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Towards more ecoefficient food production: MFA approach

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Abstract

The key for sustainable development is dematerialisation and ecoefficiency. Applied to agriculture ecoefficiency means production of nutritionally better food by using less inputs and by reducing environmental burden. In restricting the material throughput it is essential to identify the most voluminous material flows and direct the measures to them. Improving ecoefficiency of the food production requires that the benefits and inputs be quantified in an unambiguous way and that the inputs are estimated for the whole production chain. A comprehensive view of the whole system is necessary.

The food flux comprises four mutually linked loops: 1) plant production 2) livestock husbandry, 3) food processing industry and 4) human consumption. In the present paper MFA approach has been used to describe the system. A general framework and practical solutions for estimating and balancing the materials flow are outlined. The focus in this paper is agriculture,

The holistic MFA approach provides means to evaluate environmental and economic consequences of production and consumption. For decision makers MFA approach is a tool in guiding the development and assessing the progress towards increasing ecoefficiency of food production. The results can be used to develop new sustainability indicators. At the end, some of the possibilities are shortly discussed.

The study is the first step in developing MFA methods to analyse and to monitor the materials flow of the Finnish food flux. It is a part of the project “Materials Flow and Ecoefficiency of Agriculture and Sustainable Compatibility of Food Production” carried out in collaboration between the MTT - Agrifood Research Finland and the Thule Institute at the University of Oulu. The results are used also in compiling the Finnish physical input-output tables. The study, thus, contributes to the overall development of the materials flow accounting statistics.

Key words: agriculture, ecoefficiency, food flux, material flow accounting (MFA).

1 Introduction: sustainable development, ecoefficiency and agriculture

There is a broad consensus that the prerequisite for the sustainable development on the global scale is to half the use of natural resources within the next decades. This requires considerable dematerialisation of the economies, which can be accomplished only through a profound change in the production and consumption patterns. Dematerialisation means decoupling the economic expansion from the materials throughput, and this is, in fact, the guiding principle for environmental policy and societal development (Hinterberger et al. 2000, WRI 2000). On the general level the strivings towards sustainable development have been expressed as the Factor goals. The main responsibility lies upon the industrialised countries, which have to reduce their use of natural resources to one tenth compared to the

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situation today (Factor 10 Club 1997, Lovins et al. 1997). To accomplish this the emphasis has to be shifted from labour productivity to resource productivity and from expanding economies to improving ecoefficiency of production (Lovins et al. 1999).

The ecoefficiency-concept was first introduced by the World Business Council for Sustainable Development in 1992 as a goal to meet the human needs, to improve the quality of life and to adjust the production to the carrying capacity of the Earth (WBCSD 2001). The enterprises quickly assimilated the concept as a means to cost-effectively manage the environment. Now the ecoefficient management strategy has been adopted also as a guideline on nationwide level to encourage more sustainable production patterns and life styles.

Ecoefficiency –thinking is thinking in terms of the whole production chain and it requires comprehensive view on the material throughput from nature to antroposphere and back to nature. The essence of ecoefficiency is to produce more out of less, and the efforts towards increasing ecoefficiency are concretised with the Factor-goals. Ecoefficiency can be expressed with the simple equation: Ecoefficiency = Benefits/Inputs. Thus, improving ecoefficiency by a specific factor implies either increasing the benefits, decreasing the inputs or carrying out both measures simultaneously.

The concepts of sustainability, factor goals and ecoefficiency are relevant also in agriculture. However, the various farming subsidies may blur the profitability of agricultural production and the economic aspect of sustainability. It is also clear, that we cannot eat virtual food and the amount of food to be consumed is rather constant. Therefore, there are rather strict limits to dematerialisation of the food production. On the contrary, it has to increase, at least globally, to meet the demands of the growing world population and to improve the nutritional status of today's population. Applied to agriculture the ecoefficiency-concept could be defined as production of nutritionally better food by using less inputs and by reducing environmental load.

2 Purpose of the study

Improving ecoefficiency implies that the benefits and the inputs be quantified in an unambiguous way. Therefore consistent and internationally comparable methods of data collection and compiling statistics are needed. The concepts industrial ecology and industrial metabolism have brought the energy and material flows of the societies into the focus. The objective is to adapt the societal metabolism to meet the demands of ecological sustainability and the carrying capacity of the Earth (eg. Ayres 1989, Lowe 1993). This requires knowledge on mobilisation and transformation of various materials between nature and society as well as within the societies, and several methods of analysing the material flows have been developed to describe and to quantify the material turnover.

