdly, soil and rock excavation being connected with construction activities and dredge materials (extracted in dredging activities).

Beside these domestic unused flows there occur indirect flows in third economies whenever a certain import takes place. We call these flows indirect flows associated to imports. The proportion of direct imports to indirect flows associated to imports signifies a certain degree of shifting the environmental burden form one country to another. In other words, this proportion refers to the unequal exchange of environmental pressures or externalities.

Regarding indirect flows from raw material imports, these flows can be rather easily estimated as the related unused extraction in the exporting country. With regard to products, such an estimation is still more complicated. It is not always clear, that the initial extraction process took place in the exporting country. It might have taken place in any third country. Another problem imposed when trying to estimate indirect flows associated to imports is the fact, that the input-output logic of the accounting framework might easily be contradicted by a life cycle approach. These, however, are problems still to be solved.

Table 3 Summary of terminology for material input categories (see EUROSTAT 2001).

	Direct	Other
From national territory	(A) Used extraction	(C) Unused extraction
From abroad	(B) Mass weight of imports when crossing the boarder	(D) Indirect flows associated to imports

Legend: (A) + (B) = Direct Material Input (DMI). (C) + (D) = Material Flows associated to DMI but not being part of it. They were also named Hidden Flows (HF). DMI + HF = Total Material requirement (TMR).

Some problems that might arise while calculating the input side of the MFA

Iron ores or other ores – Ores are documented within mining statistics, usually following a run of mine concept. Hence, numbers in the statistical source refer to the ore (i.e. metal and associated rock) extracted. However, this is not always the case. Sometimes data sources report the metal content of a certain metal. Economy-wide MFA regards the ore as the appropriate form of input. Whenever data sources report metal contents the original weight of the ore has to be recalculated by using appropriate calculation factors.

Timber – Timber exposes numerous problems. One is due to the specific importance of water content when accounting for timber inputs. In forestry statistics timber might occur with a water content of around 55 % at the time when harvested (green weight) or with a water content of around 35 % when removed from the woodland. It has been agreed to include timber in the MFA with a water content when removed from the woodland. Secondly timber occurs in units of volume (cubic meter, etc.). These units have to be converted to mass by using specific conversion figures for different sorts of trees as being presented in our website (see conversion tables).

Animal Grazing – Animal grazing is part of direct material input. However, since the actual amounts grazed by livestock animals is not part of official statistics, the amounts have to be estimated. Usually, this is done by calculating the harvest potential of pastures (according to their quality) and by also including an assumption of the proportion actually being grazed by certain animals. Clearly, numbers for animal grazing are always soft data which can only gain accuracy on the basis of a fodder balance for livestock animals.

Sand, gravel and crushed stone – The group of construction mass minerals is often underrepresented in official statistics. This can have several reasons. Significant amounts might be extracted within certain property rights and hence they are not part of the market. Thus, they don’t appear in statistics. They might also be extracted from small companies not being included in the surveys of statistical bodies. For reasons as such they are often object to under-evaluation and amounts have to be corrected.

Table 4 Detailed classification of material inputs

DIRECT INPUTS

(A) DOMESTIC EXTRACTION (USED)

- Domestic extraction of water
  - Ground water
  - Surface water
- Domestic extraction of air
  - Air for breathing of humans and livestock
  - Air for combustion processes
  - Air for other technical use (e.g. fertiliser production, cement production)
- Domestic extraction of materials
  - Domestic extraction of fossil fuels (fossil energy carriers)
  - Domestic extraction of mineral materials
  - Domestic extraction of biomass

(B) IMPORTS

- Imported raw materials
  - Fossil fuels
  - Mineral materials
  - Biomass
- Imported semi-manufactured products
- Imported finished goods[12]

UNUSED DOMESTIC EXTRACTION AND INDIRECT FLOWS ASSOCIATED TO IMPORTS

(C) UNUSED DOMESTIC EXTRACTION

- Unused extraction from mining and quarrying
  - of fossil fuels
  - of minerals
- Unused extraction from biomass harvest
  - of plant harvest
  - of wood harvest
  - from fishing and hunting
- Soil excavation
  - excavation for construction activities
  - dredging materials

(D) INDIRECT FLOWS ASSOCIATED TO IMPORTS

- Indirect flows associated raw material input
- Indirect flows associated to semi-manufactured products or finished goods.[13]

2.7. The output side of a material flow account

[12] The EUROSTAT guidebook (EUROSTAT 2001), in comparison, allocates all semi-manufactured goods and final goods to the three main material categories. We do not suggest to follow this decision, since the different steps of processing, which are represented by semi and final goods, have to be treated separately in many respects.

[13] There is still a massive discussion on whether and how to properly integrate these flows.

Material outputs of an economy are classified by their destination. They are heading towards other socio-economic units (exports) or are exposed in a domestic environment (wastes and emissions). For waste and emissions we identify the gateways of these outputs, whether they are the air, water or soil. According to this, the main groups of emissions and wastes are

- emissions to air
- waste land filled
- emissions to water

Besides waste and emissions, outputs can also be related to dissipative use of certain products (such as fertiliser, pesticides, seeds, etc.) or as dissipative losses from consumption (such as abrasion or leakages). Dissipative use of products and dissipative losses are defined as the quantity of materials being dispersed into the environment as a deliberate activity, or unavoidable consequence of product use. Dissipative uses or losses occur mainly

- due to agricultural technologies (fertiliser, manure, etc.)
- due to road management (sand, salt, etc.)
- due to corrosion and abrasion of products and infrastructures
- due to leakages

Exports are classified in the same way as imports. Comparing imports and exports allows to account for physical trade balances. Accordingly, indirect flows associated to exports might be regarded in the same way as for imports.

Table 5 Detailed classification of material outputs

EMISSIONS AND WASTES
➢ Waste land filled
- from private and public households
- from industry and commerce
- from waste and waste water management activities
➢ Emissions to air
- from combustion and industrial processes
- from respiration of humans and livestock
➢ Emissions to water
DISIPATIVE USE OF PRODUCTS AND LOSSES
➢ Dissipative use of products
- Dissipative use on agricultural land
- Dissipative use on roads
- Dissipative use of other kind
➢ Dissipative losses
EXPORTS
➢ Exported raw materials
- Fossil fuels
- Mineral materials
- Biomass
➢ Exported semi-manufactured products
➢ Exported finished goods
DISPOSAL OF UNUSED MATERIALS DOMESTICALLY EXTRACTED (see corresponding input category)
INDIRECT FLOWS ASSOCIATED TO EXPORTS (see corresponding input category)

2.8. Linking inputs to outputs (an aggregated PIOT approach)

A next step for the integration of inputs and outputs to foster the consistency of the material flow account would be an aggregated Physical Input Output Table (PIOT) approach. This would mean to open up the system by linking inputs to outputs within an overall understanding of internal interlocking. To be able to do this, one should start with a rather superficial picture of internal complexity, as provided by a three sector model of an economy. This model necessarily should be established within an input/output framework (see Weisz et al. 1999).

Having understood the systematic of this, we might think of a more complex sector model at least including eight to ten sectors but not more than that. In such a model, we still can analyse data on a top-down basis ensuring readiness and actuality. In a next step, we can think of the relation of a certain economic sector to the overall structure. On the one hand, data for a sector can be organised in the same way as data for the whole economy. On the other hand we can zoom out one sector from the overall table and also link it back again.

Let us just briefly explain the logic of a rather simple input output model and mention where the data to fill such a model might stem from.

The aggregated physical Input Output Table (aggregated PIOT) as well as any sub-table consists of three quadrants, the input quadrant (left below), the processing quadrant (left above) and the output quadrant (right above). Additional rows or even whole quadrants, which allow to estimate additional items of interest, such as unused extraction and indirect flows associated to imports might be provided. All input flows within the table are shown vertically along the columns from the bottom up whereas all output flows are shown horizontally along the rows from left to right.

The input quadrant contains all inputs into the system. We call these inputs primary inputs to emphasise that they cross the border of the system to be balanced. For an aggregated PIOT calculation on the economy-wide level we differentiate between four input categories. Domestic extraction of resources (raw materials, water and air) and imports (inputs from other economies). The sum total of the primary inputs is the direct material input (DMI).

The processing quadrant contains all material flows within the economic system. Rows and columns are equally differentiated into three aggregated economic sectors, the primary production sector (agriculture and mining), the industry sector (including construction) and the service sector (including, besides other activities the public and private households). For these sectors the sectoral input has to equal the sectoral output. Stock changes, independently where they occur, are treated as a separate sector. Here inputs do not have to equal outputs.

Table 6 The general structure of an aggregated PIOT table

	Primary production	Industry	Services, households	stock changes		Export	Emissions	Deliberate disposals	
Primary production	x_{11}	x_{12}	x_{13}	x_{14}	domestic goods ($x_{12}+x_{13}+x_{14}$)	o_{11}	o_{12}	o_{13}	output (o_{11} to o_{13})
Industry	x_{21}	x_{22}	x_{23}	x_{24}	domestic goods ($x_{21}+x_{23}+x_{24}$)	o_{21}	o_{22}	o_{23}	output (o_{21} to o_{23})
Services, households	x_{31}	x_{32}	x_{33}	x_{34}	domestic goods ($x_{31}+x_{32}+x_{34}$)	o_{31}	o_{32}	o_{33}	output (o_{31} to o_{33})
stock changes	x_{41}	x_{42}	x_{43}	x_{44}	**stock outputs** ($x_{11}+x_{42}+x_{43}$)	o_{41}	o_{42}	o_{43}	output (o_{41} to o_{43})
	secondary input ($x_{21}+x_{31}+x_{41}$)	secondary input ($x_{12}+x_{32}+x_{42}$)	secondary input ($x_{13}+x_{23}+x_{43}$)	**stock inputs** ($x_{14}+x_{24}+x_{34}$)	total processing matrix ($x_{11}+ x_{12}+ \ldots +x_{44}$)	exports (o_{11} to o_{41})	emissions (o_{12} to o_{42})	deliberate disposals (o_{13} to o_{43})	**direct output**
Domestic Extraction	i_{11}	i_{12}	i_{13}	i_{14}	domestic extraction (i_{11} to i_{14})				
Water	i_{21}	i_{22}	i_{23}	i_{24}	water (i_{21} to i_{24})				
Air	i_{31}	i_{32}	i_{33}	i_{34}	air ($i_{31}$to i_{34})				
Imports	i_{41}	i_{42}	i_{43}	i_{44}	imports ($i_{41}$to i_{44})				
	primary input (i_{11} to i_{41})	primary input (i_{12} to i_{42})	primary input (i_{13} to i_{43})	primary input (i_{14} to i_{44})	**direct input**				

Source: Weisz et al. (1999)

The cross line in the processing quadrant contains intra-sectoral flows, referring to flows that are transferred between actors within the same sector. Sectoral inputs which are transferred within the economic system by other sectors of the same economy are defined as secondary inputs. These secondary inputs make up the total secondary input of a sector (here, intra-sectoral flows are not included). Primary inputs and secondary inputs make up the total input of a sector.

Analogous, output flows that go from one sector within the economy to other sectors of the same economy can be aggregated to domestic goods produced in one sector.

The output quadrant contains all flows that leave the economic system to be balanced. Preferably, here it should be distinguished between exports, emissions (to land, air and water) and dissipative use and loss of materials (such as fertilisers, seeds, pesticides, but also abrasion and leakages, etc.). All flows in the output quadrant can be summed up to make the direct output.[14]

For the total consistency check the calculation of the aggregated PIOT table has to fulfil the equation:

direct input = direct output + stock inputs – stock outputs

For a sectoral consistency check, total sectoral input (i.e. primary input plus secondary input) has to equal total sectoral output (i.e. domestic goods plus output into nature and into other economies). This sectoral equation rule is true for the economic sectors within the aggregated PIOT table but is not be valid for stock changes.

This kind of table directly represent a flow chart and vice versa. An aggregated economy-wide material balance as presented here is still too complex to be calculated in one step. For this reason material flows might be divided into five groups and the balances would be calculated separately for each group, using sub-tables. Sub-tables clearly have to be structured in a way that allows for aggregation to an overall table by summing up. The difficulty with this approach is, that both double counting's must be avoided and completeness must be achieved.[15]

It has to be stated, that the suggestion to consider material categories as a starting point for sub-tables is not the only opportunity to take. Especially for a sectoral approach, a functional differentiation along raw materials, semi-manufactured materials and final goods might be more promising. Nevertheless, for raw materials the difference between biomass, mineral materials and energy carriers might make sense again. Actually, this solution has been favoured by the input/output approach (Stahmer et al. 1998).[16]

The input/output approach as represented in the aggregated PIOT might also help to structure available data sources. Data to fill the input quadrant stems from Agricultural, Forestry, Fishing and Mining Statistics, and from Foreign Trade Statistics. Data to fill the intermediary quadrant can be obtained from Industry and Trade Statistics and Monetary Input Output Tables. Finally, data to fill the

[14] Matthews et al. (2000) successfully tries to set a standard for indicator classification both for inputs and outputs. One major indicator for outputs there, namely DPO (Domestic Processed Output) does not subsume exports. The argument established there is, that exports will contribute to waste and emissions in other countries.

[15] Of course double counting is a general problem of any MFA. The decision for sub-tables, however, adds additional traps for double counting.

