TOWARDS MORE ECOEFFICIENT FOOD PRODUCTION: MFA APPROACH

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Abstract

The key for the sustainable development is dematerialisation and ecoefficiency. Applied to agriculture ecoefficiency means production of nutritionally better food by using less inputs and by reducing the environmental burden. In restricting the material throughput it is essential to identify the most voluminous material flows and to direct the measures to them. Improving ecoefficiency of the food production requires that the benefits and the inputs are 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 system comprises four mutually linked loops: 1) the plant production 2) the livestock husbandry, 3) the food processing industry and 4) the human consumption. In the present paper MFA approach has been used to describe the system. A general framework for estimating and balancing the materials flow is outlined. The focus is on agriculture, specifically on the materials flow created by the biological metabolism of the animal husbandry.

The holistic MFA approach provides means to evaluate environmental and economic consequences of the production. For the decision-makers the MFA approach is a tool to guide the development and to assess the progress towards increasing ecoefficiency within the food system. The results can be used in developing new sustainability indicators. 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 systems. It is a part of the project “The Materials Flow and Ecoefficiency of Agriculture and the Sustainable Compatibility of the 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 system, material flow accounting (MFA).

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 the 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 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 the economies to improving the ecoefficiency of the production (Weizsäcker et al. 1997, 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 the 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 can be 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 the agricultural production as well as 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. There are, therefore, 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 redefined as the production of nutritionally better food by using less inputs and by reducing the environmental load.

1. Purpose of the study

Improving ecoefficiency implies that the benefits and the inputs are quantified in an unambiguous way. Therefore, consistent and internationally comparable methods of collecting the data and of compiling the statistics are needed. Introduction of the industrial ecology and industrial metabolism – concepts has brought into the focus the flows of energy and materials of the societies. Resource use and resource efficiency have become one of the main areas of interest of the environmental policy both nationally and internationally (Eurostat 1997, Görlach etal. 1999). 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 the mobilisation and transformation of the various materials between nature and the society as well as within the society, and several methods of analysing the material flows have been developed to describe and to quantify the material turnover.

Presently Eurostat is establishing the 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 system.

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

2. 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 (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 the 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 material throughput (Schmidt-Bleek 1998). The linking between the material flows and their environmental impact can be examined in more detail by allocating of the material flows to the various sectors and 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 materials flow data combined with the environmental and socio-economic statistics is a promising source for developing new sustainability indicators. Several European countries work on in linking the existing data into the national accounts (Eurostat 2001). So far the MFA 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).

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). In compiling the total material requirement (TMR) for Finland, the plant production with the associated hidden flows was accounted for as the input of the agriculture into the economy (Mäenpää et al. 2000), but the inputs were not further allocated within the agriculture. The Finnish TMR data were compared with the energy consumption and with the use of biocides and fertilisers to elucidate the development trends in agricultural production during the past 30 years in Finland (Risku-Norja 1999).

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). Ecological rucksacks for several single food products have been estimated on the basis of the MIPS (material intensity per unit service) –concept (Schmidt-Bleek 1998). In addition, there is an increasing number of product specific LCA studies also on food products.

3. 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. 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 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 (Mäenpää et al. 2000a). The share of agriculture from the Finnish GDP has also oscillated around 1 % since the 70´ties, at present it is about 1.2 % (Mäenpää et al. 2000a). 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 (Statistics Finland 2000).