Presently Eurostat is establishing material flow accounting as an integral part of the standard statistics and is developing common methods to compile national physical input-output tables (PIOTs). In these, the nation-wide materials balances are disaggregated and the inputs are allocated to the various sectors of the economy. Food production is one of these, and compilation of the physical input-output tables requires detailed knowledge on the materials flow even within the food flux.

The main purpose of the present paper is to introduce and to discuss the applicability of the material flow approach to food sector. A general framework and practical solutions for estimating and balancing the materials flow of the food flux are outlined. The focus is agriculture and the specific problems related to quantification of materials use and transformation within animal husbandry. In conclusion it will be shortly discussed, how the results can be used to promote sustainable production and consumption. The results of the study will also complement the economy-wide materials flow balance, and the study thus contributes to the compilation of the physical input-output tables.

3 MFA

The acronym MFA stands both for material flow accounting and material flow analysis. The MFA research is concerned among other things in developing methods to measure and to analyse the use of natural resources within the various sectors. The methods have been developed especially at the Wuppertal institute in Germany and within the EU-funded ConAccount –project (Bringezu et al. 1995, ConAccount 1998). The methods have been applied in producing internationally coherent data sets on the economy-wide materials flow and in comparing the material flows of various nations (Adriaanse et al. 1997, WRI 2000a). A central concept is the total material requirement or TMR. TMR comprises the direct material inputs as well as the so-called hidden flows or the ecological rucksacks.

The TMR approach focuses on the input side of the material throughput, and it is a crude overall measure on the potential environmental impact. This is because the extraction of natural resources directly interferes with the functioning of the ecosystems and because the extracted raw materials are, sooner or later, returned back to nature. By reducing the volume of extracted raw materials, the environmental impact is relieved both at the beginning and at the end of the materials throughput (Schmidt-Bleek 1998). Relating the material flows with specific environmental issues requires allocation of the material to the various sectors. The linking between the material flows and their environmental impact can be examined in more detail by identifying and quantifying the output material flows. A pilot work on this has been compiled by the World Resources Institute (WRI 2000a).

The material flow approach dates back to the late 60'íes (Boulding 1966, Daly 1968, Ayres & Kneese 1969). It is thus a fairly new field of research. The methods have been applied to assess the extent of the natural resource use and the data are needed for monitoring the extent of dematerialisation. The European Environmental Agency has implemented material flows and ecoefficiency within the major environmental signals measuring the progress towards sustainability (EEA 2000). The data can be used also as a tool in making environmental policy decisions (CEC 1999, 2001).

So far there are only few studies explicitly on the food systems. The attempts to harmonise material flow accounting of biological production have been restricted to highly aggregated data of the economy-wide MFA (Adriaanse et al. 1997, Ayres & Ayres 1998, Eurostat 2001). A model for biomass turnover within the global food system has been constructed by Wirsenius (2000). Material, energy and monetary fluxes have been analysed in assessing the resource management within the Swiss food sector (Faist et al. 2001) and in defining the sustainability space of that sector (Binder and Wiek 2001). Combined substance flow models and life cycle assessment methods were applied to evaluate the environmental advantages of the small-scale food supply systems over the large-scale systems (Thomsson 1999). In addition, ecological rucksacks for several single food products have been estimated on the basis of the MIPS (material intensity per unit service) –concept and there is an increasing number of product specific LCA studies also on food products.

In compiling the total material requirement (TMR) for Finland, plant production with the associated hidden flows was accounted for as the input of agriculture to the economy (Mäenpää et al. 2000), and material flows of Finnish agriculture were described in detail (Risku-Norja et al. 2002a). The Finnish TMR data were compared with energy consumption in agriculture and with use of biocides and fertilisers to elucidate the development trends in agricultural production during the past 30 years in Finland. The data show marked improvement in efficiency in using these suggesting development towards more sustainable production (Risku-Norja 1999).

4 The role of agriculture in Finland

As to the basic food products Finland is largely self-sufficient. During the past 30 years the plant production has markedly intensified, the yields per hectare have nearly doubled and also the production per capita has increased by about 25 % (Risku-Norja 1999). At the same time the total energy intake of the population has somewhat decreased from 12.6 to 11.3 MJ per capita per day, but today a greater part of the consumed food is from the animals (MTTL 1976, MMM 1997). The increased plant production is thus used as feed and is processed trough animal husbandry to human food.