[16] A definition of sub-tables according to five major groups of input materials, namely water , air, biomass, fossil fuels and mineral materials as a consequence introduces a substance logic into the structure of the aggregated PIOT, which generates some consistency problems. This can easily be illustrated by considering the sub-table for fossil fuels. The input quadrant contains the gateways from which fossil fuels enter the economy. These gateways are domestic extraction and imports. Difficulties emerge if the materials are not raw materials but semi-manufactured materials or final goods. These groups of materials usually represent a mix of different raw material categories and cannot easily be related to either one of the main categories (fossils, minerals or biomass). On the input side this is the case for imports. One decision could be to integrate imported products according to their main component into the different sub-tables. This would indeed help to avoid overlaps between different sub-tables, which would have to be considered when summing up.

output quadrant is available in Foreign Trade Statistics and Waste Statistics, Emission Monitoring Statistics, respectively (see table 2, above).

Clearly, an aggregated table should not be based on three sectors but rather on a ten sector model to allow for more sophisticated information.

2.9. Indicators from the material flow accounting framework

In this section we will present a set of indicators derived from the MFA framework. We differentiate between input indicators, output indicators and consumption indicators (see table 7).

Input Indicators

Direct Material Input (DMI) measures the amount of materials directly used in an economy, i.e. all materials which are of economic value and/or are use in production and reproduction activities. DMI equals domestic (used) extraction plus imports.

Total Material Requirement (TMR) includes, in addition to DMI, the unused domestic extraction and the indirect flows associated with imports. It portrays the total material background of an economy with respect to overall use of the environment. Despite being used in several international studies (e.g. Adriaanse et al. 1997) their are still open methodological questions of how to empirically achieve such an indicator. Additionally, the two different parts of the "hidden flows" tell very different stories.

Output Indicators

Domestic Processed Output (DPO) refers to the amount of materials, both from domestic extraction and imports, that were object of production within a countries economy, before being delivered to natural sinks. These flows occur at every stage of the extraction, production, distribution, and consumption chain. Exported materials are not considered to be part of DPO because their wastes occur in other countries. Included are all wastes and emissions and dissipations, whereas recycled materials are considered to stay inside the economy, and hence are also not part of DPO.

Total Domestic Output (TDO) refers to DPO plus unused extraction. This indicator represents the total quantity of material outputs to the environment caused by economic activity.

Direct Material Output (DMO) refers to DPO plus exports. This indicator portrays the total quantity of outputs, both to the environment or to other social units.

Total Material Output (TMO) refers to TDO plus exports and hence corresponds to TMR on the input side.

Consumption Indicators

Domestic Material Consumption (DMC) is a very rough indication of domestic consumption of materials. It includes intermediary and final consumption. DMC is also a rough equivalent to national account measures of aggregate income. DMC equals DMI minus exports.

Net Additions to Stocks (NAS) measures the 'physical growth of an economy', i.e. the yearly material gross addition to stock. The balance between gross additions and removals from stock is the net addition to stock.

Physical Trade Balance (PTB) measures the physical trade surplus or deficit of an economy.

For more technical aspects of the accounting we like to draw the readers attention to the recently published EUROSTAT methodological guidebook (EUROSTAT 2001), which contains more detailed list and tables and also answers to more specific questions. For more detailed results and discussions on the output side of material flow accounting see Matthews et al. 2000.

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3. ECONOMY-WIDE ENERGY FLOW ACCOUNTING

Helmut Haberl

3.1. Goals of energy flow accounting

Energy flow accounting (EFA) aims at the establishment of a *complete balance of energy inputs, internal transformations, and energy outputs of a society* or of a defined socioeconomic component in a way that is compatible with MFA. This chapter will describe methods that can be used to establish accounts of the energetic metabolism of national economies in this sense. Besides presenting methods to track inputs and outputs, it will also propose notions and concepts that can be used to describe internal energy flows. In its most simplified version the concept of EFA is presented in Figure 1.

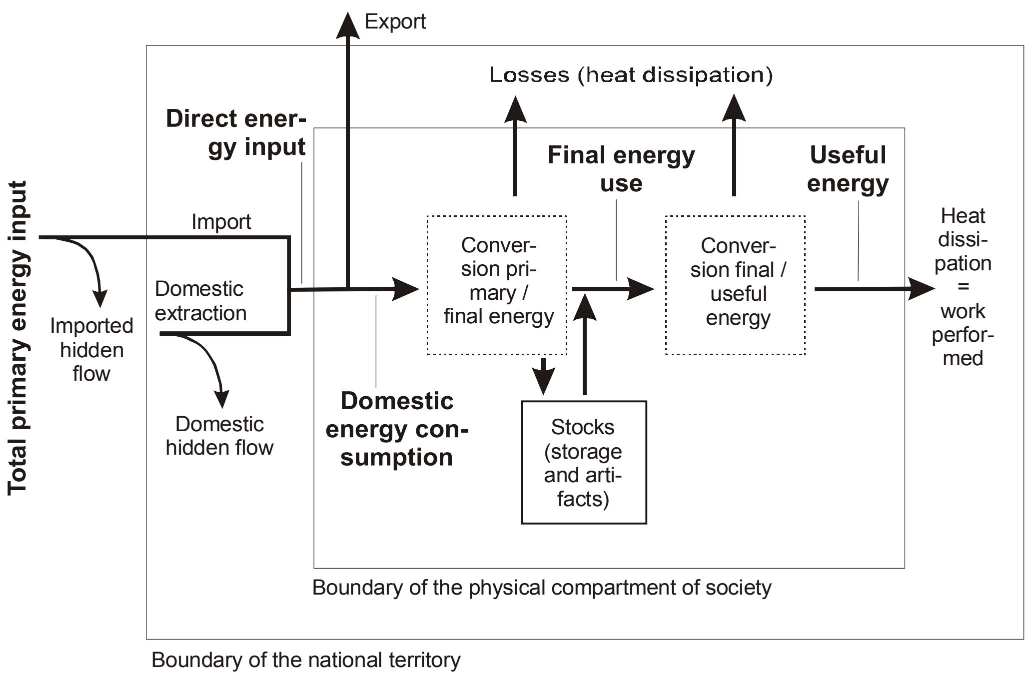


Figure 1: The concept of energy flow accounting (EFA) on the national level: important notions of EFA

Crucial issues include:

- **Compatibility with MFA:** It is essential that system boundaries are compatible with those of material flow accounts (MFA). This means that all energy inputs and outputs of physical components of society (socioeconomic stocks) accounted for in MFA – that is, humans, domesticated animals, and artifacts – are regarded as energy inputs / outputs of society.

- **Energy balance approach:** We are interested in the balance of energy inputs and energy outputs of the socioeconomic system under consideration; i.e., with MFA compatible boundaries. That is, inputs into the system must equal outputs from the system plus stock changes. This goal is different from a widely applied methodology in energy analysis, namely the calculation of the proportion between socioeconomic energy inputs into a defined process and energy gained for socioeconomic purposes (e.g., the „energetic return on investment" of various agricultural practices expressed as biomass energy harvested per unit of socioeconomic energy invested).[17]

For transition studies EFA is highly important for several reasons:

- Changes in the socioeconomic energy system are very important for sustainability: patterns of resource use (energy input), greenhouse gas emissions from energy use (fossil energy use), land-use patterns and changes in land use.

- Only a comprehensive EFA is broad enough to cover the main changes in the socioeconomic energy system involved in a transition from the agrarian mode of subsistence to the industrial mode of subsistence: according to conventional energy statistics, agrarian societies seem to have practically no energy consumption at all, because all important energy conversion processes (human nutrition, animal nutrition) are excluded.

- EFA links socioeconomic metabolism and land-use related indicators and parameters, as, for instance, HANPP (see chapter 2.1.3).

- Industrial modernization is a process that involves a great deal of substitution of work of machines for human and animal work. This transition can be studied empirically by means of a „useful energy analysis" as described in this chapter.

3.2. System boundaries and accounting methods

Energy flow accounting (EFA) vs. Conventional energy balances (CEB)

Energy balances provided by national and international statistical bodies are commonly used in economics to describe and analyze societal energy flows. In this context it is important to distinguish between *energy statistics* and *energy balances*. Energy statistics report *collected* data on the energy flow of defined socioeconomic energy sectors or conversion processes (e.g., IEA 1992; UN 1997). They do not necessarily provide a consistent picture of the energy flow through an economy. In contrast, energy balances trace the flow of commercial energy through the economy in a consistent manner. Contrary to energy statistics, energy balances also contain values *calculated* from statistical data – e.g., for energy conversion processes – based upon equations which guarantee that for every conversion process the energy inputs and outputs are equal, in

[17] The two approaches are complementary, not competing: they ask different questions and get different answers, but are equally important.

accord with the first law of thermodynamics (Bittermann 1999; IEA 1995). That is, energy statistics can be seen as a collection of data, as some kind of "measurement" of socioeconomic processes, whereas energy balances are a model of socioeconomic processes derived from these data.

Conventional energy balances (CEB) and energy statistics are indispensable data sources for any analysis of the energy metabolism of a country. However, it is essential to understand that the differences between conventional balances and the kind of EFA – which is, of course, also an energy balance – that will be described here:

- Conventional energy balances (CEB) only cover the energy used to build, maintain and operate one of the socioeconomic components analyzed by MFA; that is, artefacts. CEBs usually include all technical energy transformations in a national economy; that is, they account for the energy extracted domestically or imported in order to produce useful energy (mechanical work, high or low temperature heat, light, electronic data processing) by technical means; that is, through machinery. By contrast, EFA aims to assess all energy inputs into socioeconomic components as defined by MFA; that is, it also includes energy inputs of humans and domesticated animals, and inputs of energy-rich materials that are used for other purposes than energy generation (e.g., wood for construction, paper, furniture, etc.).

- CEBs mostly consider the so-called "non-energetic" utilization of some energy-rich materials; i.e., fossil fuels, but not that of all other energy-rich materials (above all biomass). Most CEBs have a special category of use of fossil fuels that is termed "non-energetic utilization", meaning, for example, the use of certain oil products for the production of chemicals, plastics, asphalt, etc, but CEBs do not normally consider biomass inputs used for other purposes than combustion. By contrast, EFA considers all inputs of energy-rich materials (i.e., combustible materials), above all biomass, no matter for what they are used, when calculating the energy input of a society.

- CEB often only include energy flows through the "official" economy; that is, they cover only energy flows that are regulated through market activities. In developing countries this can mean that considerable non-market flows, regulated in the subsistence economy, especially biomass used as fuel in the residential sector, are excluded. For an EFA, this should, as far as possible, be corrected.

- CEBs mostly convert all material flows considered part of the energy balance (e.g., imports of crude oil, oil products, natural gas, coal, etc.) into energy flows by using *net calorific values* of the respective materials. In contrast, EFA assumes *gross calorific values* of all materials in order to consider the full amount of energy that could potentially be gained by the combustion of the materials.[18] The difference between these two measures is that the gross calorific

[18] There are several reasons why the energetic metabolism of societies should be based upon the gross calorific value of energy-rich materials. First, using the gross calorific value is necessary to

value is defined as the full amount of energy (heat) that can be gained by burning a defined amount of a material, including the latent heat of water vapor in the flue gas – the latter amount of energy is not included in the net calorific value. The difference between net and gross calorific value of a fuel depends on its chemistry (above all its C/H proportion); typical values that can be used for most calculations are given below.

Energy Input

In order for energy flow analyses to be compatible with MFA, EFAs have to calculate a figure that is equivalent to the "direct material input" of MFAs which is accordingly termed *direct energy input* ***(DEI)***. The direct energy input can be defined as the total amount of energy actually entering the socioeconomic component under consideration, either by domestic extraction or by import.

Domestic extraction ***(DE)*** can be calculated by adding the energy content of all biomass which is harvested domestically and enters the economy, to the data on technical energy input that can be derived from energy statistics. Data on biomass can be taken from agricultural and forestry statistics and converted to energy flows using gross calorific values. What is usually not accounted for, but should be included, is livestock grazing. All these flows are accounted for in an MFA; that is, if an MFA has already been conducted it can be taken as a starting point for this calculation. Note, however, that you need to know the water content of the biomass flows accounted for in the MFA in order to be able to correctly convert biomass flows into energy flows (see below). An estimate of biomass harvest is also part of calculating the "human appropriation of net primary production" (HANPP, chapter 2.1.3); note, however, that some human-induced biomass flows are counted as "appropriated" even if they are not economically used (see below).

For *imports* ***(Im)*** we should consider the import of all energy-containing materials, not only that of energy carriers. Trade statistics usually cover trade data in considerable detail. However, including all energy-containing final products would necessitate the assessment of the gross calorific value of all imported goods – a rather imposing task. A reasonable proxy can be obtained by restricting the analysis to imported raw materials of major interest (e.g., feedstuffs, food, timber, paper, etc.).

To summarize, the following formula is applied to assess direct energy input:

DEI = DE + Im

In many cases it can be important to know how much energy is metabolized in a country. This can be assessed if energy exports **(Ex)** are calculated (applying the

make ecological and societal energy flow analyses comparable, because ecological energy analyses are based upon gross calorific values. Second, the energetic value of food and fodder is usually assessed as gross calorific value, resulting in inconsistencies where net calorific values are used for technical energy conversions. Third, new technologies (condensing furnaces) have been developed that can utilize the latent heat of water vapor in the waste gases, resulting in an efficiency rating above 100% where the energy equivalent of fuels is calculated as net calorific value.

same methodological rules as for imports). The "domestic energy consumption" **(DEC)** of a country can then be calculated as

DEC = DEI - Ex

The EFA equivalent of the MFA notion of "total material requirement" is termed *total primary energy input* ***(TPEI)*** and is defined as direct energy input plus "hidden" energy flows **(HF)**.