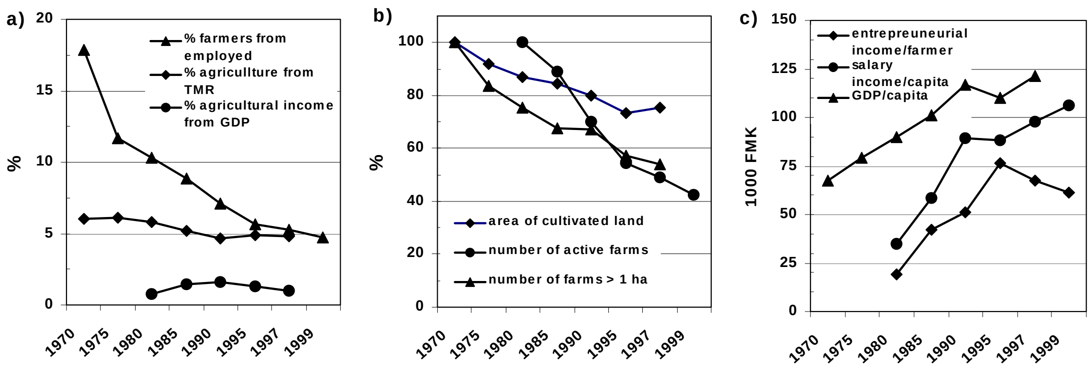


Figure 1: The role of agriculture in Finland in 1970-2000:
a) The share of agriculture from the Finnish TMR, the share of the agricultural income from the Finnish GDP and the share of the farmers from the employed labour force, %.
b) The area of cultivated land and the number of farms with an area over 1 ha in Finland in 1970-2000, 1970 = 100. The number of active farms in Finland in 1980-2000, 1980 = 100.
c) GDP per capita, salary income per capita and entrepreneurial income from agriculture per farmer in 1970-2000 in Finland, 1000 FMK.

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 (MMM 1983-2000, MTTL 2001).

In Fig. 1c the entrepreneurial income from agriculture per farmer has been compared with the GDP and total salary sum per capita (Statistics Finland 2001). The figure shows that, in average, the farmers' income is less than the 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 gentle decline. The economic development of the agricultural population has been decoupled 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, agricultural land comprises about 14 % of the Finnish ecological footprint (Hakanen 1999) and, therefore, the environmental impact of agriculture is considerable.

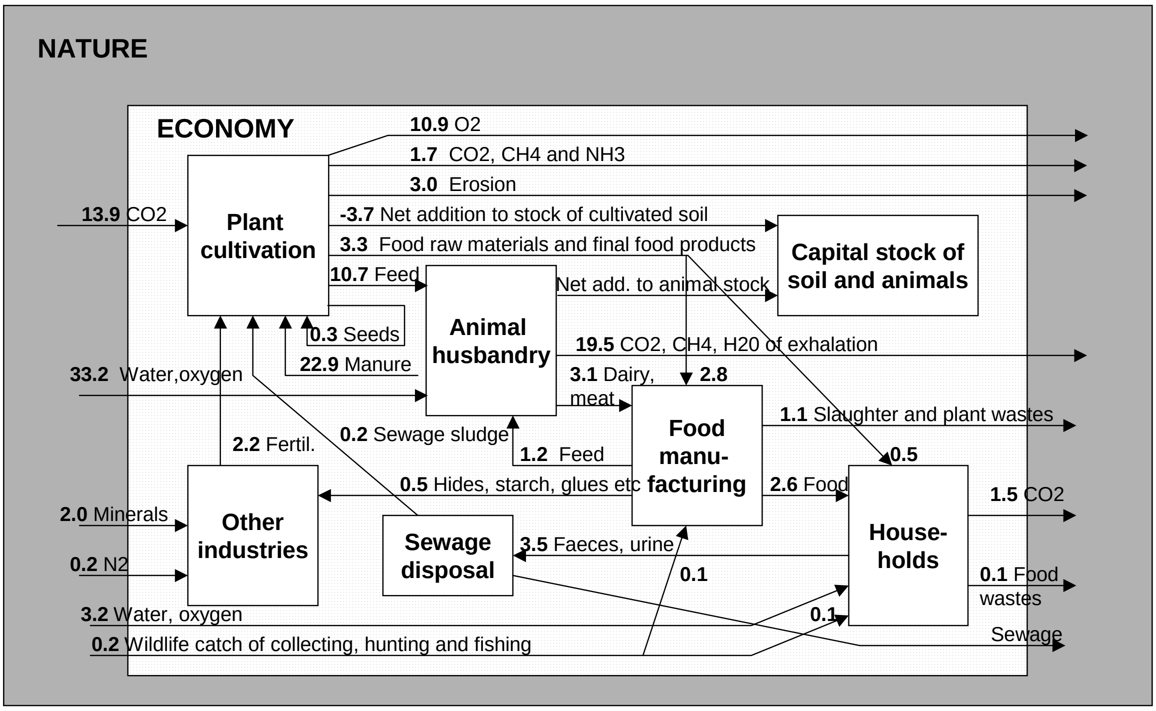
The problems are related to biodiversity, maintenance of soil fertility, eutrophication of the watersheds and to emissions of the greenhouse gases. E.g. in Finland agriculture is responsible for about 50 % of the anthropogenic nitrogen and phosphorus loading of the watersheds (Statistics Finland and Ministry of the Environment 1997) 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 (UN 1948, article 25), 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. Means to assess the progress towards more ecoefficient food production are urgently needed. The MFA methods provide one possibility.

