THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

# Human Use of Land and Organic materials

## Modeling the Turnover of Biomass in the Global Food System

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ISBN 91-7197-886-0

Doktorsavhandlingar vid Chalmers tekniska högskola
Ny serie nr 1574
ISSN 0346-718X

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Printed by Chalmers Reproservice
Göteborg, Sweden 2000

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## ABSTRACT

This thesis is directed towards the issue of the long-term demand and supply of biomass for food, energy and materials. In the coming decades, the global requirements for biomass for such services are likely to increase substantially. Therefore, improved knowledge of options for mitigating the long-term production requirements and the associated effects on the Earth system is essential.

The thesis gives a thorough survey of the current flows of biomass in the food system. This survey was carried out by means of a physical model which was developed as part of the work. For eight world regions, the model is used to calculate the necessary production of crops and other phytomass from a prescribed end-use of food, efficiency in food production and processing, as well as use of by-products and residues. The model includes all major categories of phytomass used in the food system, depicts all flows and processes on a mass and energy balance basis, and contains detailed descriptions of the production and use of all major by-products and residues generated within the system.

The global appropriation of terrestrial phytomass production induced by the food system was estimated to some 13 Pg dry matter per year in 1992-94. Of this phytomass, about 0.97 Pg, or 7.5 percent, ended up as food commodities eaten. Animal food systems accounted for roughly two-thirds of the total appropriation of phytomass, whereas their contribution to the human diet was about one-tenth. Use of by-products and residues as feed, and for other purposes within the food system, was estimated to about 1.8 Pg dry matter, or 14 percent of the total phytomass appropriation.

The results also show large differences in efficiency for animal food systems, between regions as well as between separate commodities. The feed conversion efficiencies of cattle meat systems were estimated to about 2 percent in industrial regions, and around 0.5 percent in most non-industrial regions (on gross energy basis). For pig and poultry systems, feed conversion efficiencies were roughly a factor of ten higher. The differences suggest that there is a substantial scope for mitigating the long-term production demand for crops and other phytomass by increases in efficiency and changes in dietary preferences.

**Descriptors:** global food system, biomass, physical model, livestock, feed, diet, efficiency, industrial ecology

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# 1 INTRODUCTION

One purpose of this introductory chapter is to present the general background to the thesis, as well as the wider context of different perspectives on the human use of land and organic materials (Section 1.1). Another purpose is to describe the rationale for this particular study in relation to other global food system studies (Section 1.2). Finally, a brief account is given of the specific background to this particular study (Section 1.3).

## 1.1 THE WIDER CONTEXT: PERSPECTIVES ON LONG-TERM HUMAN USE OF LAND AND ORGANIC MATERIALS

Organic materials[1] are vital components of nature and society. For society, organic materials serve as vegetable and animal *food* for humans. Organic materials are the dominating flows in the *energy* supply. Fossilized organic materials, that is, coal, oil and natural gas, make up roughly four fifths of total energy supply, and biomass, such as fuelwood, contributes with some 15 percent.[2] Furthermore, organic materials are important building and construction *materials*, such as, sawn wood, plywood and fiber boards. They are also used as feedstock for various materials, such as, paper, plastics and chemicals.[3]

The biospheric part of these organic materials, the biomass, builds up the *biota*, the living part of Earth and its ecosystems. The living biomass, together with its dead counterparts in the form of organic debris in soil and sea, is also an important link in the *biogeochemical system* of the Earth. Through the biogeochemical cycles of carbon, water, nitrogen, and other compounds, the systems of biota are intimately linked with the *physical-climate system*.

Quite obviously, any larger human extraction and use of organic materials inevitably implies a degree of influence on the make up and functioning of the Earth system. Particularly over the last three centuries, human activities have involved considerable transformations of Earth's ecosystems.

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[1] In this thesis, 'organic materials' is used as a general term for biospheric and lithospheric (fossilized) materials of photosynthetic origin, as well as for the derivatives of these materials. 'Biomass' is used as an alternate term to biospheric organic materials; it includes both phytomass (plant mass) and zoomass (animal mass).

[2] Globally, supply of coal, oil and gas was about 340 EJ (HHV) in 1998, and production of nuclear and hydro electricity was about 19 $EJ_e$ [BP Amoco 1999]. Global biomass energy use, including non-commercial fuels, was estimated to about 55 EJ per year in 1985 [Hall et al. 1993, p. 595]. If assuming a 10 percent increase in biomass energy use since 1985, total energy supply would amount to some 420 EJ (nuclear and hydro electricity *not* counted in primary fuel energy equivalents).

[3] Few estimates of aggregated numbers on the use for materials purposes are available. Berndes & Wirsenius [1996] estimated global use of fossil and biospheric material for materials purposes (various wood-based materials, textiles, plastics and other petroleum-based materials) to slightly below 1 Pg C per year, about equally divided on biospheric and fossil materials respectively (around 1990).

The human use of land for biomass production represents the most substantial alteration of the Earth system, and is the primary driving force in the loss of biological diversity worldwide.[4] Clearing for cropland — among the most extreme forms of land alteration — has implied a loss of about 11 million km$^2$ of forests and 6.7 million km$^2$ of savannas and grasslands, which is roughly 20 percent of the original extension of both vegetation types.[5]

Human use of land, and the associated use of biomass, has also substantially altered the biogeochemical cycles of particularly carbon, water and nitrogen, entailing effects such as climate change, acidification, and terrestrial and aquatic eutrophication.[6] Furthermore, it has implied introduction and widespread use of persistent and toxic organic compounds.

Even though the use of biomass has contributed substantially to the alteration of the global carbon cycle, the dominating factor behind this change has been the human use of fossil organic materials. A 30 percent increase has been estimated for the atmospheric concentration of the greenhouse gas carbon dioxide since the seventeenth century, introducing an imbalance in the energy flows of the global climate system. This energy flows imbalance, or radiative forcing, will lead to a response in the climate system, establishing a new energy balance.[7]

The demand for services related to biomass are likely to increase substantially in the coming decades. A major driving force behind this increase is the population growth. The most recent UN estimate foresees a world population of about 8.9 billions by the year 2050, to be compared with the current population of about 6 billion.[8] Probably even more important, however, is the continuing increase in economic standard — the global average per capita income, measured as GNP per capita, can be expected to double to 2050.[9] These factors will expand the demand for food, materials and energy

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[4] [Vitousek et al. 1997]

[5] [Ramankutty & Foley 1999]. Numbers refer to clearing between 1700 and 1992.