"Hidden" flows can be either domestic **(DHF)** – i.e., biomass harvested but not used, for example, the crop residues plowed back into the soil – or imported **(IHF)**. At least for all energy flows included in energy statistics, these "hidden" flows are a well-researched issue (e.g., Fritsche et al. 1992; Spreng 1995) and can be assessed with reasonable accuracy. It is more difficult to account for hidden biomass flows, but it is certainly feasible.

In order to avoid double counting, imported derived energy carriers (e.g., electricity) have to be subtracted.[19]

The formula for TPEI is:

TPEI = DEI + DHF + IHF – imported derived energy carriers

Hydropower and Nuclear Energy

Most energy flows can be assessed as material flows converted into energy units by using an appropriate conversion factor; i.e., the gross calorific value of the materials involved. The treatment of other energy conversions and transfers is less straightforward.

For example, **hydropower** harnesses the potential and kinetic energy of water. In energy statistics, several approaches are used. It was long common to calculate the amount of fuel that *would have been used* in a thermal power plant to generate the same amount of electricity (usually assuming an efficiency of 33%). One may of course use any arbitrarily assumed efficiency to extrapolate the water power utilized from the amount of electricity generated. For example, the United Nations energy statistics (UN 1997), the IEA energy balances (IEA 1995), and the EU-wide rules for harmonizing energy balances assume the primary energy used to be equal to the amount of electricity produced (efficiency 100%).[20]

An alternative approach, which is used in no officially published CEB we know of would be to try to reflect the physical processes at hand. The amount of water

[19] The formula *total primary energy input (TPEI) = direct energy input + hidden flows* leads to double counting when an energy carrier included in the direct input has been derived from other forms of energy. Consider imported electricity produced in a thermal power plant. In this case, the entire energy input of the plant will be counted as "hidden flow," while the imported electricity will be part of the direct input. To avoid double counting, only the energy used to produce the electricity should be taken into account when calculating TPEI.

[20] Losses which result from using off-peak electricity to pump water upwards into reservoirs in order to produce peak load electricity in pumped storage power plants are considered separately. Before Austria adopted the EU-rules, hydropower use was extrapolated from hydroelectricity generation on the basis of an assumed efficiency of 80% (Bittermann 1999).

energy used could be calculated based upon the efficiency of turbine and generator, both between 95 and 99%. We propose to use this approach for an EFA, but the difference to the assumption of an efficiency of 100% is quantitatively not important. The IEA approach ("substitution method") should not be used for EFAs.

That is, for an EFA two steps are necessary:

1. Find out, which method was used in the CEB.

2. Calculate hydropower needed on the basis of the amount of electricity generated from hydropower, assuming an appropriate efficiency (95% is probably a good proxy, if no detailed data is available).

The formula is:

Hydropower input = (1/0.95) * (electricity produced from hydropower)

(If available, use any real data on hydropower plant efficiency instead of 0.95.)

The efficiency can be considerably lower if a large part of the electricity produced comes from pumped storage power plants. In some cases – i.e., if there is little natural runoff captured by the plant – these plants can use more electricity than they produce.[21] Also, electricity produced from pumped water should not be regarded as an energy input to society but as an energy conversion process within society. Therefore, in order to avoid these problems, only the electricity produced from natural runoff captured by pumped storage power plants should be taken into account when calculating the hydropower input of a society.

The second significant case is **nuclear energy**. Here it is a reasonable solution to assess the amount of heat generated through nuclear fission (the thermodynamic efficiency of nuclear power plants is usually about 30-33%). For example, UN energy statistics calculate the primary energy used in nuclear electricity generation (which is called quite misleadingly "primary electricity") by assuming a plant efficiency of 33% (UN 1997).

That is, if no additional data on the efficiency of nuclear power plants or the amount of heat produced by nuclear fission is available, the input of nuclear energy can be estimated by the following formula:

Nuclear energy input = (1/0.33) * (electricity produced by nuclear power plants)

In the IEA energy balances, **geothermal energy** (primary energy) is calculated from the electricity generated assuming a thermal efficiency of 10%. If possible, it would be preferable to estimate the amount of geothermal energy actually captured and use such approximations only if no further data is available.

Similar approaches can be used to consider "new renewable" technologies as, for example, wind power, photovoltaics or thermal solar energy collectors, where

[21] Pumped storage power plants are used to shift electricity from off-peak time periods to peak load periods. In periods with low power demand (off-peak), they use cheap electricity to pump water in a storage lake which can be used in peak load periods to produce expensive electricity.

necessary. For treating heat pumps the amount of heat harnessed should be calculated in order to assess the DEI gained by using this technology.

"Non-energy" use

CEBs usually include as "non-energy" use the utilization of oil derivatives for chemical syntheses (e.g., the production of synthetic materials, asphalt, etc.). Non-energy use, thus, means that some material which also *could* be used as a source of energy is used for a purpose not regarded as energy flow, because a part or all of a material's energy content remains in the product.[22] A correct treatment of these flows is essential for EFAs. For example, consider the energy gained from the incineration of wastes such as the synthetic materials produced from fossil fuels. In this case, appropriate treatment of the flows is essential to avoid double-counting. Matters become even more complicated when we turn to biomass, where complex utilization chains abound (Hall 1984). In CEBs, this biomass problem does not arise because CEBs usually include only the biomass used for combustion, but none of the biomass used for other purposes, including nutrition.

We propose to regard *all flows of energy-rich materials* as energy inputs, irrespective of the purpose for which they are being used.[23] Therefore, we should regard the construction of a wooden house as an input to a societal *stock* of energy which can be released later on.[24] This also means that we have to calculate flows into and out of stocks (as internal socioeconomic flows).

While the notion "stocks" in CEBs usually refers to energy stored for future use (e.g., natural gas storage, crude oil storage), the inclusion of all energy-rich materials requires the introduction of an energy stock consisting of energy-rich products (buildings, furniture, libraries, etc.). Eventually, as these products become wastes, their energy potential can be tapped. On the other hand, if they are deposited, this should be regarded as an energy output flow back to nature.

Internal socioeconomic flows

CEBs provide two notions to describe the flow of energy through a national economy that are also useful for EFA:

[22] To some extent, of course, chemical syntheses involve exothermic reactions actually involving energy flows, however, in general a significant part of the potential energy stored in an energy-rich material will remain in the product.

[23] This can be argued on the grounds that, for assessing the environmental impact of the harvest of a particular kind of biomass on the ecosystem from which it is taken, it is largely irrelevant for which purpose society uses the biomass. Therefore, from an ecological point of view, it is preferable to regard all flows of energy-rich materials as societal energy flows. There is also no a priori reason to regard one material flow (e.g., crude oil in a pipeline) as energy flow, just because most of it will probably be used to generate energy, and exclude another material flow (e.g., the construction of a wooden house) because the timber probably will not be burned in the next decades. In analogy, MFA does not ask if a material will be used for a durable product or for combustion.

[24] In fact, the idea of recovering energy from used-up materials when they cannot be recycled as raw materials anymore is advocated as a strategy for the more efficient use of biomass (Haberl and Geissler, *in print*).

- *Final energy use*; i.e., energy sold to final consumers, defined as all consumers that use energy to provide energy services (Lovins 1977), but not to produce other energy carriers that are sold on the market (e.g., production of electricity in a thermal power plant fueled by heating oil). The latter process – production of derived energy carriers – is part of the conversion of primary to final energy. A firm can be both, consumer of final energy and part of the energy conversion sector at the same time. For example, a pulp and paper mill can consume electricity and other final energy carriers and, at the same time, use biomass residues and / or natural gas in a cogeneration plant to produce electricity and heat which are (partly) sold on the market. Final energy can also be characterized as energy carriers: electricity, district heat, natural gas, refined oil products (heating oil, gas, diesel, etc.), etc.

- *Useful energy*, i.e., energy derived from final energy that is actually performing the task for which final energy is used. Mechanical work is maybe the most important category to be considered here, because it is the force driving all kinds of production processes (including all material flows). In most CEBs that include a useful energy analysis (this is often not the case) it is common to distinguish work of stationary motors from that of vehicle motors. Probably the quantitatively most important category in most contemporary industrial societies is heat which may subdivided into different temperature niveaux (low temperature [<100°Celsius], medium / high temperature). A similar distinction is that between heat used for space and water heating and process heat (including industrial processes and cooking). Other categories are light and data processing; both usually account only for a smaller part of useful energy available to a society. If available, useful energy analyses are generally based on random sampling surveys and technical extrapolations of low accuracy.

CEBs, thus, allow to trace energy flows through a society in considerable detail, using internationally comparable notions such as final energy and useful energy. EFAs can use these available data, but it should also consider those flows not accounted for in CEBs. We here propose an accounting scheme that leaves the general structure of energy balances intact, but allows for the inclusion of these "missing flows."

Two interrelated problems must be solved:

1. How should the flow of nutritional energy be accounted for?
2. How can we treat the provision of drive power by draft animals and humans?

Whereas nutritional energy is quantitatively relevant even in industrial society, accounting for animate power could be regarded for an industrial society as an academic problem: a hard-working human can deliver up to 100 Watt (W) for 8 hours per day (0.8 kWh/d).[25] Even assuming 300 working days per year this is less than 1 GJ/yr – a small amount of energy compared to the 100-200 GJ/yr of

[25] Throughout this paper, I will use the SI units "Joule" (J) for energy, "Watt" (W) for power, and occasionally the derived unit "Kilowatt-hour" (kWh, 1 kWh = 3,6 MJ); together with suitable prefixes (k ... 10^3, M ... 10^6, G ... 10^9, T ... 10^{12}, P ... 10^{15}). 1 kcal = 4.1868 kJ.

commercial final energy which the average member of an industrialized country uses (Smil 1992). However, for comparisons between different modes of subsistence, exactly these processes matter.

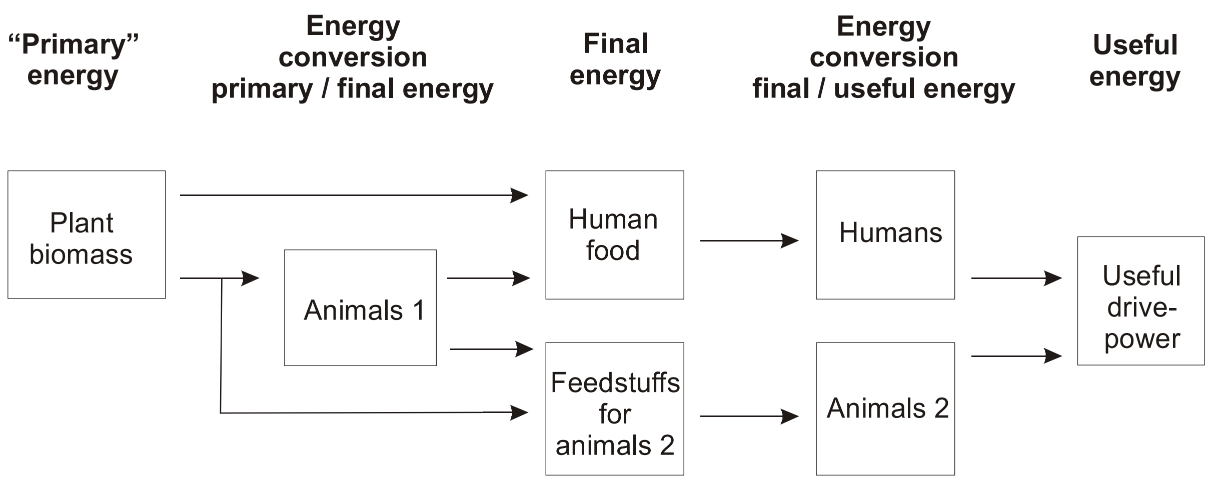
To tackle these problems, we must identify the most important energy conversion processes and assign them to the steps of energy conversion in an energy balance as described in Figure 2. These conversion processes are:

1. The conversion of animal fodder, both into human foods such as meat, milk, eggs, etc., and into other biomass products such as wool, leather, etc. and

2. the conversion to power (work) of the biomass ingested by humans and domesticated animals.[26]

Energy balances usually differentiate between two stages of energy conversion: (1) The conversion of primary energy to final energy and (2) the conversion of final energy to the useful energy needed to produce energy services.

We propose to use a "trophic-dynamic" approach that regards the food consumed by humans as final energy so that human-derived power has to be defined as useful energy. The animal component has to be hypothetically split up in two sub-components performing two different processes: livestock (Animals 1) as converters of nutritional energy on the one hand, and domesticated animals (Animals 2) as consumers of feedstuffs (final energy) and deliverers of power (useful energy) on the other hand.



[26] In agricultural societies, other conversion processes can be important, too; one example is the utilization of heat dissipated by humans and livestock for space heating (by placing the living room of a farm house over the stable). A significant part of ingested food is used for growth, reproduction and maintenance of the body functions of humans and domesticated animals, not for power delivery. As this is not a physical energy output of this component, however, it can not be counted as a flow of useful energy. On the other hand, this means that we should be cautious about interpreting the ratio of work output to food input as a measure of the "efficiency" of this conversion process.