Agriculture has experienced a profound structural change during the past few decennia. This is reflected in the number of farmers and farms as well as in the area of cultivated land. Judged from the Finnish TMR and from the national economy the role of agriculture appears to be quite insignificant (Fig. 1a). The share of agriculture from the TMR is only 5 %, and it has not changed markedly during the past 30 years. The share of agriculture from the Finnish GDP has also oscillated around 1 % since the 70´ties, at present it is about 1.2 %. In 2000 the number of people employed in agriculture, inclusive fishery and game husbandry, was almost 121,000 persons, i.e. about 5 % of the employed labour force.

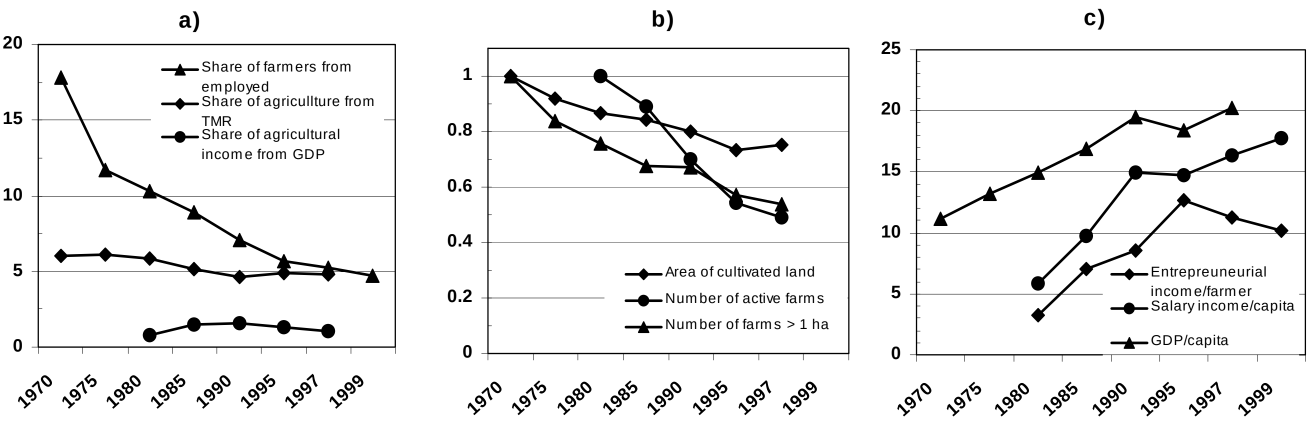

Fig. 1 The role of agriculture in Finland in 1970-2000:
a) Share of agriculture from the Finnish TMR, of agricultural income from the Finnish GDP and of farmers from the employed labour force, %. Source: Mäenpää et al. 2000a, Statistics Finland 2000.
b) Area of cultivated land and number of farms with an area over 1 ha in Finland in 1970-2000, 1970 = 1. Number of active farms in Finland in 1980-2000, 1980 = 1. Source: MTTL 2001.
c) GDP per capita, salary income per capita and entrepreneurial income from agriculture per farmer in 1970-2000 in Finland, 1000 €. Source: Statistics Finland 2001

Compared to the situation in 1970 the number of the farms with an area of over 1 ha has dropped by almost 50 %, the number of active farms is now only little over 40 % from what it was in 1980. The cultivated land area is now slightly under 2 millions hectares, in the 1970 it was 2.6 millions hectares (Fig. 1b). At the same time the average size of the farms has increased from under 10 hectares to little over 28 hectares.

In Fig. 1c the entrepreneurial income from agriculture per farmer has been compared with the GDP and total salary sum per capita. The figure shows that in average the farmers' income is less than the average salary income. There has been a substantial economic growth up to the middle of the 1980'ies, but the gap has not been mitigated. During the 1990'ies the GDP and the total salary income have continued to increase, but the farmers income has turned to decline. The economic development of the agricultural population has been detached from the overall development of the society. At least from the farmers' point of view the data suggest economically unsustainable development.

In spite of the apparently small contribution of the farming to the Finnish economy, environmental impact of agriculture is considerable and extends far beyond agroecosystems. The problems are related to biodiversity, maintenance of soil fertility, eutrophication of the watersheds and to emissions of greenhouse gases. E.g. in Finland agriculture is responsible for about 50 % of the anthropogenic nitrogen and phosphorus loading of the watersheds (Rosenström and Palosaari 2000) and for about 10 % of the atmospheric total greenhouse gas emissions (Pipatti 2001).