[6] [Vitousek et al. 1997]. The authors give some examples of orders of magnitudes: Of the fresh water that is relatively accessible, humanity currently uses more than half, with agriculture accounting for about 70%. Agriculture and burning of fossil fuels adds at least as much fixed N (about 120 and 20 Tg N/year respectively) to terrestrial ecosystems as do all natural sources combined, and land transformation implies mobilization of at least 50 Tg N/year.

[7] Although the magnitude of the introduced radiative forcing due to the change in carbon dioxide concentration is fairly well established, the exact response of the climate system to this forcing is still due to considerable uncertainty. A doubling of the atmospheric concentration of carbon dioxide compared to the pre-industrial level is estimated to increase the mean surface temperature of the Earth in the range of 1.5 to 4.5 $^{o}$C [Houghton et al. 1992].

[8] [UN 1998]. Refers to the medium estimate.

[9] Relative to average GNP per capita in 1992-94. Own calculation based on the GNP growth assumptions to 2025 and 2100 in the IPCC scenario IS92a [Houghton et al. 1992, pp. 78-79], and the UN population forecast cited above.

services in general. Within the food sector, increased incomes in current low-income and medium-income countries are likely to raise the demand for animal food.[10]

Another factor which is likely to contribute to an increased demand for biomass is climate change. Due to an increasing risk of negative consequences of the climatic changes, considerable restrictions in the use of the fossil organic materials must be considered as likely within the nearest 2 to 3 decades. Depending on the extent and character of such restrictions, they may imply strong tendencies to increased demand for other energy sources than fossil fuels. Biomass can be considered as one of the major carbon-dioxide-neutral alternatives, mainly due to its relatively large resource potential, current technical status and economic competitiveness.[11]

Issues related to the mid- and long-term human use of land and organic materials have been dealt with from a variety of perspectives and with different focuses. We can here discern three main perspectives:

(1) The first perspective, which we might call the *resource* or *supply* perspective, has its main focus on the support of the human population with the material essentials. A major concern in this perspective is the issue of satisfying the human demand for different natural resources. This issue has been a source of concern since long. For example, attempts to estimate the maximum number of people that the Earth can feed have been performed since more than a 100 years.[12] Characteristic for this perspective is also that the concern has not been founded on the associated effects on the Earth systems. Rather, it has been founded on problems with scarcity of land and land productivity. Apprehensions for declining land productivity — due, for example, to soil erosion, diminishing fresh water supplies or insufficient reforestation — also belong to this. At a rough characterization, this concern might be described as having a predominantly anthropocentric perspective, where nature mainly is considered as a supplier of raw materials and other resources.

In current studies with reference to the long-term prospects of human use of land and biomass, this anthropocentric perspective is dominating, even though the aspects of impact on the Earth systems are increasingly included. There are certainly good reasons for this anthropocentric focus since poverty and hunger still inflict a large share of the

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[10] Delgado et al. [1999, p. 24] estimated that in the ‘developing world’, consumption per capita of meat is likely to increase by about 50% to 2020 (relative to the consumption in 1993).

[11] For instance, in the renewables-intensive global energy scenario (RIGES), Johansson et al. [1993] estimated that biomass-based fuels might account for nearly 40% (150 EJ) of the global fuel supply in 2050 (counting commercial fuels only). For biomass-based electricity, the contribution was assumed to be lower, about 18% (21 $EJ_e$) of the global electricity supply in 2050. In the biomass-intensive variant of the low $CO_2$-emitting energy supply system (LESS), compiled by Williams [1995], biomass was assumed to account for nearly a third (181 EJ) of global primary energy supply in 2050, and almost half (331 EJ) of the primary energy in 2100.

[12] Smil [1994] states that E. G. Ravenstein in 1891 was probably the first researcher to assess this limit — Ravenstein came up with a maximum total of about 6 billion people.

human population — according to present estimates, about 800 million people are undernourished.[13] It has also been recognized that the current undernourishment is essentially not due to inherent limitations in land resources and land productivity, but mainly due to economic and social conditions.[14] Therefore, social science, especially economics, has a strong position within these studies. Most of these studies also tend to follow traditional sectoral divisions. Generally speaking, food and agriculture is treated as one area, forestry and forest industry as another, and energy as yet another.[15]

(2) The second perspective is the *global change* perspective, which may be described as natural science research devoted to the understanding of different compartments of the Earth system, and the systemic and cumulative changes in these induced by human disturbances.[16] As examples of studies within this perspective can be taken the climate change studies.

On the international level these studies are often coordinated in large programs and organizations, such as the International Geosphere-Biosphere Programme (IGBP), instituted in 1987 by the International Council of Scientific Unions (ICSU). The original goal of IGBP was formulated as: "to describe and understand the interactive physical, chemical and biological processes that regulate the total Earth system, the unique environment that it provides for life, the changes that are occurring in this system, and the manner in which they are influenced by human actions".[17] Another major example is the Intergovernmental Panel on Climate Change (IPCC), which was launched in 1988 in a co-operation between UNEP and WMO.

(3) The third perspective, which we may call the *industrial ecology* perspective, has its main focus on the flows of energy and materials in society, the 'societal metabolism'. A major issue in this perspective is adaptation of the societal metabolism to restrictions imposed by the demands of environmental sustainability. Integrated studies of different compartments of the societal metabolism and their interactions with the natural systems, are considered as essential in the analysis of the prerequisites for such an adaptation.[18] Of central interest is the total societal mobilization of materials, as well as the intensities

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[13] [FAO 1999]. Refers to 1995/97.

[14] It is established knowledge that main causes of hunger are poverty and marginalization, besides war and violent conflicts [Ibid.]. Up to at least 2010, it is unlikely to be any major global constraints to expand world food production at a rate sufficient to match the growth of the demand [Alexandratos 1999].

[15] To give an idea of what kind of studies we have in mind, on the global level, examples are Alexandratos [1995] (agriculture), Nilsson [1996] (forestry), and Nakicenovic et al. [1998] (energy).

[16] Pernetta [1995] gave an interpretation and account of the term global change.