Figure 2: Conversion of plant biomass to food / feedstuffs and to human and animal work in a "trophic-dynamic" approach

This approach distinguishes two different processes: the conversion between different kinds of biomass is treated as a "primary to final" energy conversion, and the conversion of food to work is considered a "final to useful" energy conversion. In this case, the work of both animals and humans is treated symmetrically and "transmission" losses are aggregated into these conversion processes. (This is usual in energy balances. The conversion balance of electricity generation, for example, lumps together cooling losses, friction, generator losses, the plant's own electricity consumption, etc.) A problem of this approach could be that splitting up the "animal" sector for calculation can pose problems in tractability, especially if the same animals are used for both purposes (e.g., eating the meat of draft animals).

The assessment of food energy flows is conceptually straightforward (it may be difficult to gather the data, though): All relevant biomass flows are converted into gross calorific value using standard tables on their chemical composition or measured values (sufficient data for nearly all quantitatively important biological materials are usually available in the literature, so that no measurements should be needed).

What has been omitted for reasons of clarity from Figure 2 is that there are different kinds of energy outputs of humans and animals besides work:

1. Feces can have a quite considerable gross calorific value (and are, accordingly, often used for heating and cooking in many societies)
2. Heat dissipation

In order to get a complete balance, this has to be considered.

Accurately assessing the amount of mechanical work delivered by humans and working animals is a very difficult task. Exact calculations would require: An assessment of the hours worked per year disaggregated

1. by species: humans, horses, mules, donkeys, oxen, etc. and
2. by workload (heavy, medium, light, etc.).

If such data are available, calculations yielding at least a correct order of magnitude can be performed on the basis of specific data that can be found in the literature. Of course, this can only yield an estimate of the quantity of work performed; the utility of the work (qualitative aspects) can not be grasped by energetic analyses.

Putting together the balance

In the end, an EFA aims at establishing a balance of energy inputs, internal flows, and outputs of a national economy. This balance is based on several conversion balances that have been described above (in more or less detail).

For each of these balances, as well as for the overall balance, the first law of thermodynamics dictates that

energy input = energy output + changes in stock

Of course, it is almost always possible to achieve this by calculating all inputs and outputs for which data are available, and securing that the balance is met by assuming that the amount of energy missing at the "output" side must be "energy loss" (heat dissipation). (If inputs are smaller than outputs this is a strong indication for a fundamental flaw in assumptions and / or data). However, if there are data on outputs that do not directly depend on data on inputs, but on separate measurements, this is also a good opportunity to consider if the "efficiencies" resulting from the input/output balance are realistic. This provides a valuable "consistency check" for all calculations.

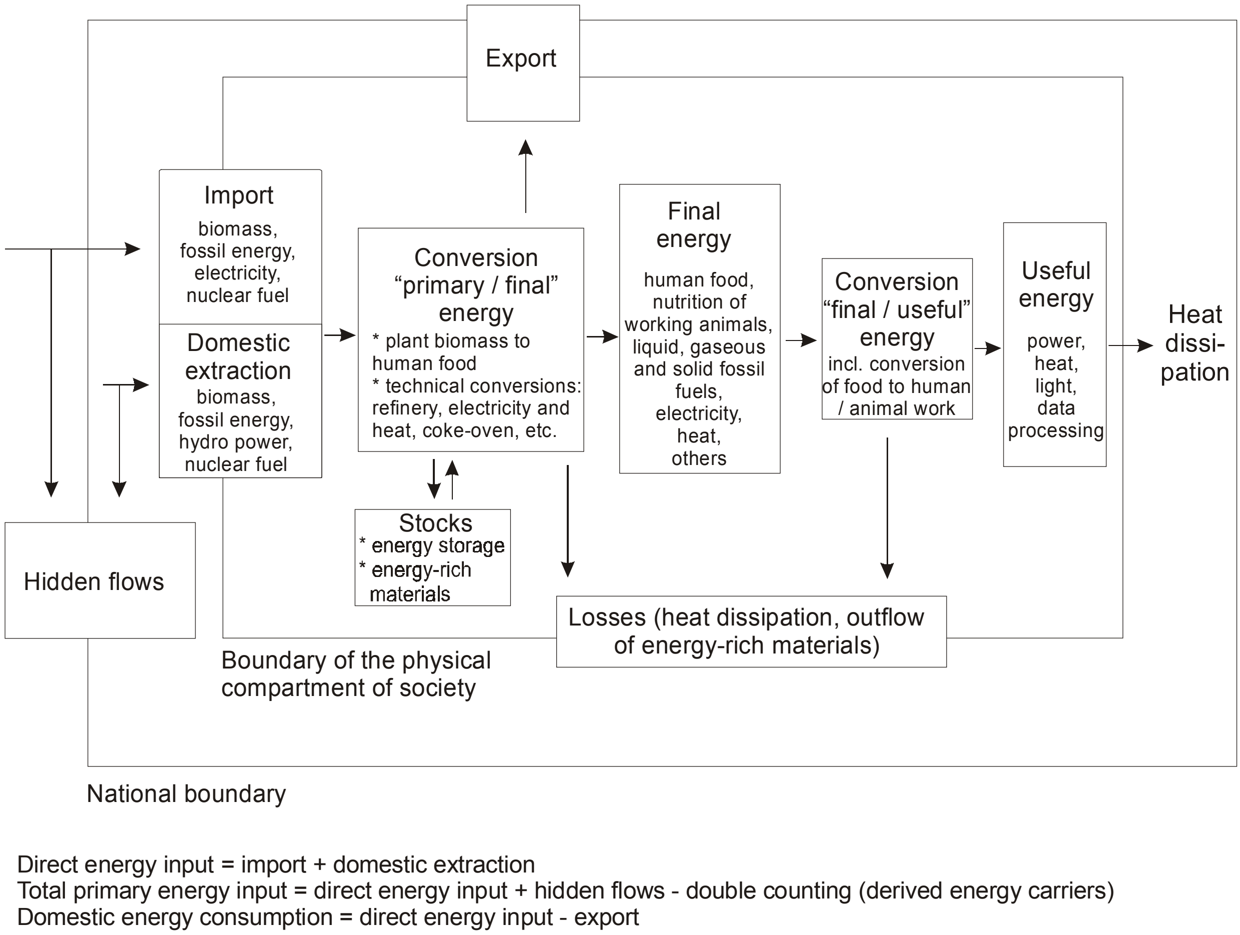


Figure 3: Balance sheet for a national (or regional) EFA: main energy flows and important components to be considered.

3.3. Input side

Many important insights can be gained by assessing the energy input of a society (DI and DEC). This is also the part of the EFA for which sufficient data should be available for all national studies. As indicated above, this can be mostly calculated on the basis of a CEB plus a MFA. For this it is necessary that biomass flows in the MFA are sufficiently disaggregated (qualitative description of main biomass fractions, water content).

It is important that this condition (sufficient detail in biomass flow analysis in the MFA) is taken into account when planning the MFA! Properly planned, this should not increase the amount of work of establishing the MFA significantly, but it will allow to establish the input side of the EFA with little additional work, based on the conversion factors given below.

3.4. Final energy, useful energy

Although this part of the EFA can yield very important insights, there might be problems in data acquisition. If there is no useful energy analysis in official energy statistics or CEBs available – which will probably often be the case – it can be very difficult or at least resource consuming to perform a useful energy analysis. Some rough approximations are possible if there is a statistics on final energy use that is broken down by sectors (agriculture, industry, services / commercial / small enterprises, domestic) and energy carriers (coal, various oil products [at least, vehicle fuels and heating oil should be distinguished], natural gas, electricity, district heat, etc.).

If such data is available, then rough estimations are possible, for which purposes this final energy is used. For example, you can assume that gasoline and diesel fuel are used for vehicles. It is also mostly possible to find plausible assumptions for which purposes which fuel will be used in which sector (e.g., electricity in households: light, household appliances, air conditioning, etc.; fuels in households: cooking, space and water heating [if applicable]; heavy fuel oil in industry for process heat or electricity generation; etc.). It might also be possible to obtain efficiency data of existing appliances or machinery in the country under consideration: in most cases there will have been conducted research on these issues, at least for some important sectors / appliances.

3.4.1. Data sources

As already indicated, each EFA will start with a compilation of energy statistics and CEBs. The UNO publishes a comprehensive energy balance for most countries of the world (UN 1997) which may be useful; however, CEBs published by national statistical offices will usually be more detailed and informative. CEBs of OECD countries are published by the IEA (IEA 1995); the advantage of these balances is that they are internationally standardized, the disadvantage is that SEA countries are not member of the OECD.

Data on working hours of humans can be available in national statistical offices, however, these will usually only cover paid work in the „official" economy, not household labor – this has to be corrected, especially for transitions studies.

Data on working hours of working animals will usually not be available and must usually probably be derived from case studies.

Most biomass flows, including livestock counts, etc., will be assessed in the MFA. These data will usually be available from national statistical bodies. A wealth of such data is also available through the FAO. The FAO homepage (http://www.fao.org) contains a database in which many of these data can be found.

3.4.2. Support tools: Units, conversion factors and calorific values

Units, conversion factors

We propose to carry out all calculations using the SI units „Joule" for energy and „Watt" for power.

1 Watt = 1 Joule / second

1 Joule = 1 Watt * second

1 Watt-hour = 3.600 Joule

1 kWh (kilowatt-hour) = 3.6 * 10^6 J

For some purposes (e.g., electric systems) it may be convenient to use kilowatt-hours (kWh), but in the final balance all data should be converted in Joule. Use appropriate prefixes:

1 kJ ... 10^3 J

1 MJ ... 10^6 J

1 GJ ... 10^9 J

1 TJ ... 10^{12} J

1 PJ ... 10^{15} J

1 EJ ... 10^{18} J

All other units, including kcal often used for nutritional balances, should be converted to J. The following tables give conversion factors for some frequently used units:

Table 1: Conversion of frequently used energy units to SI units

Energy unit	**SI unit**
1 kWh	3.6 * 10^6 J
1 BTU (British thermal unit)	1.0551 * 10^3 J
1 kcal (Kilokalorie)	4.1868 * 10^3 J
1 toe (ton of oil unit)	4.1868 * 10^7 J
1 tSKE (ton of hard coal unit)	2.9308 * 10^7 J

Source: IEA Energy Balances of OECD Countries 1992-1993

Table 2: Conversion factors for mass

Mass unit	SI unit
1 long ton [lt]	1016 kg
1 short ton [st]	907.2 kg
1 metric tonne (tonne) [t]	1000 kg
1 pound [lb]	0.545 kg

Source: IEA Energy Balances of OECD Countries 1992-1993

Table 3: Conversion factors for volume

Volume unit	SI unit
U.S. gallon [gal]	0.0038 m^3
U.K. gallon [gal]	0.0045 m^3
Barrel [bbl]	0.159 m^3
Cubic foot [ft^3]	0.0283 m^3
Litre [l]	0.001 m^3

Source: IEA Energy Balances of OECD Countries 1992-1993

Table 4: Specific gravity of selected fuels

Fuel	Specific gravity [1000 kg/m^3]
Crude oil	0.775-0.96 (0.86)
Aviation gasoline	0.73
Fuel oils (undifferentiated)	0.91
Gas-diesel oil	0.87
Jet fuel	0.81
Kerosine	0.81
Liquefied petroleum gas (LPG)	0.54
Motor gasoline	0.74
Residual fuel oil	0.95
Bitumen	1.04
Lubricating oils	0.90
Naphtas	0.72
Paraffine wax	0.80
Petroleum coke	1.14
White spirit	0.81

Figures in brackets: standard values to be used if no further information is available. Source: UN 1995, Energy Statistics Yearbook

Calorific values, conversion of net and gross calorific values

Net calorific values of fossil fuels

The following net calorific values were compiled from IEA energy balances and UN energy balances. For solid fuels, values are only indicative, since the quality of fuels can vary greatly.

Table 5: Net calorific values of important fuels

Fuel	Net calorific value [MJ/kg]
Solid fossil fuels (coal)	
Bituminous coal, anthracite	24.3-29.6
Sub-bituminous coal	17.38-18.2
Lignite	5.29-21.56
Coking coal	24.18-34.33
Peat	8.37-9.26
Patent fuel coal	27.05-31.40
Coke oven coal	25.65-32.66
Liquid fossil fuels (oil / oil products)	
Refinery gas	48.15
Ethane	49.40
LPG	47.31
Aviation gasoline	44.80
Motor gasoline	44.80
Jet fuel	44.59
Kerosine	43.75
Naphtha	45.01
Gas oil /Diesel oil	43.33
Heavy fuel oil	40.19
Other oil products	40.19
Crude oil	42.35-43.20
Gaseous fossil fuels	[MJ/m^3]
Natural gas	35.0-46.06 (39.02)
Coke-oven gas	15.07-39.02 (17.59)
Gasworks gas	15.49-27.1 (17.59)
Blast furnace gas	2.86-8.44 (4.0)

Figures in brackets: standard values to be used if no further information is available. Sources: IEA Energy Balances of OECD countries 1992-1993, UN 1995 Energy Statistics Yearbook.

Conversion of net and gross calorific values

If data on the chemical characteristics of fuels is available, it is possible to convert net calorific values to gross calorific values using the following formula:

GCV = NCV + r * (9*h+w)/100

where

GCV ... Gross Calorific Value

NCV ... Net Calorific Value

r ... evaporation enthalpy of water (2.5 MJ/kg)

h ... hydrogen content of fuel (%)

w ... water content of fuel (%)

Table 6: Indicative factors for converting net and gross calorific values

Fuel	NCV [MJ/kg]	GCV [MJ/kg]	GCV/NCV [factor]
Wood, air-dry	15.5	17.0	1.10
Anthracite	27.9	29.1	1.04
Lignite	10.9	13.0	1.19
Natural gas	32.0	35.2	1.10
Crude oil	42.0	44.7	1.06

Note: if data on the NCV of fuels is available, it is preferable to correct these with the factor GCV/NCV instead of using the GCV cited in table 5, because these values only refer to specific fuel qualities.