4. The materials flow of the food system

4.1. System definition

The materials flow of the food system comprises four mutually linked loops: 1) plant production 2) livestock husbandry, 3) food processing industry and 4) human consumption. In the compilation of the TMR of the 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. 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.

Figure 2: The system boundaries and the summary of the material flows of the food flux, thousand metric tons.



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.

4.2. Agricultural production

The production statistics of the plant cultivation and animal husbandry in Finland in 1995 provide the necessary background data (MMM 1996). 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.

The direct material outputs (DMO) of the domestic plant cultivation (food and feed) in Finland in 1995 were 14000 metric tons. 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. About 2800 tons were used in the food processing and alcohol industry, the residues from which are largely returned to agriculture as animal feed.

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 consisting of reindeer, sheep, horse and the wild have been excluded.

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 it can be calculated that for each kilo glucose produced, 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 the dry matter basis, and the weights reported in the 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 feed stuffs 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 organism. 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 the 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 the production animals. Energy approach is practical because, depending on the circumstances the composition and, therefore, also the water content of the feed may vary considerably, but in the same circumstances the energy requirement is quite constant. The energy content is also 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.

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).

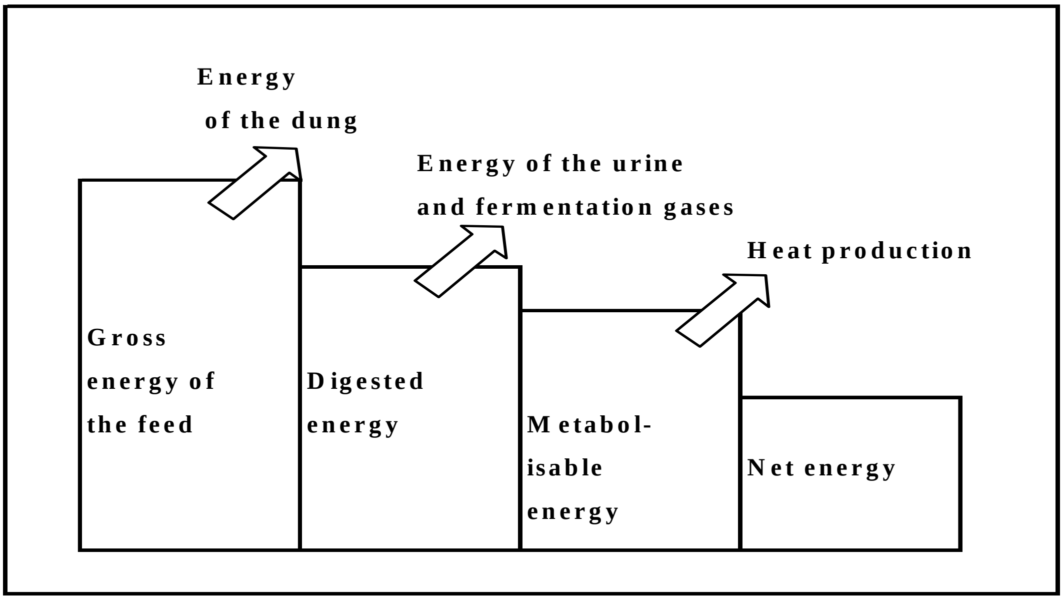


Figure 3. The division of the gross energy of the feed (MKL 1999)

The daily energy balance is exemplified in Fig. 4 with that if a dairy cow. The undigested part forms about one quarter of the total energy, 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. These transformation losses together with the maintenance produce the heat for the animal.