It should be also remembered, that food is not a commodity among others, but fundamental for survival. Right to food is expressed also in the United Nations´ declaration on human rights, and food should be treated according to its very special character rather than as commercial merchandise. Food has to be produced also in the future and the production will continue to modify the environment in various ways. However, despite the fact that the food production globally is to be increased to meet the needs of the growing population, the environmental impact of the production has to be radically reduced. MFA methods provide one possibility to assess the progress towards more ecoefficient food production.

5 The materials flow of the food flux

The food flux comprises four mutually linked loops: 1) plant production 2) livestock husbandry, 3) food processing industry and 4) human consumption.

In compilation of the TMR of four nations, the photosynthetic activity responsible for the plant growth is considered as the phenomenon of nature. The system boundary between the economy and nature is defined accordingly: the harvested plants with the associated ancillary biomass are inputs from nature, while the biological metabolism of the livestock and humans occurs within the economy (Adriaanse et al. 1997). However, plant cultivation is economic activity that has marked environmental impact. A comprehensive view of the food production requires that it be included within the system. On the other hand, the ancillary biomass has been excluded in this work, because it is returned to the soil on harvesting and it never enters the economy.

The PIOT data must be consistent with the economy-wide MFA data. Applying the MFA approach to the animal husbandry encounters problems, which are related to transformation of the materials by the animal metabolism. This is because water and air are usually taken as free goods and are not accounted for in assessing the material flows. However, the feed as well as the various animal products contain variable amounts of water. Transforming the vegetable feed stuffs to food for humans also requires oxygen and liberates carbon dioxide and water vapour. Ignoring these would result in a considerable material imbalance and, as e.g. in case of milk production the outputs would greatly exceed the inputs, which obviously is an oxymoron.

To overcome these problems, the system boundaries between the economy and nature have been here redefined. The system is outlined and the material flows are summarised in fig. 2. In addition to solar energy, the inputs from nature comprise only water, CO_2 and O_2, inputs from the other sectors of economy include fertilisers, biocides and the fuels. Outputs back to nature are the gaseous O_2, CO_2, water, methane (CH_4), ammonia (NH_3) and the emissions from the fossil fuels. Other outputs are the surpluses of nutrients and biocides, sewage as well as the wastes from the products proper, i.e. plant, slaughter and food wastes. The gaseous emissions end up directly into the air and the sewage into the watersheds, whereas others enter the soil, remain there or are subsequently moved into the watersheds or into the air.

The production statistics of agriculture provide the necessary background data. These include the area of cultivated land, volume of the various plant products, the carcass and live weights of the slaughtered animals and the amount of the various animal products. Other data include the sales statistics of the various agrochemicals and the energy consumption.