Gross calorific values of important biological materials

Calorific values of biomass are species-specific and even specific to tissues / organs of an organism (this holds for plants and animals). Therefore, the values cited in the following table should only be used as a first approximation. In order to obtain accurate evaluations it is necessary to have as much information on major biomass flows as possible: quality of the materials, and, above all, its water content. While the calorific value of dry biomass can vary by a factor of about 2, the water content ranges from 10% to 95%. Therefore, no meaningful calculation can be performed if no data on water content is available.

Table 7: Typical calorific values of important biological materials

Material	Typical water content of fresh material [%]	Gross calorific value of dry matter [MJ/kg]
Cereals - corn	14%	17.9-18.8 (18.3)
Cereals - straw	14%	17.8-18.4 (18.0)
Roots, tubers (potatoes, sugar beet)	78-88%	15.8-16.8 (16.3)
Vegetables	10-95%	17.1-20.7 (18.5)
Fodder plants	73-87%	17.3-20.7 (18.5)
Fruits	81-90%	19.4-20.4 (20.0)
Deciduous temperate forests	n.d.	19.3-19.7 (19.5)
Coniferous forest	n.d.	19.7-20.1 (19.9)
Grasslands	n.d.	16.8-17.8 (17.5)
Alpine/polare tundra	n.d.	22

Sources: Ajtay et al. 1979, Bazilevich et al. 1971, Golley 1961, Whittaker und Likens 1975, Lieth 1975, Olson 1975, Rodin et al. 1975

3.5. References, bibliography

Examples of good practice

Details on conceptual issues and some empirical examples (not much documentation, however) can be found in:

Haberl, H.: The Energetic Metabolism of Societies, Part I: Accounting Concepts, Part II: Empirical Examples. Submitted to the Journal of Industrial Ecology. Available for download at the SEA-Trans-Homepage

An article on Austria 1830-1995 using the methods presented here will be available at the end of November:

Krausmann, F. and H. Haberl: The Energetic Metabolism of Austria 1830-1995. Submitted to Ecological Economics. Available for download at the SEA-Trans-Homepage (probably in the beginning of December)

Seminal books and papers

Cook, E. 1971. The Flow of Energy in an Industrial Society. Scientific American. 224(3): 135-144.

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4. HUMAN APPROPRIATION OF NET PRIMARY PRODUCTION (HANPP): TOOLS TO RELATE SOCIO-ECONOMIC METABOLISM AND LAND USE

Helmut Haberl

4.1. Goals of HANPP studies

The notion of „human appropriation of net primary productivity" (HANPP) has been coined as a tool to assess, to which extent human land use changes the availability of energy in ecosystems (Vitousek et al. 1986, Wright 1990, Haberl 1997). This chapter will describe how this and related indicators – that can be used to relate socio-economic metabolism and land use – can be assessed.

One of the most important measures that can be used to characterize the energy flow through ecosystems is net primary production (NPP); that is, the amount of biomass (energy) produced by green plants on a defined area in a defined period of time (usually one year). Contrary to many other important measures of ecological energy flows (e.g., gross primary productivity, net ecosystem productivity, etc.) NPP can be assessed for larger regions on the basis of ecosystem models or „bookkeeping models" (i.e., models that extrapolate from typical values of NPP/m^2 for vegetation units for larger regions on the basis of vegetation data) with acceptable accuracy (e.g., Ajtay et al. 1979, Lieth 1975, Lieth und Whittaker 1975).

The notion of HANPP refers to the observation that, by using the land, humans alter these ecological energy flows. For example, agriculture and forestry harness biomass energy for socio-economic purposes and thereby reduce the amount of NPP remaining in ecological food chains. Other types of land use, such as soil sealing, alter ecosystems and so have an impact on net primary productivity even if no biomass is harvested. Thus, HANPP – defined as the aggregate effect of land-use induced changes in productivity and biomass harvest on the energy availability in ecosystems – can be used to assess the effect of land use on the availability of biomass energy in ecosystems (Haberl 1997). HANPP simultaneously measures two processes:

1. Changes in the productivity of ecosystems that result from socio-economic activities (e.g., replacement of pristine ecosystems with agro-ecosystems or built-up area), and
2. Socio-economic harvest of biomass.

HANPP is defined as the difference between the energy flow (NPP) of potential vegetation and the amount of energy (biomass) remaining in ecological cycles after human harvest has been subtracted.

Similarly, it may be asked how other ecosystem processes and structures are affected by land use. Land use has an influence on the standing crop – i.e., the biomass stock – of ecosystems (Houghton et al. 1983; Houghton 1995; Schimel 1995). Converting forests to cultivated land reduces the amount of carbon stored in living vegetation and accelerates biomass turnover. Additionally, managed forests store less carbon than pristine forests, even if forest management techniques include regrowth after harvest (Harmon et al. 1990). Standing crop reductions change the amount of carbon stored in vegetation and result in net carbon flows from vegetation into the atmosphere, contributing to increasing atmospheric CO_2 levels.

Therefore, it is very useful to calculate changes in the amount of standing crop caused by land use with the indicator HISC that can be defined as

$HISC = SC_{pot} - SC_{act}$

where

SC_{pot} ... standing crop of potential vegetation

SC_{act} ... standing crop of current (actual) vegetation.

This indicator, as well as time series of SC_{act}, are highly relevant because they indicate changes in carbon storage of vegetation – an issue which is very important with respect to currently debated climate change issues (vegetation as carbon source / sink).

Biomass turnover is defined as NPP/SC [yr^{-1}]. Thus, if HANPP and HISC have been assessed, it may also be asked to what extent land use changes the turnover of plant biomass in ecosystems. In general, land use tends to accelerate biomass turnover, because vegetation with low turnover and large SC is replaced with agro-ecosystems with high turnover and low SC.

Similar indicators as HANPP and HISC could also be constructed to monitor changes in the flows of major plant nutrients (N, P, etc.) associated with the industrialization process. This, however, requires additional methodological considerations and will not be explained in this chapter.

Land-use related indicators as those discussed above are highly relevant for transition studies for the following reasons:

- Indicators like HANPP or HISC relate socio-economic metabolism to land use. While it has long been realized that these processes are related (Meyer und Turner 1994), concrete methods to empirically and theoretically examine this relation are scarce. We believe that HANPP and related indicators are a good approach to tackle this question.
- Theoretical considerations (e.g., Sieferle 1997) and empirical studies (e.g., Krausmann, *in print*) suggest that industrial modernization is related to a systematic change in the *function of land use (agriculture and forestry) for society*. While land use is the predominant source of energy for all pre-industrial

societies (other sources as, for example, wind or water power being quantitatively negligible), energy sources that are practically not area-dependent (fossil fuels, nuclear energy, hydropower) become much more important during industrialization. Whereas a positive relation between socio-economic inputs and outputs is a „raison d'etre" of agricultural societies (otherwise they are unable to feed themselves), this is not the case in industrial society (e.g., Pimentel et al. 1973).

- This means that low-input / low-output agro-ecosystems are replaced with high-input / high-output agro-ecosystems. This greatly increases the efficiency with which area is used: outputs per unit area increase by factors of up to 5 or more. This allows considerable increases in population density to take place, on the other hand, it also requires large increases in the amount of energy inputs in agriculture.
- Since there is evidence that a reduction in the availability of energy in ecosystems is associated with a decline of biodiversity, a monitoring of HANPP is highly relevant to understand driving forces for biodiversity loss and propose strategies to avoid biodiversity loss to continue.
- HANPP is also related to changes in the standing crop of ecosystems. A reduction in standing crop (SC) means a reduction in carbon stored in vegetation; i.e., it indicates that vegetation acts as a carbon source to the atmosphere. This is highly relevant for climate change.
- Current studies indicate that industrialization is associated with an increase in the „efficiency of area use". The increases in yields allow industrialized countries to produce more agricultural produce on smaller areas; that is, HANPP goes down and SC_{act} goes up. The effect is that the vegetation cover of most industrialized countries acts as a net carbon sink. This is, however, only possible because (1) fossil energy inputs increase agricultural productivities and (2) SC on their territory had been reduced before industrialization started, so that these reservoirs are now „filled up" again. If industrial countries blame developing countries for their carbon emissions from land-use change, they should blame themselves first for having done the same thing in the past, instead of crediting themselves for their „biological carbon sinks" in international treaties on greenhouse gas reduction like the Kyoto protocol.
- The studies carried out in the SEA-Trans project should empirically examine these generalizations and theoretical considerations outlined above and try to deepen our understanding of the interrelations between land use and socio-economic metabolism.

4.2. System boundaries and accounting methods

General note: the rationale behind these indicators

In an attempt to quantify the impact of human land use on ecosystems, we propose to evaluate the effect of land use on fundamental ecosystem properties as, for example net primary production (NPP), standing crop (SC) and biomass turnover. Biomass turnover can be derived from the first two without further data acquisition.

The indicators we propose are based upon the following general approach: we propose to compare actually observable ecosystem patterns (i.e., properties of the current vegetation) with those which one would expect to find in the absence of human activities (i.e., the ecosystem properties of the potential natural vegetation, [Tüxen 1956]). The difference between actual and potential conditions can be used as a means of assessing the human impact on ecosystems, or, in other words, "human domination" (Vitousek et al. 1997) or socio-economic „colonization" (Fischer-Kowalski und Haberl 1993, Fischer-Kowalski und Haberl 1997, Haberl und Schandl 1999) of ecosystems.

By „colonization" we mean that society actively changes certain processes or parameters of natural systems in order to make them more useful for societal needs. Land use can be seen as socio-economic colonization of terrestrial ecosystems: agriculture and forestry change important parameters of ecosystems. This may go so far as to lead to the emergence of entirely new types of ecosystems, often described as „agro-ecosystems" (Gliessmann 1990). Whereas Vitousek´s notion of „human domination of ecosystems" only focuses on the effect of human actions on ecosystems, the notion of „colonization" acknowledges the active role of society and refers to the socio-economic utility of the interventions into natural processes.

The comparison between actual and potential conditions is a tool to analyse the *extent* to which certain ecosystem patterns and processes are colonized by socio-economic activities. Since biomass harvest is an important part of material or energy input of a society (as assessed in EFA or MFA, see chapters 2.1.1 and chapters 2.1.2 of this toolkit), HANPP relates socio-economic metabolism to land use.[27] These indicators can also be used to assess other aspects of the colonization process. For example, by calculating the amount of HANPP needed to gain one unit of biomass input (material or energy flow), we can assess the *efficiency of colonization*: how much impact on natural processes is needed for one unit of input flow?

Definitions

HANPP is defined as the difference between the NPP of the potential natural vegetation (Tüxen 1956) and the amount of NPP remaining in ecosystems. The former property is termed NPP_0 – i.e., the NPP of the vegetation that would prevail in the absence of human interference. The NPP remaining in ecosystems

[27] Definitions of biomass harvest can be different for HANPP analyses and for metabolism analyses: biomass removed from the ecosystem component under consideration (e.g., straw ploughed into the soil) is usually regarded as „appropriated", but not as a part of „direct material input" or „direct energy input" of a society. It should rather be regarded as a „hidden flow" (i.e., materials / energy mobilized, but not economically used).

is termed NPP_t – i.e., the amount of biomass currently available in ecological cycles.

HANPP is formally defined as follows:

$HANPP = NPP_0 – NPP_t$

where

NPP_0 ... productivity of potential (undisturbed) vegetation (Tüxen 1956)

NPP_t ... NPP remaining in ecosystems after human harvest has taken place

NPP_t can be assessed as

$NPP_t = NPP_{act} - NPP_h$

where

NPP_{act} ... NPP of the actually prevailing vegetation

NPP_h ... NPP harvested by socio-economic activities

Note that HANPP can exceed 100% of NPP_0 if harvest is taking place in forest ecosystems or other ecosystems with large biomass stocks. In these ecosystems, harvest can not just extract biomass generated in a few months (up to one year) prior to harvest, but it can also extract long-accumulated biomass stocks. For example, in old-growth forests, SC per unit area is about 30 times or more the amount of yearly NPP per unit area. In countries with „sustainable forestry regimes" harvest from forest ecosystems will only be a fraction of the NPP of forest ecosystems: some 30-50% of the NPP in forest ecosystems is allocated to harvestable timber. That is, if HANPP in forest ecosystems exceeds this level in a larger region or a whole country for a longer period of time, this indicates an unsustainable forest management regime. Under such conditions, a decrease of SC over time would be expected.

As mentioned above, HISC is defined as

$HISC = SC_{pot} - SC_{act}$

where

SC_{pot} ... standing crop of potential vegetation

SC_{act} ... standing crop of current (actual) vegetation

As mentioned above, turnover is defined as NPP/SC and has the dimension [yr^{-1}]. The socio-economic impact on turnover can be assessed by relating the turnover of the actual vegetation to that of the potential vegetation.

Basic features of the modelling strategy proposed

The main aim of HANPP studies are not predictive models of ecosystem processes, but an analysis of the impact of human land use on ecosystems. Currently available ecosystem models focus on the appraisal of the effects of changes in climate or other geophysical parameters on ecosystem processes (e.g., Cramer et al. 1999; Schimel et al. 1997). They are, however, not tailored towards the assessment of the impact of land use on energy availability in ecosystems. Although this would be desirable, ecosystem models currently are not able to model HANPP, HISC or related parameters.