[17] [IGBP 1990]

[18] For instance, recognizing the large human disturbances of fundamental natural systems, Allenby [1999] put forward the challenge for an 'earth systems engineering' based on ability to rationally engineer and manage coupled human-natural systems in an aggregated way. In the second international conference on industrial ecology (June 2000), a main theme is 'carbon cycle engineering' (information available through www.grc.uri.edu).

and trends in the societal use and turnover of different materials.[19] Hence, various kinds of material flow analyses are key methodologies in the field.[20]

These three perspectives involve a vast range of specialist disciplines and studies. However, due to the inherent characteristics of the issues related to the mid- and long-term human use of land and organic materials, it is obvious that integrating studies with a multi-disciplinary, cross-sectoral or cross-scale scope are also required.

For instance, within the IGBP, development of cross-cutting studies along key thematic lines, such as the carbon system, the global water cycle, and food and fiber, is considered as one of the next steps within global change research.[21] A major example of integrative studies within climate change research is the integrated assessment model for climate change, IMAGE, which is specifically designed to analyze cross-linkages and feedbacks in the global society-biosphere-climate system.[22] An example which might be considered as belonging to industrial ecology is the MATTER project (MATerials Technologies for greenhouse gas Emission Reduction). This project involves modeling of both the energy and materials turnover in society — including the food sector — in order to assess possibilities to decrease greenhouse gas emissions through adaptation within the societal materials systems.[23] Another example of cross-sectoral studies is the Global Land Use and Energy model (GLUE), which has been designed for integrated analysis of long-term energy resources in form of residues from the food and forestry sectors as well as bioenergy plantations.[24]

## 1.2 GLOBAL FOOD SYSTEM STUDIES: WHY THIS STUDY?

In the preceding section, we briefly outlined some major research perspectives dealing with aspects of the long-term human use of land and organic materials. In this section, the focus is on the food system. The central question here is: What are the characteristics for the current global food system studies with a mid- and long-term perspective?

In comparison to long-term studies of related systems — for example, those of the global energy system — we see three tendencies characteristic to food system studies:

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[19] Adriaanse et al. [1997] proposed the concept Total Material Requirement (TMR) as a measure of the total mobilization of materials; the societal metabolism in four countries (Germany, Japan, the Netherlands, and the USA) was analyzed using TMR. A review of major concepts related to dematerialization and intensity of materials use was made by Cleveland & Ruth [1999].

[20] [Socolow 1994]

[21] [Moore III 1999]

[22] Model descriptions and examples of model applications are given in Alcamo [1994] and Alcamo et al. [1998].

[23] Model descriptions are given in, among others, Gielen et al. [1998] and Gerlagh & Gielen [1999]. Information regarding the MATTER model and its applications is also available through www.ecn.nl.

[24] Descriptions of model and results are given in, among others, Yamamoto et al. [1999] and Yamamoto et al. [1994].

(1) In general, there is no strong emphasis on physically explicit descriptions of the processes and flows in the system. In particular, physical descriptions on a mass and energy balance basis are extremely rare, at least so far as the aggregated system level is concerned. (2) For the majority of global studies, emphasis lies on edible-type crops[25] in general, and on cereals in particular. (3) In most cases, emphasis lies on how to increase the crop production, particularly that for cereals; that is, most studies are strongly *supply oriented*, to use a concept from the area of energy system studies. In contrast, relatively little attention has been paid to the *end-use* and *conversion* parts of the system, such as, the influence on the supply requirements of changes in dietary preferences or enhanced efficiency in the animal food systems.

Of course, there is an element of generalization in these characteristics. The outlined tendencies do only apply to a varying degree. Nevertheless, in our view, a remarkably large number of global food system studies have a relatively one-sided attention to crops.[26] However, for the majority of studies the focus is not that narrow. For example, the FAO studies on medium-term prospects for the global food production include all significant edible-type crops in their analysis.[27] However, they do not include the categories forage crops or pasture.[28] This means that the projections do not provide an explicit description of the total requirements and supply of feed. Feed use of forage crops, pasture, and by-products other than cereals brans, are only implicitly included, described as a proportion of total production or demand.[29] Efficiency of animal food production (in the model expressed as output per animal) as well as food use per capita and diet are projected; thus, the relative influence of these factors on the demand and supply picture is not explicitly analyzed.

Another significant example, bearing much of the same structures as the above-mentioned FAO studies, is a study made within the framework of the Stockholm Environment Institute (SEI) PoleStar project.[30] As in the FAO studies, this study did not include forage crops and pastures. Likewise, the analyses of animal feed use were not

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[25] By ‘edible-type crops’ we refer to cereals, starchy roots, sugar crops, oil crops, etc (see Table 2.6, p. 47 for further details).

[26] Crosson & Anderson [1992] and Dyson [1996] can be taken as exponents of the cereals-oriented direction of global food system studies. Characteristic for this direction is that the conclusions regarding the global food demand and supply prospects are generalizations drawn from analysis of the prospects for crops only.

[27] The most recent ones [Alexandratos 1988, Alexandratos 1995] include medium-term projections (to 2000 and 2010 respectively) of demand, supply and prices of major edible-type crops and animal food commodities, performed with the FAO World Food Model (described in FAO [1993]).

[28] By ‘forage crops’ we refer to grasses and legumes cultivated for harvest (that is, not for grazing), whole-cereals and other fodder crops. ‘Pasture’ includes all types of grazed phytomass, permanent as well as cropland pasture. (See Table 2.6, p. 47, for further details.)

[29] [Alexandratos 1995, pp. 407-412]

[30] Leach [1995] formulated long-term projections (to 2050) of demand and supply of major edible-type crops and animal food commodities, based on the Food and Agriculture Module of PoleStar (described in Bartholomew et al. [1995a] and Bartholomew et al. [1995b]). It should be noted that, in contrast to the FAO World Food Model, this model is entirely physical and does not contain modeling of prices or other economic parameters.

based on complete feed balances — only the feed use of cereals and other edible-type crops was explicitly included. Other major feedstuffs, such as forage, pasture and by-products, were regarded as ‘free goods’, and their use were thereby included only implicitly.[31] Increases in efficiency of animal food production were not described; changes in efficiency were implicitly included by assumptions on changes in use of edible-type crops per unit of animal food output.