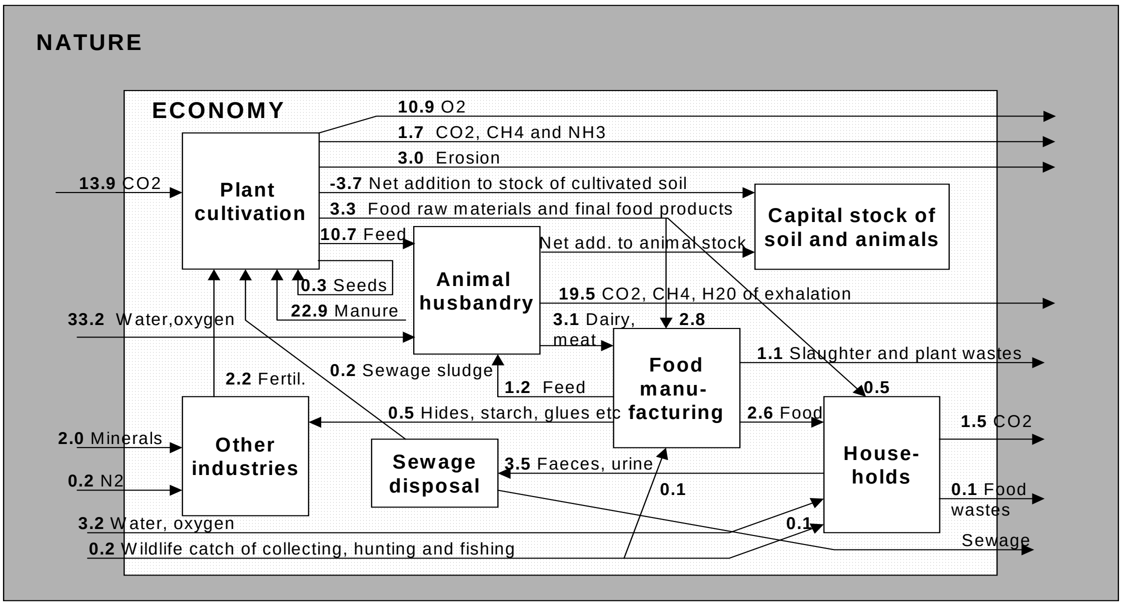

Fig. 2. The system boundaries and summary of the material flows of the food flux in Finland in 1995, thousand metric tons (Risku.Norja et al. 2002)

The direct material outputs (DMO) of the domestic plant cultivation (food and feed) in Finland in 1995 were 15000 metric tons, out of which approximately 2050 metric tons is pasture grass.

The products of the animal husbandry, beef, pork, poultry and eggs together comprise about 535 metric tons and 2565 millions litres milk. Pig, cattle and poultry comprise 96 % of the meat production. The remaining consists of reindeer, sheep, horse and the wild. These have been excluded, although in areal studies their proportion could be significant.

Feed constitutes approximately 75 % of the domestic plant production. Out of this, 7155 tons is hay and silage and 2050 tons pasture grass. About two thirds of the cereal production is feed grain; turnip rape, pulses and potatoes are also used for animal feed. About 2000 tons were used in the food processing and alcohol industry, the residues from which are largely returned to agriculture as animal feed.

Plant cultivation. The primary inputs from nature, water and carbon dioxide, are estimated on the basis of the volume of the harvested products from the equation of the photosynthesis ($6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$). On the basis of molar weights it can be calculated that production of one kilogram glucose, 1.47 kg carbon dioxide and 0.6 kg water is needed, and 1.07 kg oxygen is liberated. The equation calculates the products on dry matter basis, and the weight reported in production statistics have to be converted into dry matter by extracting the water content of the products.

Animal husbandry. The material transformations by the metabolic processes are varied and complicated. The essence of the animal metabolism is to liberate energy from the feedstuffs to be used for growth, production of heat, motion and for maintenance the basic metabolic functions. The feed is broken down and oxidised or burned mainly to water and carbon dioxide within the digestive system of the animal. The process links the gas exchange of breathing intimately with the nutritional cycle; the oxygen necessary for burning is inspired and the carbon dioxide is expired via the lungs. The process is exothermic, and a great deal of energy is liberated.

Quantification of the materials flow of animal husbandry is based on information on animal nutrition. The energy content is the basic unit used in nutritional studies, and a lot of detailed data are available on the energy economy of production animals. Energy approach is practical because in given circumstances the energy requirement is quite constant, although the water content of the feed may vary considerably. The energy content is easily converted to weight units on dry matter basis and the data from various animals are directly comparable. The water content of the feed and of the various output products can then be adjusted for the different animal species and by paying attention to the specific production circumstances.

Data on the gross energy and drinking water requirement, the energy contents of the various animal products as well as that of urine, dung and methane, and on the allocation of the energy to growth and maintenance are needed for each production animal species. Here, material flow balances have been separately calculated for production of milk, eggs, beef, pork and poultry. The data are estimated on the daily basis and they are converted to yearly amounts by taking into account the animal-specific life- and production cycles. The material flows are measured in actual weights, and the weight of the dry matter obtained from the energy approach has to be converted into fresh weights by taking into account the water content of the feed, animal products, dung and urine. Detailed description of the calculation methods is given elsewhere (Risku-Norja et al. 2002a).

The organism cannot utilise all the feed it consumes. The total or gross energy of the feed is divided into digested, metabolisable and net energy (Fig 3). The daily energy balance is exemplified in Fig. 4 with that of a dairy cow. The undigested part forms about one quarter of the total energy intake, and it is expelled as dung. Part of the digested energy is excreted as fermentation gases and with the urine. The rest is metabolisable energy that is used for maintenance and production. Part of the metabolisable energy is lost on building up the various compounds of the milk and tissues from the split molecules of the feed. These transformation losses together with the maintenance produce the heat for the animal.