Therefore, we have to use a flexible approach that allows to use all available data on human activities and their impacts; e.g., agricultural statistics, forestry statistics, forest inventories, land use statistics, remotely-sensed data and estimates on land use and land cover. These data can be combined with the same IBP data on productivity and standing crop that are also used to calibrate ecosystem models (Cramer et al. 1999). This approach is related to the „bookkeeping model" as used in carbon inventories (Houghton et al. 1983, Houghton 1995, Houghton et al. 1999).

Calculating HANPP involves the calculation of the following parameters:

1. The yearly productivity of potential vegetation; i.e., the productivity that would prevail in the absence of human intervention.

2. The yearly productivity of actually prevailing vegetation, usually subdivided into several classes of land use and land cover.

3. The amount of biomass harvested annually.

For calculating HISC, SC_{pot} and SC_{act} have to be assessed. If these parameters are available, human impact on turnover can be assessed without further data acquisition (see above).

In general it is preferable to use averages for 3-5 years or results for typical years, because we are primarily interested in structural changes, not in inter-annual variations.

As a result of the International Biological Programme (IBP), rather reliable data exist for the aboveground NPP of many vegetation units. However, data on belowground NPP and belowground standing crop are still rather uncertain. Current studies show that belowground NPP of forest ecosystems was significantly underestimated in most IBP research in the 1970s, when it was usually estimated at 15-30 % of aboveground NPP [Lieth und Whittaker 1975]. More recent work revealed that belowground productivity may, in some cases, even exceed 100 % of aboveground NPP [Melillo und Gosz 1983; Vogt et al. 1982; Vogt et al. 1986]. Similarly, data on belowground standing crop are uncertain. The belowground standing crop is highly seasonably variable and difficult to measure [Waring und Schlesinger 1985; Vogt et al. 1986; Sing et al. 1984].

Due to these uncertainties and the lack of reliable data compilations, it may be necessary to restrict the analysis to aboveground NPP (abbreviated as ANPP), aboveground standing crop and aboveground turnover. On the other hand, in order to be able to deal with carbon issues it would be highly desirable to consider belowground processes (e.g., IPCC 2000, WBGU 1998).

However, **if you decide to consider aboveground and belowground processes, it is essential that all data sheets are organized in a way that**

allows to account for aboveground and belowground processes separately. If you consider belowground processes, it is also essential to perform an error analysis; that is, to estimate the order of magnitude of error in your calculations, because data uncertainty for belowground processes is especially high (an error analysis will, of course, be valuable even if you only work on aboveground processes).

Aboveground NPP is usually termed ANPP. Aboveground SC can be conveniently denoted as ASC.

NPP_0 – NPP of potential vegetation

Two different approaches can be used to estimate the NPP of potential vegetation of a region. You can use

- ecosystem models (biosphere-models) or
- bookkeeping models.

4.2.1. Ecosystem models

Ecosystem models (e.g., Cramer et al. 1999; Cramer und Field 1999, Schimel et al. 1997) model NPP (together with a host of other ecosystem parameters) depending on input variables as, for example, climate variables (temperature, precipitation, etc.), soil conditions, vegetation type, etc. These models can usually be run over time until a climax state is reached. This value could be used as a proxy for the NPP of potential vegetation in a region.

The simplest model of this type is the „Miami-model" of Lieth (Lieth 1975); however, it is not only outdated, but contains also assumptions on the belowground NPP prevalent at that time, which were probably much too low (see above). Therefore, it should not be used for other purposes than to obtain a first rough estimate of the order of magnitude.

4.2.2. Bookkeeping models

If no ecosystem model is available, an estimate of the NPP_0 of a region can be obtained with a „bookkeeping model" which works as follows (Ajtay et al. 1979, Lieth und Whittaker 1975):

$$NPP = \sum_{i=1}^{n} npp_i * a_i$$

where

npp_i ... NPP of vegetation type i per unit area [$kg/m^2.yr$ or $MJ/m^2.yr$]

a_i ... area of vegetation type i in the region (country) under consideration [m^2]

npp_i can be estimated by regression analysis from existing databases of NPP of different vegetation units (e.g., Ajtay et al. 1979, Rodin et al. 1975; Bazilevich et al. 1971, Bolin et al. 1979, Cannell 1982, Cooper 1975, DeAngelis et al. 1981, Duvigneaud 1971, Hall et al. 1993, Lieth und Whittaker 1975, Lieth 1978, Long et al. 1992, Reichle 1975; Reichle et al. 1975). In performing these regressions, it is essential to include only studies of comparable vegetation units and to exclude incomplete estimates that could distort the regression (for example, in many studies of the NPP of forest ecosystems, some components as for example litter fall or fruits have been omitted. Also, recent studies have found that most IBP methods for estimating the NPP of tropical and semi-tropical grasslands yielded too low values due to flawed definitions [see Long et al. 1992]).

a_i can be estimated if maps of potential vegetation are available for the region under consideration.

In any case, the accuracy of the appraisal of NPP_0 will depend on the accuracy with which the area of the different vegetation units can be estimated and the accuracy of the description of the potential vegetation. Since most ecosystem models are „calibrated‟ using the same IBP data on the NPP of different vegetation units, there is no good reason to believe that their results are more accurate than a well-researched bookkeeping model, at least if good data on potential vegetation is available.

Productivity of actually prevailing vegetation

In order to estimate the NPP of actually prevailing vegetation a breakdown of land cover in the region under consideration is necessary. There are two main types of sources of land cover data:

- Statistical data
- Remotely-sensed data; that is, data derived from satellite imagery or aerial photography.

Both kinds of data sources have advantages as well as shortcomings.

4.2.3. Statistical data

If statistical data exist, they have the great advantage to be available in tabular form; mostly disaggregated by administrative units (e.g., municipalities, districts, counties, provinces, etc.). Statistical land-cover data can sometimes distinguish many different kinds of land use and land cover (for example, Austrian land-cover statistics distinguishes more than 40 different land-cover classes). They can sometimes be linked to other important data; e.g., agricultural land-use surveys can also contain data on yields (which are important for estimating NPP_{act}, see below); forest inventories usually contain data on certain important biomass storages (e.g., stem wood), species composition, and possibly some important flows (timber harvest, etc.).

4.2.4. Remotely sensed data

Satellite data and aerial photography can be used to produce land-cover surveys that can serve as a basis for estimating the NPP of actually prevailing vegetation. However, these data are often available as maps, but not available in tabular form – in this case it is difficult to use them as a basis for calculations. With GIS programs it is usually possible to extract the data needed from digital maps; this, however, requires some GIS expertise. On the other hand, GIS can also be used for producing maps. This will, however, usually require to also have other ecological, climatic and geomorphological data available in digital maps, above all temperature, precipitation, soil data, a digital elevation model, etc.

In both cases, the NPP of many vegetation units can be evaluated with the use of so-called „harvest indices" or „harvest factors" that relate NPP to the commercial harvest for many agricultural crops (e.g., Loomis und Gerakis 1975; Loomis 1983).

Basically, the formula is of the following form:

NPP = H * F

where

H ... denotes commercial harvest

F ... denotes the appropriate harvest factor.

Plant breeding aims to increase the proportion of edible (commercially useful) parts with respect to the total plant biomass (i.e., the harvest index). Data on harvest indices and harvest factors are, therefore, region specific and time specific. Accurate calculations are, therefore, only possible if data on harvest indices are available for the region and the point(s) in time, for which the calculation is made. Such data can be usually found in the agricultural literature or obtained from agricultural departments of the region under consideration.

In calculating NPP_{act} in a time-series, it is indispensable to assess the change in harvest indices for the most important cultivars over time (see, e.g., Austin et al. 1980; Donald und Hamblin 1976; Donald und Hamblin 1984; Feil 1992; Riggs et al. 1981; Sing und Stoskopf 1971).

In assessing the NPP of other vegetation units, the „bookkeeping model" described above can again be applied if data on the vegetation units occurring in the region are available in the literature.

If forest inventories are available for different points in time, they will probably contain estimates of stem wood increase and timber harvest for the time interval under consideration. From such data an estimate of the current productivity of forest ecosystems can be generated by using „expansion factors" that relate total NPP to stem wood growth (i.e., change in stem wood storage plus timber harvest). Such factors can be derived from literature data on the NPP of forest ecosystems which allocate NPP to different components of forest ecosystems (e.g., stem wood, branches, twigs, leaves / needles, fruit, etc.). The data collection of Cannell (Cannell 1982) contains such breakdowns that can be used for regression analyses on the basis of which such factors can be derived.

Biomass harvest

Biomass harvest can be derived from agricultural statistics and forestry statistics. However, these statistics usually account for fresh weight of biomass or for biomass at some standardized water content (e.g., in Austria grains are standardized to 14% water content in agricultural statistics). In MFA, different approaches according to water content of biomass are used (see chapter 2.1.1 for recommendations on this issue). For HANPP calculations, all biomass flows have to be expressed either as dry matter, or as carbon flow, or as energy flow (see below). In any case, the calculation will usually start by converting statistical figures to dry matter, because most conversion factors for energy content or carbon content are based upon dry matter. Data on the water content of most commercially used products can be found in the agricultural and nutrition science literature (some typical values can be found below).

Although the same data basis is needed for EFA and MFA, it should be noted that there can be some differences in the definition of „harvest" between MFA / EFA on the one hand and HANPP calculations on the other hand. For example, in a calculation of aboveground HANPP, biomass removed by human activities from the aboveground component (e.g., biomass residues ploughed into the soil) is regarded as „appropriated", whereas it is not regarded as a „direct input" to society in EFA and MFA.[28] Such differences in definitions can result in differences between NPP_h and „domestic extraction of biomass" according to EFA and MFA.

Potential standing crop

The same methods can be used as for NPP_0. However, it is important to note that ecosystems in an early stage of succession tend to accumulate biomass (standing crop), whereas after a longer time usually a steady state is achieved. Therefore, when performing regressions on the typical SC of main vegetation units it is important to consider the age distribution of forest ecosystems.

The appraisal of the standing crop of potential vegetation in Austria can be based on vegetation data – i.e., distribution of tree species in the potential vegetation. The potential vegetation can be assumed to consist of climax vegetation; i.e., it is necessary to assume that old-growth forests prevail (Reichle 1975, Shugart 1984). The standing crop of old-growth stands of those tree species occurring in the potential vegetation of the region under consideration can be calculated using logistic regressions for the standing crop of the respective species depending on stand age (Figure 2), using the equation

$$SC(t) = K / (1 + b \cdot e^{-r.t})$$

[28] It is appropriate to regard these flows as "hidden flows" related to biomass use in MFA and EFA.

where *SC* denotes standing crop, *t* stand age, *K* the standing crop of old-growth stands of the respective species, *b* a regression factor, and *r* a growth factor. The regressions can primarily be based on IBP research data (Cannell 1982).

Actual standing crop

Land use has an influence on the standing crop – i.e., the biomass stock – of ecosystems (Houghton et al. 1983; Houghton 1995; Schimel 1995). Converting forests to cultivated land reduces the amount of carbon stored in living vegetation and accelerates biomass turnover. Additionally, managed forests store less carbon than pristine forests, even if forest management techniques include regrowth after harvest (Harmon et al. 1990). Standing crop reductions change the amount of carbon stored in vegetation and result in net carbon flows from vegetation into the atmosphere, contributing to increasing atmospheric CO_2 levels.

In order to account for the reduction of standing crop through forest management, it is useful to calculate the standing crop on the basis of a forest inventory, if available. Forest inventories usually contains only data on usable timber. These data can be used to obtain estimates of standing crop using "expansion factors" based on data from the literature (Cannell 1982; Burschel et al. 1993) to reflect branches and twigs, leaves, fruit, blossoms and understorey. These expansion factors are dependent upon stand age (Körner et al. 1993; Mitscherlich 1975; Paulsen 1995).

The standing crop of agricultural areas should be assessed as the peak biomass of fields – i.e., the standing biomass at the time of harvest – assessed on the basis of the harvest factors described above.

4.3. Data sources

Data on NPP and standing crop of many vegetation units are compiled in Cannell (1982) and De Angelis et al. (1981). On the internet, the Oak Ridge National Laboratory (ORNL) maintains a database that contains NPP data of almost all studies published so far in a standardized format: http://www-eosdis.ornl.gov.

Land cover data and data on agricultural harvests (yields) are collected by the Food and Agricultural Organization (FAO) of the UNO. Data for the years starting with 1960 are available at http://www.fao.org.

4.4. Units, conversion factors

Units

It is essential that only SI units (Kilogram, Joule, etc.), if appropriate with prefixes such as Mega- (10^6), Giga- (10^9), Tera- (10^{12}), Peta- (10^{15}), etc., be used in order to facilitate comparison of results between country studies. Other units (kcal, BTU, long tons, short tons, pounds, etc.) should never be used.

It is possible to calculate HANPP in three different units:

1. Energy flows: basic unit = Joule per year [J/yr]
2. Material flows (biomass flows): basic unit = kg dry matter per year [kgDM/yr]
3. Substance (carbon) flows: basic unit = kg carbon per year [kgC/yr]

Results are not identical, because the energy content of different biological materials varies to some extent (the calorific value of woody biomass is higher than that of herbaceous biomass).

Conversion factors

For conversion factors between different energy units see chapter 3.

For conversion factors between different units for mass see chapter 3.