A few studies do diverge from these mainstream features of global food system studies. Such an example is Penning de Vries et al, who made scenarios for 2040 of food demand and potential supply.[32] In contrast to the above-mentioned studies, this study included the entire food phytomass production — however, with a very reduced approach: food phytomass production was modeled by the categories ‘grain’ and ‘grass’ only (both expressed in grain equivalents). Also, the descriptions of feed use in animal food production included the *total* feed use; however, also the representation of animal food commodities was relatively limited: only ‘dairy products’ and ‘meat products’ were included.[33] Another interesting feature of this study is that the food demand estimate for 2040 was explicitly made for three different types of diets with respect to their shares of animal food (‘vegetarian’, ‘moderate’ and ‘affluent’).

By this brief account of some studies we do not want to imply that the mainstream global food system studies are inadequate. Indeed, to increase the production of edible-type crops, particularly cereals, is a principal concern in the global food sector, and will remain so for the foreseeable future. However, the prevalent direction of food system studies has entailed that a number of issues regarding the long-term food situation have been left insufficiently investigated. In our opinion, among the more relevant issues are:

i) The total extraction and turn-over of biomass of the food system, and the relative importance of forage crops, pastures and by-products and residues.[34]

   In comparison with the edible-type crops, there is little systematic and coherent knowledge about the flows of forage crops, pasture, and by-products and residues in the food system. This applies to the global as well as the country level — also for the industrial countries. Largely, this is due to lack of monitoring as well as inadequate statistics of the production and use of these flows. Since these flows for certain are most considerable — the global area of permanent pasture (33 million km$^2$),

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[31] [Leach 1995, p. 28]

[32] To our knowledge, that study was first published in Penning de Vries et al. [1995]. Excerpts and variants of the same study have also been published elsewhere, among others Penning de Vries et al. [1996] and Penning de Vries et al. [1997]. In this study, model-based estimates were made on food production potential in 15 world regions, assuming two alternatives of crop production, one ‘yield-oriented’ (‘high external input’) and one ‘environment-oriented’ (‘low external input’). These production potentials were compared with estimates of food demand in the regions for the year 2040.

[33] In our view, it is not unequivocally clear that these are the very animal food categories included in the study; however, they are the only ones that are mentioned.

[34] Internal by-products are, for example, crop by-products, such as, straw & stover, and crop processing by-products, such as brans and oilseed meals.

for example, is more than twice that of cropland — this deficiency in knowledge means that the knowledge of the *total picture* of the food system is incomplete. This applies to the total picture as regards the food system's resource use, in terms of phytomass, land, water and so on, as well as the system's relative magnitude of and intervention in the biogeochemical cycles. Also, it has implied a defective picture of the degree of actual use of internal by-products and residues, as well as of the potential for increased use of these resources in the food system or other systems.

ii) The physical efficiencies of the food system.

Generally speaking, the efficiency of food systems from a physical point of view is not well described or well known. This applies not only to the aggregated levels of the food system, but also for separate parts of the system (such as, different animal systems). This has contributed to a deficiency of coherent pictures of the potential for mitigating the long-term requirements for production of crops and other phytomass by efficiency increases. In our opinion, there is a profound lack of knowledge regarding efficiency as a long-term mitigation option for the food system on a global and regional level. We guess that this is due not only to lack of focus on and attention to efficiency as such, but also due to the of absence of an established, internationally uniform terminology and set of concepts as regards physical descriptions of the food system.

In our view, this criticism applies to the animal food systems in particular. Due to the nature of livestock systems, differences in genotypes, management practices and so on, can involve substantial variations in efficiency — that is to say, the possible range in efficiency is very large. Moreover, it is not self-evident or straightforward how the physical efficiency should be measured, or which efficiency concepts are relevant. Another circumstance that has impeded systematic and global-scale studying of efficiency, is the fact that the livestock production science lacks very much of consensus and established standards on the international level.[35] In addition, published figures on efficiency of animal food production are often deficient in terms of stringency and transparency; ambiguous and even clearly inadequate figures are rather common. That applies also to studies in which physical efficiency is a central aspect.[36]

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[35] For example, in Europe there are virtually as many different systems for calculating energy and protein requirements as there are countries. In the mid 1980s, there were at least 20 different systems for cattle in use [van der Honing & Alderman 1988]. The need for common units and systems was identified and emphasized [Ibid., p. 233].

[36] For example, in a study of technological development in the U.S. agriculture, [OTA 1992, p. 138], values on current and future efficiencies for 'beef', 'poultry' and 'swine' were presented with the concept 'meat output per feed input' without defining neither the 'meat' nor the 'feed'. Without any specifications of their basis, such product-per-feed concepts are of little value from a physical efficiency point of view. That applies especially when it comes to cattle systems: Feedstuff commonly fed to cattle in industrial countries may range up to a factor of four in net energy value for growth (measured on a DM basis), and in non-industrial regions far more. Furthermore, the relative feed use of the reproducing part of the system (dame plus replacer) is much larger for cattle systems than for other animal food systems; for beef cattle systems in industrial countries, the reproducing part normally accounts for around two thirds of the system's total feed use, to be compared with one fifth for swine systems, and one tenth for broiler pro-

*Notes continue on next page.*

iii) The links between food consumption of separate commodities (that is, the diet) and the resource requirements and emissions that the consumption implies.

Partly as a consequence of the above-discussed lack of knowledge, there are few systematic studies available of the connections between the consumption of a particular commodity, and the land use and flows that this consumption induces. This has implied that there is lack of coherent pictures of the relative importance on resource use and emission inducement of changes in food consumption patterns. Such consumption changes may involve the expected increases in animal food use due to raised per-capita incomes, but also changes due to shifts in preferences (towards, for instance, less of animal food). Analogous to the case with efficiency, in our opinion, there is a lack of knowledge regarding changes in consumption pattern as a general, long-term mitigation option for the food system.

To close this section, there are certainly a number of adequate reasons behind the mainstream direction of global food system studies. However, the trends that society are facing in the new century add new prerequisites for this kind of studies. In our opinion, these new prerequisites make some issues increasingly relevant, which earlier might have been considered to be of little interest. Hence, in the long-term perspective, a number of issues regarding the food system emerge as clearly neglected. This standpoint was a major motive behind this thesis.

## 1.3 THIS THESIS AND ITS SPECIFIC BACKGROUND

In the preceding sections, we have shortly described the two, intertwined thematic levels to which this thesis is related. In this section, we will briefly describe the more specific background, as well as present the purpose and scope of the thesis.

### 1.3.1 A brief historical account

One point of departure in the work behind this thesis was that studies of the options for adaptation of the societal metabolism to environmental sustainability, should be based on analysis along the grand biogeochemical cycles, such as carbon and macro nutrients. In that sense, this thesis may be characterized as originating from an ‘industrial ecology’ perspective (see Section 1.1 above).