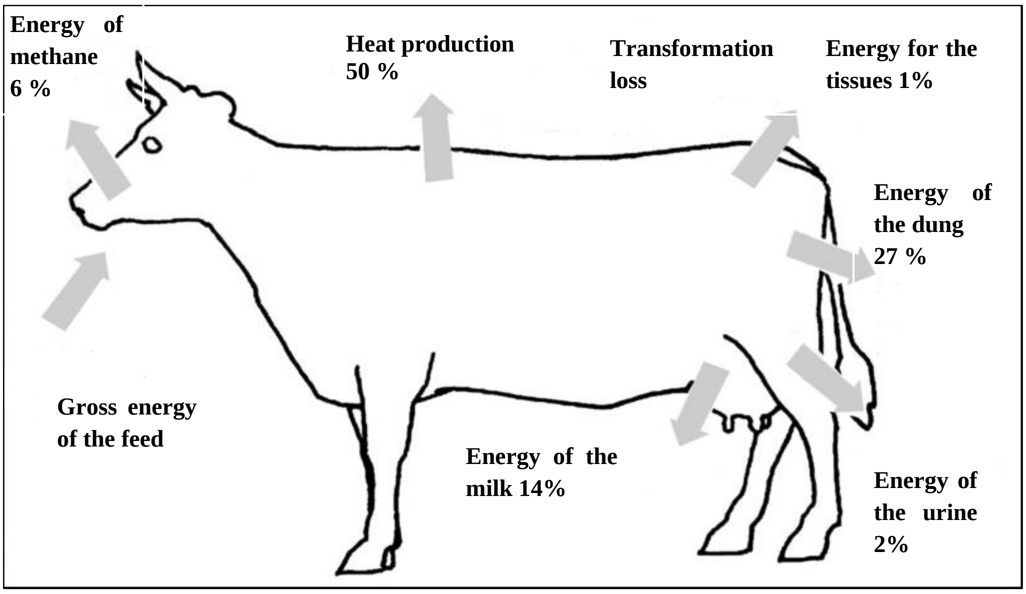


Figure 4: The average daily energy balance of the dairy cow modified from MKL (1999) by taking into account the production cycle of the cow

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. The data are estimated on the daily basis and they are converted to the 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 (Mäenpää et al. 2001).

5. Discussion

The MFA approach can be carried out at different scales ranging from nation-wide to area and sector levels. The efforts to improve ecoefficiency of the various sectors are concretised by sector-specific factor-goals. The goals must be realistic and obtainable, and for that a comprehensive view of the material throughput within the various sectors 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 the analysis of the future development trends, to set 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 the societal metabolism and of its changes over time. In this context the factor goals and eco-efficieny are practical tools for monitoring and assessment.
The focus in this paper is on the material flows of agriculture. The total material flows are extrapolated from the volume of plant production and from the data concerning one average animal representative of its species. In addition to the inherent differences between the various animal species, the feed requirements vary considerably depending on the age and the activity of the animal. The material flow balances have, therefore, been separately calculated for production of milk, eggs, beef, pork and poultry. 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.

This study is the first step in developing MFA methods to analyse and to monitor the materials flow of the Finnish food systems. 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. It is hoped that the suggested approach will contribute to the overall development of the material flow accounting statistics.

Next steps will be to analyse the effects of the changing consumption and production patterns on the material and monetary flows within the agriculture. The materials flow of the food system will be complemented with more detailed data on the input sector, food processing industry and on the consumption and import to give a holistic picture of the system. Finally the sector data will be integrated into the national statistics and the economic and environmental effects of the various options on the national level will be analysed.

The ultimate purpose in doing this is to improve the eco-efficiency of the food production in order to adjust the production to a level to meet the demands of sustainability. GDP/TMR has been taken as a general expression of eco-efficiency, (OECD 1997, KTM 1998). The approach can be applied also at the sector level by relating the value added of and the material inputs to that sector. Other aspects of eco-efficiency can be highlighted in a similar way by relating the volume or value of the production to some measurable environmental consequence of the production.

An important group of actors in promoting the realisation of the ecological goals are the citizens, because their consumption patterns are reflected in the state of the environment. Their means of action are, however, often severely impaired by the overflowing and often contradictory information coming from various sources. The fragmented and confusing information can be reassembled under the eco-efficiency-concept to provide a holistic view. This gives the citizens an opportunity to judge the consequences of their own behaviour and to make environmentally sound choices. Dietary choices specifically affect the materials flow of the food system. From the consumer point of view the energy content or nutritional value of the food products could be useful nominators. The benefits of the various food products and 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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