As a first approximation it can be assumed that the carbon content of dry matter of biological materials is 45%. That is, in converting dry matter to carbon, a conversion factor of 0.45 can be used (Schlesinger 1997).

Calorific values of many biological materials are compiled in chapter 3.; more data can be found in the literature.

4.5. References, bibliography

Examples of good practice

An article containing details on definitions, a lot of references, and the empirical example of Austria 1950-1995 is:

Haberl, H., K.-H. Erb, F. Krausmann, W. Loibl, N. Schulz, H.Weisz, 1999. Land Use-Induced Changes in Ecosystem Processes: Human Appropriation of Net Primary Production and its Influence on Standing Crop and Biomass Turnover. IFF-Social Ecology papers Vol. 57, Vienna.

The following article contains some methodological considerations for evaluating HANPP in time series and empirical results for Austria 1830-1995:

Krausmann, F. in press. Land Use and Industrial Modernization, An empirical Analysis of Human Influence on the Functioning of Ecosystems in Austria 1830-1995. Land Use Policy.

Both papers are available for download at the SEA-Trans Homepage.

Seminal papers

Whittaker, R. H., and G. E. Likens. 1973. Primary Production: The Biosphere and Man, Human Ecology, 1, 357-369.

Vitousek, P. M., P. R. Ehrlich, A. H. Ehrlich, and P. A. Matson. 1986. Human Appropriation of the Products of Photosynthesis, BioScience, 36, 368-373.

Wright, D. H. 1990. Human Impacts on the Energy Flow Through Natural Ecosystems, and Implications for Species Endangerment, Ambio, 19, 189-194.

Haberl, H., 1997. Human Appropriation of Net Primary Production as An Environmental Indicator: Implications for Sustainable Development. Ambio 26 (3), 143-146.

Sources for conversion factors and background data

Ajtay, G. L., P. Ketner, and P. Duvigneaud. 1979. Terrrestrial Primary Production and Phytomass, in The Global Carbon Cycle, edited by B. Bolin, E. T. Degens, S. Kempe, and P. Ketner, pp. 129-182, J. Wiley and Sons, Chichester, New York, Brisbane, Toronto.

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5. ANALYSIS AT THE LOCAL LEVEL

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It is proposed to conduct local case studies in addition to the national analysis. There are some good reasons for this:

- Apart from the 'big-picture' analysis, case studies provide the possibility to take a detailed look at a specific social entity in a region of special interest.
- If the case study is conducted in a rural setting, it usually gives you insights into the functioning of the subsistence economy normally underrepresented in national studies.
- In a case study , it is possible to qualitatively select a target segment of the populace (e.g. 'transition' society') and study its dynamics thoroughly.
- In countries with a high percentage of subsistence production, a lot of data for the national study cannot be retrieved from official statistics and other publications. Estimates will be an important tool in the research work, as will be first-hand data generation in the field.

In addition, case studies are expected to generate a better idea of how transition processes take place on the local level. Be it a village, an agricultural community, or a haphazard assembly of families in the industrial periphery, these studies can provide knowledge on concrete material and social effects of industrialisation processes and give insights on the development of cultural coping strategies of the studied communities.

It is important to bear in mind that the methods discussed in the following have originally been developed for national-level analyses (see preceding chapters). Only in recent years have they been adapted to the community level. This was made possible through research experiences in Thailand (Grünbühel 1999), the Nikobar archipelago (S.J. Singh, in progress), and in on-going studies conducted in Latin America (by the University of Bogota, Columbia and the University of Para, Brazil). As the methods for this level of research are still in a developmental process, step-by-step recipes cannot be given out to the researchers. Instead, the authors hope for creative contributions and intensive feedback by the researchers carrying out such studies. The following represents the summation of experiences made in local studies of this sort thus far, and tries to connect to the general concept of Societies' Metabolism as outlined in the previous chapters.

5.1. Systems boundaries

The first step is to define the social system under investigation e.g. a village or another delineated social community. This social system is located in a certain territory, a spatial area that the social system dwells on and exploits its resources from. This is what we consider the *domestic environment* (living space, forests, agricultural space, coastal areas etc.) There are two kinds of boundaries: one delineates the social system and its domestic environment, and one distinguishes one social system (and its territory) from another.

- The systems boundary for the social system defines the agents of material flows that accept ***inputs*** from outside the social system and discharges ***outputs*** from the social system. Within this boundary are located the *human population, livestock* and maintained *artefacts*. These physical components are ***society's stocks***. The input and output flows per year serve to produce or reproduce these elements of society's stock. Furthermore every stock requires a certain amount of labour input for its maintenance.
- Second, we define the boundaries of the society's territories, which is the area that this social system dwells on and exploits for natural resources. The extent of colonisation is understood through data on land use classification of the study area which leads to the accounting for the ***Human Appropriation of Net Primary Productivity (HANPP)***. Classifications include areas for plantations, horticultural gardens, water bodies, open space, streets, built up area, market place, kitchen garden, mangroves, coral reefs and different kinds of woodlands (bamboo grove, closed forest, forest under use etc.).

5.2. Material and energy flows at the local level

The aim is to be able to account for all energy and material flows into and out of the selected social system. The results can in the end be represented in different ways, but the most usual are (metric) tons/capita.year (for materials) and joules/capita.year (for energy flows)[29]. In this way, values become comparable (within certain limits) to the national level values.

In both Material Flow Analysis (MFA) and Energy Flow Analysis (EFA) we classify flows into 3 basic categories (see also: concepts of MFA & EFA in previous chapters):

- Inputs (all flows of material or energy crossing the society's boundary *entering* the social system.)
- Outputs (all flows of material or energy crossing the society's boundary *leaving* the social system.)
- Internal flows (all flows of materials and energy within the social system and not crossing the society's boundary.)

Inputs are further differentiated into several kinds of flows. Here, the origin of the material/energetic flow becomes important.

- Domestic extraction: Defines flows where material/energy is extracted from the *domestic environment*.

[29] It is strongly recommended to use only SI units in research and reporting

- Imports: Materials/Energy that stems from sources outside of the domestic environment, i.e. from different social systems.
- In analogy, outputs are classified similarly, albeit with an additional category.
- Wastes/emissions: describes the flows leaving the social system and deposited in the domestic environment (including the atmosphere).
- Exports: Produce and goods being economically transferred out of the social system under consideration. This category also includes wastes that are deposited outside the domestic environment.
- Deliberate disposals: Can be perceived as a subcategory of (a). This includes materials that are deliberately deposited in the domestic environment (e.g. Manure, chemical fertilisers, seeds for agriculture, etc.)

There is an additional category that becomes necessary when attempting a real balance, i.e. calculating inputs against outputs. The designation of ***society's stocks*** includes physical components of the social system that remain in the society and build up over the duration of one year. Without this concept, the balance of inputs vs. outputs cannot be equalled. Usually, inputs will be higher than outputs, making the society under consideration a growing system. Over the length of a year, stocks are added to by input flows, which do not immediately result in output flows. Much slower than they grow, stocks are also dissolved and added to regular output flows.

Society's stocks include the following segments:

- Population: the actual population size is considered as a material stock.
- Livestock: Although confusing, livestock (i.e. domesticated animals) is considered as part of the social system. The actual number of animals makes up the animal stock of the studies system.
- Artefacts & Buildings: All materials, tools, goods, products, furniture, constructions, buildings, etc. remaining in the social system for at least the entire course of one year belong to the stock category and should be accounted for as such.

5.3. Types of Materials in MFA

Water

Although not totally accounted for in national MFA, local level data on water consumption can be important for describing transition processes. This is especially true when considering irrigation agriculture as the main mode of production.

In general, it makes sense to categorise different types of water use, e.g.

- drinking water

- household water (washing, cooking, etc.)
- water for agricultural use (irrigation & livestock consumption)

Most probably there will be a different accounting method for every type of water use. (a) Drinking/household water: Where there is a tap water system, water consumption can be drawn from the measurement devices of the water company (usually given in m^3). Where water is carried to the household from a source, samples can be made of the amount and frequency of water carried every day. Cooking water can be obtained from the food preparation samples (see biomass, below). (b) Irrigation water: In agricultural systems, there are numerous different types of artificial irrigation, e.g. through channels and dykes, terracing, water pumps, human labour, etc. Depending on how irrigation is performed in the considered social system, the method of accounting has to be adapted to it.

Biomass

Biomass flows are among the most important in subsistence/transition societies. In farming communities most biomass is a domestic extraction input, the biggest share coming from the harvest of the staple crop (i.e. for Southeast Asia: rice).

Food for humans is thus one item to be accounted for. The research technique hereby used is usually one of sampling along the social status continuum. The results of human food intake in the considered social system can be represented in both kg and J (weight and energy). It makes sense to differentiate the source of food extraction. Depending on whether food is the staple crop, whether it is extracted by hunting and gathering in the forest, by fishing, or planted in the kitchen garden. This information does not play a large role in MFA terms, but very well does play importance when investigating the kind and quantity of labour spent for food production.

Food for livestock is equally important. Since livestock is part of the social system (see above), its food intake is calculated as an input. However, there are different categories to regard:

- forage & scavenging: this applies to domesticated animals that feed themselves in the 'wild' environment.
- grazing: although irrelevant in the MFA concept, for reasons of determining land use categories it might be useful to differentiate between forage and free grazing of livestock (see HANPP, below)
- feeding: the part of the animal diet being fed to livestock by humans is equally interesting. For MFA, it makes a difference if feeds have been processed before feeding them (which would constitute an internal flow) or not (which would be calculated as an input). Further, it is interesting, whether feeds are extracted domestically (e.g. as residues of agricultural production) or imported (industrially produced animal food).

Animal food intake is usually easily obtainable from agricultural statistic sources. However, questioning experienced farmers on amounts and types of feed is equally viable.

Other biomass flows. Naturally, there are additional biomass flows other than those providing nutritional energy. In a Southeast Asian farming community, harvest of **wood** and **bamboo** for building construction and production of tools and furniture is an important in-flow.

Further, there is additional biomass extracted when harvesting crops: straw, chaff, and husk come with the rice plant taken from the field and usually they are not wasted but put into good use (for animal feed, stable bedding, building construction, etc.)

We may also think of other biomass materials extracted from the domestic environment, which might be of lesser importance. This could be grass (for animal feed or roofing material), natural rubber, resin, raw silk (for producing textiles), etc.

Not the least, also immigration and emigration of the local population as well importing or exporting livestock ought to be considered as biomass flows. This should not be confused with natural population growths, which concededly represent increasing stocks, however they are not 'extracted' from other systems, but are part of the reproduction of the own system.

In order to achieve data on human food consumption, making samples of food consumed in different households seems preferable. These households should be carefully selected and should represent the entire social continuum of the considered community. Naturally, the more samples there are, the more precision is achieved, however number of samples must be related to the field situation and resources of the fieldworker. During the samples it seems advisable to monitor the entire cooking and food preparation process as well as the actual consumption and disposal of left-overs. It is also important to note the number, age and status of the consumers.

Animal consumption can easily be drawn from consulting relevant agricultural literature or experts at local agricultural research institutions. What is needed, is number, age, kind, and size of livestock kept in the considered community. Animals not held during the entire length of a year are usually accounted for in the proportion of their duration of presence in the social system.

For biomass used as building materials (such as wood or bamboo), in the total estimation of building materials stocks (see section below), biomass would be included. In many Southeast Asian cultures, wood is the most prominent material (in quantity, if not in weight) used for building living shelters.

Biomass for other use, e.g. wood used as an energy carrier, either directly burned or transformed into charcoal, household surveys can be applied. Similar to the samples of nutritional intake, household members can be observed during their daily chores, from which important insights on the kind and quantity of materials used can be taken.

Minerals

The largest portion of extraction in this category is usually minerals for building construction. Wherever there is a social system containing concrete houses as artefacts, concrete as well as sand and gravel constitute some of the largest flows (in terms of tons) in the MFA, even if the concrete buildings are not numerous in quantity. In addition, one should include asphalt in road construction; clay in building bricks; all kinds of metals used for tools, machines, and other goods; rocks and stones (for tools and in building construction), and any other types of minerals one might come across in the field study.

Most minerals (especially those used for building construction) will probably be accounted for as stocks, them being found in the already existing structures and infrastructure. However, it is mostly possible to estimate the in-flows of these materials; it will possibly be difficult to calculate out-flows since these materials usually have high durability.

Since a large part of minerals are stocks, all standing structures and infrastructure need to be accounted for. Houses that are similarly built can be sampled, i.e. calculate a m^2 value from one representative building and measure only the built-up area of other building of the same type. Special constructions are measured separately. Categorise and lump together building materials by the kind (concrete, wood, iron, bamboo, bricks,...) and separate mineral stocks from other building materials.

For infrastructure, e.g. paved roads running through the studied system, it is sufficient to interview the building agency (public works department) and find out about materials used and quantities applied.

For the growth of stocks, i.e. in-flows of minerals, there might be the chance to observe building construction activities. It might be possible to estimate the increase of houses or the growth of the paved road network during the course of a year. From hints such as these or others, it might be possible to arrive at a mean yearly growth of mineral stocks.

Fossil Fuels

In this category, all fossil energy carriers are subsumed. The most important are gasoline (including diesel), coal and petroleum. All fossil fuels are industrially refined, and thus represent an import into the studied community.

In most cases, fossil fuels are flows, since there is little reason in stocking these commodities. Fossil fuels are used for cooking, heating, mechanical labour in farming tools and drive power in vehicles.

The fossil energy carriers play an important role in EFA. The amounts of each type has to be converted into a calorific value (see the chapter on EFA above for conversion factors).