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duction systems (estimates made in this thesis, all values on ME basis). Another example is a study in which long-term scenarios (to 2021) of the Swedish agriculture were made [SNV 1997]. In a table (p. 29) with the alleged function of comparing current and future feed efficiencies of major animal food products in Sweden, grazed feed has been omitted without any commenting, which means that the reader gets the impression that the table shows the total feed consumption figures. If the stated amount of grazed feed (stated in Appendix 4 of the report) were included, the feed consumption figure for beef meat would be double the figure in the table (measured on a DM basis).

Originally, attention was directed to the carbon cycle and its associated land use. An observation made at an early stage was that there is a lack of coherent knowledge of the *total* societal uses of carbon and land, that is, including food, materials and energy together. This is an effect of the predominantly single-sector approach in studies dealing with use of food, energy, and forest products and other materials. As regards analysis of the long-term prospects for supply and use of services related to biomass and land, such sectoral approaches were considered as insufficient. One reason for this notion is that the sectoral studies run the risk of overestimating their available share of the resource base in the form of land and other resources required for biomass production, such as nutrients and water. Likewise, the sectoral studies may also overestimate their respective potential for use of by-products and residues which can be used in more than one of the sectors — this applies, for example, to crop by-products such as cereals straw.

As a consequence of this interest for the issue of the increasing demand and competition for land and organic materials from the sectors of food, materials and energy, we performed a first, preliminary study of the global long-term demand.[37] This preliminary estimate suggested that the long-term demand for biomass, for the food and materials sectors alone, might be a factor of 2 to 3 times the present.

Following this preliminary study, we initiated work on a cross-sectoral model of the human use of land and organic materials. The intention with this model was both to estimate the long-term demand of organic materials for food, materials and energy, and the biomass production potentials. The pursuing of this working line resulted in development of some parts of the outlined model system. At the most, complete sub-models for the demand for food and materials purposes were produced, plus a preliminary sub-model for the demand for energy purposes.[38]

Subsequently, increasing attention was directed towards the food sector part of the model system. One reason for this shift in focus was the gaps in knowledge about the food system which we described in the preceding section. Also, lack of the personal resources required for pursuing the original intention was a factor behind the turn in working line.

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[37] [Berndes & Wirsenius 1996]. (The study was also more thoroughly presented in Karlsson et al. [1996].) In that study, rough estimates were made of the present and long-term use of organic materials (expressed in terms of carbon content) for the purposes of food, materials and energy. As an estimate of the long-term requirements were taken those for a global population of 10 billion people, having per-capita consumption levels (of food, energy and materials) corresponding to the current ones in the industrial countries.

[38] Some of these model parts were documented in an working report [Wirsenius & Berndes 1997]. With these sets of sub-models some preliminary calculations were carried out — however, these were not documented.

### 1.3.2 Purpose, nature and scope of this thesis

The overarching purpose of this thesis was to fill the gaps in knowledge, as described in Sections 1.1 and 1.2. The operative purpose was to make a thorough survey of the flows of biomass in the food system, on the global level as well as on regional levels. The more specific questions which this survey intended to answer are given in Chapter 3 below (see p. 55).

With respect to the large number of flows and process that are part of the food system, a model was considered as an indispensable tool for accomplishing the survey. No existing model was found to be sufficient for the purpose at hand; a new model had to be developed. Hence, the work described in this thesis involved two parts: (1) development of a physical model of the biomass flows in the food system, and (2) application of this model, that is, performing the survey of the biomass flows as intended.

Particular emphasis was laid on the three issues described in Section 1.2; enabling investigation of these issues formed the basis for the decisions made in the construction of the model. For example, the aim that the total extraction and turn-over of biomass of the food system were to be covered, determined the upstream boundary of the model system.

In the current model, no other flows than the above-ground phytomass production, and flows originating from transformations of this phytomass, are included in the model system. Related resource appropriation, such as land use, and related flows, such as (external) energy or macro nutrients are not included. However, owing to the relatively high level of detail and the physical consistency, the current description of the system constitutes a suitable basis for including such parameters.

# 2 DESCRIPTION OF THE FOOD PHYTOMASS DEMAND MODEL

The purpose of this chapter is to briefly present the Food Phytomass Demand (FPD) model which was developed as part of this thesis, as we described in the previous chapter.

After an introductory section which gives an overview of the major model characteristics, each principal part of the model is presented in separate sections. The background to the model was already given in the preceding chapter. Comments on the significance of the model, and possible improvements, are mainly dealt with in connection with the application of the model, that is, in Chapter 3.

## 2.1 GENERAL DESCRIPTION OF THE MODEL

### 2.1.1 Principal features

From a prescribed end-use of food, the FPD model calculates the necessary production of phytomass in form of various crops and pasture. Thus, the driving input of the model is end-use per capita and population, and output is phytomass above-ground production (see Figure 2.1).

The FPD model is purely demand-oriented, that is, it contains no explicit variables describing restrictions of phytomass supply, such as, crop production. In this sense, this model might be compared with ‘bottom-up’ models, which are used in, for example, energy system studies.

All quantities in the model are physical. Economic variables, such as GDP per capita, are used only indirectly as a basis for setting the physical variables to economically consistent values.

In comparison with other models of the global food system — some of which were referred to in the previous chapter — the FPD model is distinguished by the following features:

- It is physically explicit and physically consistent, which here means (1) processes are described on a mass and energy balance basis, and (2) flows are at minimum described in the quantities dry weight, as-is weight (that is, including water) and gross energy (HHV).
- It includes all major types of phytomass being used in the food system. Besides the edible-type crops, such as cereals, and oils and sugar crops, various types of animal forage crops as well as pastures are included.