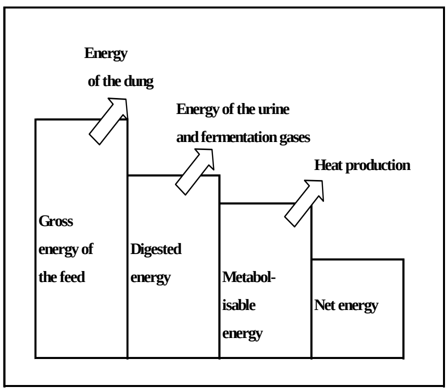

Fig. 3. The division of the gross energy of the feed (MKL 1999).

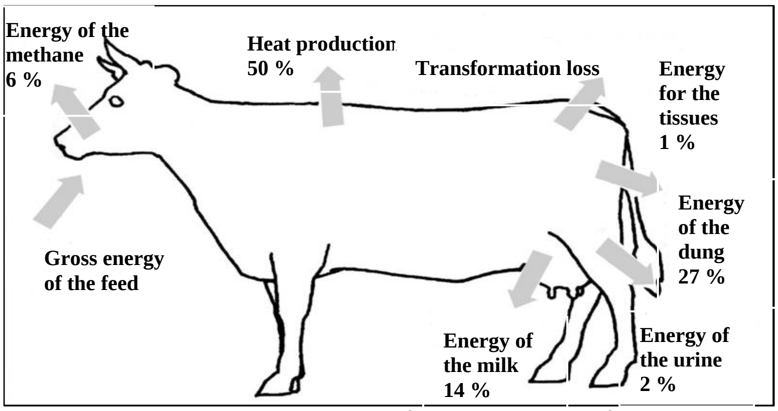

Fig. 4. The average daily energy balance of the dairy cow modified from MKL (1999) by taking into account the production cycle of the cow.

6 Discussion

MFA approach can be carried out at different scales ranging from nation-wide to regional and sector levels. The efforts to improve ecoefficiency of various sectors are concretised by sector-specific factor-goals. The goals must be realistic and obtainable, and for that a realistic picture of the within-sector material throughput is needed. The starting point is the description of the present situation in an accurate and internationally harmonised way. This reveals the hot spots and allows deciphering future development trends, specifying the goals and provides also means to evaluate the progress in reaching the goals. For continuous monitoring MFA is a powerful tool, because the aggregated data provide an overview of the structure of societal metabolism and of its changes over time.

This study is the first step in developing MFA methods to analyse and to monitor the materials flow of Finnish food flux. The data will be used to complement the economy-wide material flow balance, and the study contributes to the compilation of the physical input-output tables.

The focus in this paper is on agriculture. The proposed method to estimate the materials flow within animal husbandry is universal. The material flows are extrapolated from the data concerning one average animal representative of its species. Faulty background data may give totally misleading results when multiplied with the number of individuals of each animal species. Therefore, attention has been paid especially to the reliability of the background data, which have been critically viewed by the specialists of animal nutrition at the MTT. The data applied here refer to the circumstances of conventional farming in Finland. Applying the method to different production circumstances requires that the data be adjusted accordingly.

Combining the material flow data with those on monetary flows the approach allows analyse the effects of changing consumption and production patterns on the material and monetary flows within the agriculture. Integrating the data on agriculture into the national statistics, economic and environmental impact of various options can be analysed on national level as was done by Risku-Norja et al. (2000).

The ultimate purpose in doing this is to adjust the food production to a level complying with the demands of sustainability. Defining the sustainable level requires comprehensive view on the cause and effect relations. Considering the materials flow data together with environmental and socio-economic statistics is a promising source in developing new sustainability indicators. Several European countries work on in linking the existing data into the national accounts (Eurostat 2001). So far the data have been used to describe the development trends in the use of natural resources, the material intensity of the production and the dependence of the TMR on the economic structures (eg. Adriaanse et al. 1997, EEA 2000, Mäenpää et al. 2000).

Improving ecoefficiency means lowering environmental burden without decreasing human welfare or profitability of production. GDP/TMR has been taken as a general expression of ecoefficiency (OECD 1997, KTM 1998). Similar approach can be applied at sector level by weighing the value added against the material inputs within sectors. Other aspects of ecoefficiency can be highlighted in a similar way by relating the volume or value of production to some measurable environmental consequence of production. Dietary choices specifically affect the materials flow of the food flux. From the consumer point of view the energy content or nutritional value of the various food products could be useful. The benefits of various food products or modes of food production could be compared and weighed against their environmental or economic impact. In this way the data can also be used to promote sustainable food consumption.

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