Use of fossil fuels can easily be determined by conducting interviews with the consumers. Most often - especially if it is not a wealthy community - do they know about their individual, or household's consumption, albeit sometimes only in money-terms. Otherwise, interviewing merchants who sell these products might also give clues on total consumption in the community. Observation is a third method that might give some data on consumption patterns.

Finished goods

Most local MFAs come across several different types of products, where it is difficult to define the exact number and kinds of materials, which these products are made of. In this situation, when the identification of the various materials in a certain product does not significantly increase the interpretative value of the MFA balance, finished goods are lumped together into one category. In most cases finished goods are imports, remain in the social system as stocks and are later discarded as waste. Examples of such finished goods are motor vehicles, electronic appliances, agricultural machines, imported furniture, etc.

Goods, being mostly stocks, could be included in an initial household survey, which identifies all materials used and consumed within the households. Sometimes it might only be possible to obtain the number of goods in an individual household. In this case it might be possible to arrive at an estimate weight of specific products by interviewing the producer or making sample measurements.

To identify in-flows, interviewing local merchants or household members could be options.

5.4. Special considerations for EFA

Most of the data needed for EFA has already been collected when assembling the MFA. However, what is important is to achieve an understanding of the differences and yet compatibility of MFA and EFA. Using the same system boundaries, energy flows can be identified in two ways.

1.Energy conversions (mostly combustion) of energy carriers from chemically stored energy or electricity to useful energy, such as drive power, light and heat

2.Nutritional energy ingested by humans and animals used for their own basic metabolism, their reproduction and for labour expended within the social system

Electricity, provided the selected community is connected to a electrical power network can usually be easily accounted for. Questioning the consumers and asking for their electricity bills might suffice to find out about the kWh consumed. Another option might be to interview a responsible person from the power company or make own estimations considering the number of light bulbs and electric appliances used in an average household.

The total quantity of **energy carriers** were already accounted for in the MFA. In agricultural communities, *refined fossil energy carriers* (coal, propane gas, gasoline, petroleum) need to be considered as imports, since they are not extracted and refined within the studied social system. After having calculated the quantity of such energy carriers by the type, it is advised to use conversion tables (such as those provided in section 2.1.2. of this manual) to arrive at the quantity of energy stored chemically in these materials.

Whereas fossil fuels are mostly used for powering machines and motor vehicles, *biomass* used for energy generation (wood, charcoal, animal dung, straw, resin, etc.) is usually fired to produce heat needed in food preparation processes. Here also, what is first needed is the quantity and type of the biomass used for energetic purposes. Thereafter, each material can be converted into its net calorific value from existing conversion tables.

Human **nutritional energy** is best accounted for by applying the household sample method (see 2.2.2.1. – Biomass, above). Differentiating various types of food according to their ingredients, gives the possibility of applying a calorific value to each (again, use tables). The aim is to arrive at an average nutritional energy intake by human, represented in Joule (J). Equally proceed regarding animal nutritional energy intakes.

5.5. HANPP-accounting at the local level

Human Appropriation of Net Primary Production (HANPP) measure the amount of energy in the natural environment withdrawn and/or prevented by human activity. Primary production is the amount of biomass produced by an ecological system to (a) reproduce itself, (b) grow, and (c) provide nutrition to heterotrophic organisms, i.e. feed the natural food-chain. As human society interferes with the natural environment it inhabits, primary production of biomass is either extracted through harvesting or prevented to exist by clearing vegetation. When considering the magnitude of human interference with natural system, HANPP serves as a viable indicator (for details, see section 4 of this manual). Comparing the HANPP values of different modes of production can lead to insights of sustainability options of the societies considered.

The following provides some suggestions of how to calculate HANPP in the local study. Using the same system boundaries as in the MFA/EFA, the first step is to classify the domestic environment of the studied community in terms of different *land use patterns*.

- **built up area** (houses, churches/temples, schools, dispensaries, outhouses, field huts, community houses etc.), and all area consumed by paved streets and gravel roads; also, **cleared or open space**, such as courtyards, footpaths, market places, football fields, etc. wells, waterways, ,

- **fields, gardens, and plantations**, e.g. crop fields, coconut plantations, kitchen gardens, planted forest, etc.

- **forest** (natural), mangroves, coral reefs, beaches, i.e. all natural ecosystems, not or minimally interfered with by humans.

The various classes of land use areas are calculated in m^2/km^2. Measuring methods could be a measuring tape in case of small areas, a speedometer fixed to a bicycle for relatively larger areas and other methods like a compass for measuring angles. The best, however, would be data of land use from the local revenue office or a good satellite or area map.

Potential NPP

To consider potential NPP of the area investigated, i.e. the NPP that the ecosystem would produce in absence of human interference, what is needed is the type of vegetation cover in areas minimally used by humans (if available, e.g. natural forest classification). This should be available from the local forest department or the directory of national parks. Another source could be local research institutions, local NGOs working on ecology, or the national ministries of forestry and agriculture. Usually, talking to colleagues with a background in forestry or biology solves the ordeal.

Actual NPP

This refers to the amount of NPP actually remaining in the ecosystem after interference by human activity (harvest and prevention of NPP by humans). Hereby, land use classification comes into play. Depending on the type of land use, actual NPP can vary between 0% (built-up or cleared areas) and more than 100% (heavily fertilised crop field) of the potential NPP. Calculating an average of these, one arrives at a percentage that is usually significantly lower than the potential. The difference between actual and potential NPP is then referred to as NPP ‘appropriated by human activity’ (i.e. HANPP)

Harvest

Biomass, fuel wood and timber harvest can be calculated from data calculated from the material flows data. Wood and other vegetal biomass used for cooking and heating and timber used in construction are, provided they are domestically extracted, harvested from the local ecosystem. More important, harvest of crop from fields, gardens and plantations need to be calculated. This also, should be possible in consulting the MFA data sheets. However, when estimating harvested quantities, gross amounts of biomass withdrawn from the field need to be taken into account, i.e. the grain, including husk and straw[30]. Vegetational biomass remaining on the fields (harvest residue, grass, weeds) however, are subsumed under ‘actual NPP’.

5.6. Fieldwork and data-gathering

[30] As, for example, with rice, the amount of husk is 2 times the amount of harvested white rice, and the amount of straw harvested is again 1.4 times the amount of paddy (grain + husk).

Criteria For Choosing A Research Location

- Representativeness. Considering that the study is not an ethnographic study, the research location should be fairly 'typical' for the selected region. Naturally, this is difficult to achieve, since every location has its unique features. However, according to the general theme of the project, the subject of investigation is the 'transition' society, i.e. traditional/rural society on its way towards industrialisation. An isolated plantation community in a shifting cultivation or hunter-gatherer environment might fit the criteria; small-scale farmers in a region, where different modes of production co-exist might well do.

- Rate of economic development. In most cases, locations under consideration for the study will neither be highly developed nor totally 'traditional'. Both subsistence and market economy will co-exist within the same community. The community under investigation would rely mainly on self-generated resources for their livelihood. At the same time, links to the global economy will be present and probably fast-growing. To avoid picking exceptions, avoid nearness to large urban areas, but also extreme isolation and remoteness.

- Ethnic and social make-up. To avoid complication of the study, it might be advisable to choose a location of relative ethnic homogeneity. Careful: This advice only applies if different ethnic groups usually live in spatially separated areas. If multi-ethnic communities on the local level are usual, choose adequately.

Likewise, the social structure is of particular concern. It should follow the general pattern of the entire region, and if not, the specific circumstances should be described in the report and caution must be exerted when validating the study for a larger area.

- Seasonality. Regarding the time frame of the research, seasonality must be considered. Particularly agricultural societies are largely dependent on the seasons throughout the year. There may be seasons in which the community has a heavier workload to deal with than in others, i.e. material and energy flows would reach a peak whereas they drop below average in other times of the year. Conducting research during the peak times may virtually deprive you of all your informants. On the practical side, in remote locations there might be seasons in which access to the community is denied due to weather conditions (e.g. heavy rains).

- Outside interventions. If possible, the research location should not be target of outside interventions, e.g. being a state development site or having on-going co-operation projects with NGOs and other development agencies. This would distort the above mentioned representativeness.

- Delineation of location ('system boundaries'). Not always will you choose an easily identifiable autonomous community. Therefore it is important to both geographically and socially draw boundaries of your research location. The community under investigation should have (a) a common territory it dwells on,

(b) a social structure related to this territory, and (c) a definite natural environment, it draws its resources on. This could be a certain district of a small town with its own governance, an isolated village, a clan living on common space, or a pioneer settlement of a few families.

Research

1. Pre-fieldwork steps

After having agreed upon a research location that is suitable for the overall aims of the project, several decisions have to be taken, before commencing the actual research.

- Ideally, the research can be commenced with a brief pilot trip to the location. This can help to establish necessary contacts with the local people, arrange research permits with local authorities, clarify practical details, such as accommodation and living arrangements, and test the kind of reception that can be expected by the future informants. Also at this stage you might want to execute what is termed the 'delineation of the location' above.

- The pilot study provides many new aspects, ideas, and warnings about the proposed research site. These should influence the final research design so that it can be adapted to the particular conditions you have found on the ground. Reconsidering of time schedules, working tasks, and other adaptations might be necessary.

- A period of literature research is recommended at this point. Background knowledge on the cultural make-up of the social group and its structure will be important. Also, familiarisation with biological and physical properties of the materials expected during the phase of research is recommended. What is the particular metabolism of the domestic animals? What are typical harvesting rates of plants bred on the site. What are energy properties of the types of food consumed? Determining specific weights of the different building materials used, the kinds and characteristics of energy fuels, the non-local resources expected in the location, etc.

2. Fieldwork

- When first entering the field, the first task is to produce an overview of the socio-economic system dealt with. Several statistical questions can be answered here.

1. Population size. Determining the size of the population in the research location. This will not be easy for two reasons: (a) In most locations population varies seasonally due to labour migrants and (b) there are often more people provided for by the produce of the location than are actually present, i.e. migrants consume food produced in their place of origin; non-resident families and guests have to be provided with gifts and exchanges, etc. The necessity of using two population figures might arise, one actual figure at the time of the sample, and the other maximum figure including migrants and all non-residents.

2. Territory. What is the extent of space consumed by the research location? This will have to be divided into

Village land

Built-up area

Paved roads

Gravel roads

Footpaths

Agricultural land

Forest

Other natural ecosystems

3. Basic social data. Gathering statistical data to produce an overview of the local society.

Number of households

Number of children, elderly, women, men

Number and kind of domestic animals per household

Amount and kind of land used by/allocated to the household

Sources of income generation and their relations within the household

Relations of producing and non-producing household members and number of migrants

Breakdown of durable consumer goods (number of cars, refrigerators, electrical appliances, gas cookers, etc.)

Approximate income classification of households (needed for later sampling!)

- During research the investigator will have to operate with an array of scientific methods in order to achieve a detailed picture of local material flows. The four most important items are

a) Measuring and Counting

b) Interviewing

c) Estimating

d) Sampling

The researcher will follow the societal throughput of materials as closely as possible, from the initial introduction into the socio-economic system until the final outlet. These materials will most likely be:

a) Water

b) Biomass (food, domestic plants, livestock, building materials, manure,…)

c) Fossil materials (fossil fuels, plastics, chemical fertilisers)

d) Minerals (building materials, iron)

In addition to accounting for the material flows, the data should include all stocks - materials that remain within the socio-economic system for a duration of one year or longer. Stocks also consist of the above mentioned materials.

Not everything can be measured and weighed. Therefore, in many cases one has to rely on accounts by the informants. This is also necessary in order to understand different stages in production processes. Often informants can provide only broad estimations. It will be your task to verify these with your own estimations.

Sampling is often used, especially when personnel is limited. Everything cannot be measured, therefore one should try to be exact with samples. Picking samples can be difficult since they have to be representative for large parts of the community. A great deal of experience with the research location will be needed. After gathering preliminary data on social structure, qualitative classifications households into social categories, e.g. 'high income' – 'low income', or 'high status' – 'regular household' are useful. When categorising considering as many variables as possible and following indigenous values will lead to exact results. For example, in some cultures, cattle is held in higher esteem than cash. The cattle owner may therefore hold higher rank although he is poor according to outside standards.

Since many items do not consist of homogenous materials, the researcher's flexibility will be tested at certain times. Here again, it is best to take precise samples of relations of materials and then estimate for the remaining items.

- Depending on the distance between research location and the academic base, there might not be an opportunity to return to the site and account for omitted data after the fieldwork is completed. In this case referring to prior case studies (of which there are few, see references below) or holding contact with the researchers conducting the other Country Studies in the project is probably the best advice for valid outcomes. Naturally, such estimations are not preferable, however, they are certainly valid as long as they are well-founded.

- Time samples. A second time sample gives (1) data on seasonal variation of material flows and (2) information on the increase of stocks within the studied community. This is important information in the 2nd project phase, when it comes to modelling for the future. A second sojourn in the field does not have to be as extended as the first. It should take place either during a different climatic season (e.g. rainy – dry season) or after the course of one year.

5.7. References

References that further describe the local MFA approach as outlined in the chapter:

Fischer-Kowalski, M., W. Bruckner, C.M. Grünbühel, H. Schandl, H. Schütz, and H. Weisz. Material Flow Accounting (MFA) Information Package. Vienna.1999. http://www.univie.ac.at/iffsocec/amazonia21/

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Publications applying similar or related approaches to the one described in the chapter:

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