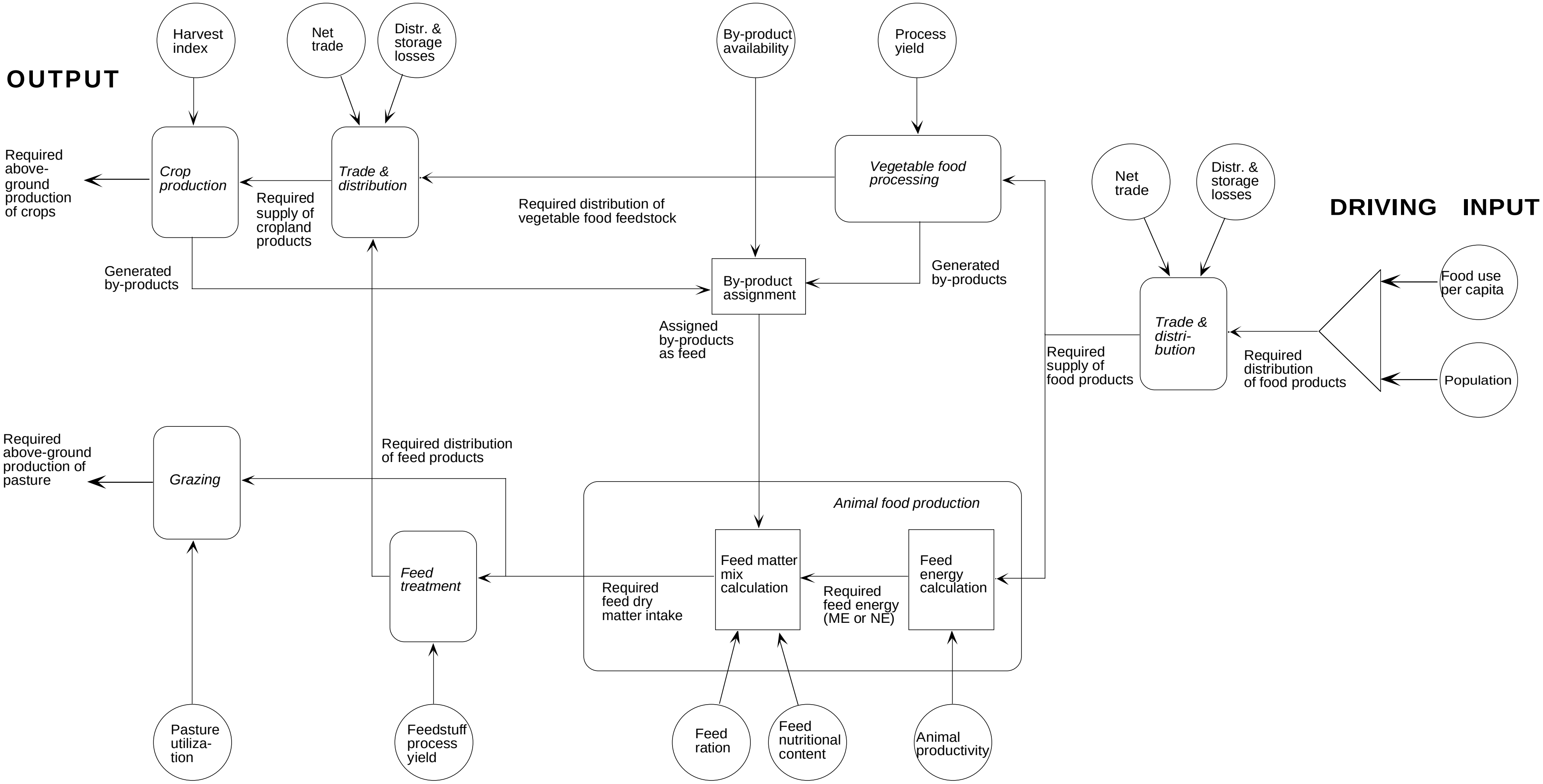

**Figure 2.1** Simplified conceptual structure of the Food Phytomass Demand model.

- It contains detailed and explicit descriptions of productivity, feed energy requirements and feed dry matter use for all major animal food systems. Such descriptions are included for each principal animal category (cow, calf, etc) in each of the animal food systems.
- It contains physically consistent descriptions of the generation and the subsequent handling of all major by-products and residues of biomass origin in the food system, including, among others, crop by-products (such as straw), processing by-products (such as oilseed meals) and manure.

### 2.1.2 Temporal and spatial scales

In essence, the FPD model is stationary, that is, it does not produce sets of output data based on a time sequence. Quantities in the model are calculated on a yearly basis mainly. There is one exception from this: Feed energy requirements of livestock are calculated on a *daily* basis. The result of these calculations are feed energy requirements expressed in yearly quantities.

The model consists of eight parallel sub-models, each describing one world region. These region-models are identical from a structural point of view, that is, they contain the same structures of flows and processes, and parameters and variables. This enables inter-regional comparisons of region-inherent efficiencies, and analysis of the relative importance of trade flows. The regional delimitations are given in Table 2.1.

### 2.1.3 System boundaries

The FPD model output is the required *terrestrial phytomass* production *above ground* induced by human food intake. Hence, the up-stream boundary of the model is above-ground phytomass production. From this point forward, the model keeps track of the further transformations of the phytomass forward in the system. The down-stream delimitations depend on the character of each flow. For biomass eaten by animals and humans, down-stream boundaries are respiratory heat and gases, and feces and urine.

The model does not include flows related to the flows of phytomass and phytomass-derivatives, such as fertilizers, electricity or fuels.

Since the upstream boundary is above-ground phytomass production, the model does not deal with *how* the phytomass is produced. Thus, it does not include the actual process of photosynthesis and dry matter production.

Only terrestrial phytomass production induced by consumption of *food services* is included. Therefore, phytomass required for draft work and draft animals, which, although clearly related to the food system, here are considered as *energy*-related services, is not included. Analogously, cultivation of fiber crops, such as cotton, is considered as *materials*-related processes, and are strictly speaking not part of the FPD model.

**Table 2.1** Regional structure of the FPD model.

**East Asia**
Cambodia
China
Hong Kong
Indonesia
Japan
Korea DPR
Korea Rep.
Laos
Malaysia
Mongolia
Myanmar/Burma
Philippines
Singapore
Thailand
Viet Nam
(+ 3 small states)

**East Europe**
Albania
Belarus
Bosnia-Herzegovina
Bulgaria
Croatia
Czech Rep.
Estonia
Greece
Hungary
Latvia
Lithuania
Macedonia, FYR
Moldova Rep.
Poland
Romania
Russian Federation
Slovakia
Slovenia
Ukraine
Yugoslavia

**Latin America & Caribbean**
Argentina
Bolivia
Brazil
Chile
Colombia
Costa Rica
Cuba
Dominican Rep.
Ecuador
El Salvador
Guatemala
Haiti
Honduras
Jamaica
Mexico
Nicaragua
Panama
Paraguay
Peru
Puerto Rico
Uruguay
Venezuela
(+ 24 small states)

**North Africa & West Asia**
Algeria
Armenia
Azerbaijan
Egypt
Georgia
Iraq
Israel
Jordan
Lebanon
Libyan Arab Rep.
Morocco
Oman
Saudi Arabia
Sudan
Syrian Arab Rep.
Tunisia
Turkey
United Arab Emirates
Yemen
(+ 6 small states)

**North America & Oceania**
Australia
Canada
New Zealand
Papua New Guinea
United States of America
(+ 24 small states)

**South & Central Asia**
Afghanistan
Bangladesh
India
Iran
Kazakhstan
Kyrgyzstan
Nepal
Pakistan
Sri Lanka
Tajikistan
Turkmenistan
Uzbekistan
(+ 2 small states)

**Sub-Saharan Africa**
Angola
Benin
Burkina Faso
Burundi
Cameroon
Central Afric Rep.
Chad
Congo
Côte d'Ivoire
Dem. Rep. of the Congo
Eritrea
Ethiopia
Ghana
Guinea
Kenya
Lesotho
Liberia
Madagascar
Malawi
Mali
Mauritania

**Sub-Saharan Africa (continued)**
Mozambique
Niger
Nigeria
Rwanda
Senegal
Sierra Leone
Somalia
South Africa
Togo
Uganda
United Rep. Tanzania
Zambia
Zimbabwe
(+ 13 small states)

**West Europe**
Austria
Belgium
Denmark
Finland
France
Germany
Ireland
Italy
Netherlands
Norway
Portugal
Spain
Sweden
Switzerland
United Kingdom
(+ 11 small states)

However, these fiber and yarn production activities give rise to by-products which are usable in the food system, such as oils and feed meals. In order to assess their contribution and relative importance for the food supply, descriptions of these activities, here referred to as 'system-external related processes and flows', are included in a separate model which is linked to the FPD model.

Likewise, fish flows are strictly speaking not part of the model system, since these are considered as being related to *aquatic* phytomass, as opposed to terrestrial phytomass. However, for the same reason as for cropland-related fiber crops, fish flows were included in the FPD model (for use as food and feed, respectively). These flows are designated as ‘system-external related flows’.

### 2.1.4 Approach in depiction of processes and flows

For practical reasons, any physical model of the global food system has to rely on a considerable degree of simplification in the depiction of flows and processes since their number in the real system is very large. This simplification in the depiction may be approached in different ways. In our view, a distinction may be made between on the one hand ‘real-character’ approaches and on the other ‘equivalent-character’ approaches. In a ‘real-character’ approach, depiction of the real system into a model system is made by a (larger) number of flows and processes of ‘real’ character, that is, flows and processes which essentially correspond to *existing* ones. In contrast, in an ‘equivalent-character’ approach, depiction is made by a (smaller) number of flows and processes of ‘equivalent’ character, that is, which do not necessarily correspond to existing ones — rather, they are intended to be *average* representatives of a *group* of existing processes and flows.

To illustrate this rather abstract wording, let us consider the depiction of the food end-use of cereals. In the FPD model, cereals end-use is represented by four different cereals products flows which more or less correspond to existing ones (see Table 2.2, p. 22). This is an example of ‘real-character’ depiction. An ‘equivalent-character’ depiction of the cereals end-use might, for instance, instead consist of one flow, called ‘products’.

The main approach in the construction of the FPD model was the ‘real-character’ approach. A major reason for choosing this approach was the fact that the utilization of biomass in the food system has a clear character of *diversity* and *specificity*, that is to say, that the use refers to *specific plant* and *animal structures* of very diverse kinds. If taking a simplistic approach, it might be argued that a model description of the food use could be reduced to merely the flows of starch, sugars, lipids and proteins. However, in our opinion, such a reduction would miss a critical point. These four compounds are embedded in many different biomass structures, which often are specific for species or subspecies of plants and animals. What actually determines the use of such individual structures are preferences which pay regard to many more aspects than, for example, nutritional ones. In our view, this circumstance, in combination with the fact that the supply of these structures have different cultivation and conversion characteristics (for instance, with respect to the types of by-products produced), makes it from a general validity point of view important to depict the system by a relatively large number of ‘real-character’ flows.

The selected model flows and processes are called *representing* flows and processes. The major choices of representing *flows*, which to a great extent determined the rest of the model flows and processes, were those at the *food end-use* (Table 2.2, p. 22) and the *phytomass production* (Table 2.6, p. 47), respectively. The choice of representing *processes* was to a large extent determined by the choice of representing flows at end-use and phytomass production. Categories of processes included in the FPD model are:

- *End-use* of food commodities (described in Section 2.2)
- *Conversion* of phytomass to animal food commodities (described in Section 2.3) and to vegetable food commodities (described in Section 2.4)
- *Production* of phytomass (described in Section 2.5)
- *Trade* of products and *distribution* of products, by-products and residues (described in Section 2.6)

All processes are depicted on a mass and energy balance basis. The description of each process complies with balance of *total dry matter* and *total (or gross) energy*, respectively. Balance of water is not maintained. (Balance of protein is maintained in a limited number of processes.)

As mentioned above, the main strategy in the construction of the FPD model was to depict each process with real-character flows rather than equivalent-character flows. This implied that the number of representing flows included in the model was determined by the number of flows in the corresponding real process.

The total number of model flows, counting all separate flows in all processes, amounts to about 140 (in each regional sub-model, that is). How detailed should the flow and process depiction be in order to produce valid descriptions of the required phytomass production? No generic method was identified for deciding which number of representing flows that can be considered as necessary with respect to model validity. In the application of the model (Chapter 3), a number of points of insufficient validity and needs for improvement were identified. This is set fourth in Section 3.3 (p. 179).

### 2.1.5 Variables and parameters

The variables and parameters that constitute the *input* in the process descriptions are divided into mainly the following categories:

- Driving variables
- Yield variables
- By-products & residues assigning variables
- Feedstock mixing parameters
- Trade variables
- Composition parameters

The *driving variables* are those which conceptually are the starting point for the calculations, here the food end-use variables. The category *yield variables* includes all variables that describe the input-output relations for flows of mass and energy through a process. The variables belonging to the category *by-products & residues assigning variables* handle use of internally generated by-products and residues as feedstock or commodity. The amount assigned for a certain purpose expresses the amount *maximally* available for this purpose. *Feedstock mixing parameters* include parameters steering the mix of feedstuff or feedstock (apply to conversion processes only). The *trade variables* express flows of products between the regions. *Composition parameters* describe the quality of each flow in the model.

The total number of input variables and parameters for each region model is approximately 1 550, of which 700 are composition parameters. In total, for the entire model of eight region models, there are approximately 12 500 variables and parameters.

### 2.1.6 Structure and terminology of flow-course

The term ‘flow-course’ refers to the course of events which the flows undergo. The FPD model contains a specific terminology of concepts for describing this flow-course. This terminology is consistently used for all flows in the model system, although in some cases, such as for gases, the concepts have only a formal meaning.

There are some particularly essential steps in the flow-course, which in the FPD model are described by using the following terminology:

- *Generation*. This is the formal designation for the production of flows.
- *Supply*. Supplied amount refers to the amounts provided from a model sub-system. The difference between ‘generated’ and ‘supplied’ consists of ‘internal use’ and ‘not recovered’. ‘Internal use’ refers to any active use within the same sub-system as where the flow is generated (for example, use of seeds is described as an internal use in the crop production). ‘Not recovered’ simply means that the generated amount, or a fraction of the generated amount, is not made available for further use within or outside the food system. Thus, by definition, the amount ‘not recovered’ is lost (from a use point of view, that is). In the FPD model, ‘not recovered’ is expressed by its reverse quantity, here called ‘recovery rate’.
- *Distribution*. Distributed amount refers to the amount actually available for use within the particular region. The difference between ‘supplied’ within the region and ‘distributed’ within the region consists of ‘net-trade’ and ‘distribution & storage losses’.

## 2.2 USE OF FOOD

This part of the model represents the use of phytomass and phytomass-derived commodities for the purpose of food. Its main function is to calculate *required distribution* of food *products* within the region, given the stated food end-use per capita and population in the region.

### 2.2.1 Characteristics in representation

Descriptions of food use

In the FPD model, the depiction of use of food commodities includes three major variables:

- End-use of food commodities per capita (driving variable, in MJ ME/capita & day)
- Intake of food commodities per capita
- Population

'Intake' represents food commodities actually eaten — thus, it represents a relatively distinct point in the food system. 'End-use', on the other hand, is a vaguer concept. It might be defined as use of a food commodity in order to generate a food *service*, that is, an economic utility — in contrast to generate, or maintain, physiological mechanisms, which is what might be considered as the fundamental purpose of 'intake'. In comparison with 'intake', the 'end-use' concept represents a less distinct point in the food flow; it refers to a more or less undetermined, and varying, point up-stream of the intake.

Why introduce another food use variable besides the obvious variable 'intake'? We see at least two specific reasons.

Firstly, and most importantly, regular and systematic data, such as statistics, are generally not available for food intake. Normally, statistics on per-capita food consumption do not refer to the amount of food eaten — rather, most statistics refers to the amount of food supplied at some point in the distributional chain, often at the wholesale level. Obviously, if such data are to be used as a basis for a description of the food use, a variable like 'intake' is inadequate.

Secondly, as touched upon above, the end-use concept reflects other aspects of food use than merely the intake of energy and other nutrients. (1) Some food commodities, or parts of commodities, only serve as means for service production. This apply to, for example, oils and fats used for frying, and bones in meat products. These flows are not actually intended to be eaten, but yet is an important or even inevitable part of the food use. (2) It is a well established fact that when per capita income rises, the use of food, measured as supply at wholesale, rises. Generally speaking, this is partly due to a larger intake per capita and partly to a higher rate of food wastage, that is, a larger fraction of the food consumption (or food supply) is not eaten, but is wasted.

In the FPD model, the actual shaping of the structure of the end-use description was essentially determined by the structure of the food consumption statistics in FAOSTAT, which is the major source of regular, worldwide data.[39] Thus, the chosen representing flows for the food end-use (see Table 2.2 below) correspond more or less to the flows included in FAOSTAT food consumption statistics. Unfortunately, this implied that the model food end-use description is not very consistent in terms of the degree of refinement for the individual flows. This also entailed that the end-use does not refer to any uniform, specific point in the food distributional chain.

Due to the above-mentioned differences in availability of regular data, 'end-use' was chosen as *driving variable*, instead of 'intake' which might be considered as the more self-evident choice. This means that it is the stated level of end-use per capita, and not the intake per capita, that determines the required phytomass production. In the FPD model, intake per capita is calculated as an *average share* of the end-use per capita. Intake for each separate flow, including parts of commodities (such as, lean tissue in carcass), is expressed as share relative to this average share.

Calculation of generation of residues

In the FPD model, flows representing residues are 'non-eaten food', 'respiratory heat' and 'human feces & urine' (see below). The amounts of residues generated per capita are determined by the end-use per capita, intake per capita, and the composition of the food commodities.

From the difference between 'end-use' and 'intake', the generated amount of 'non-eaten food' is calculated. Each food commodity and part of commodity (see Table 2.2 below) is specified in terms of gross energy (GE) and metabolizable energy (ME). The amount of feces and urine is calculated as the difference between GE and ME for the eaten flow, that is, for the amount of 'intake' of each separate commodity and part of commodity. The amount of respiratory heat equals the amount of ME of the eaten flow.

### 2.2.2 Representing flows

The commodities representing food use in the FPD model are shown in Table 2.2. Also shown are estimates of the significance of the representing flows in the real food system.

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[39] FAOSTAT is the statistical database of the Food and Agriculture Organization of the United Nations (FAO). In FAOSTAT, the food consumption statistics are given in the data domain Food Balance Sheets. Excerpts from FAOSTAT are available at http://apps.fao.org.

**Table 2.2** Vector of representing flows in food use in the FPD model. Significance of each flow is indicated by its share in the real system.[a]

| Commodity group, category and sub-category | Representing commodity and part of commodity | | Share of *total* | Share of *category* |
|---|---|---|---|---|
| | Products | By-products (and system-external flows) | | |
| ***Vegetable food*** | | | | |
| **Cereals** | | | 50.9% | |
| | Wheat straight flour | | | 39.3% |
| | White rice | | | 41.7% |
| | Maize grits, meal & flour | | | 11.7% |
| | Sorghum grits, meal & flour | | | 2.9% |
| | *Sum within category* | | | *95.6%* |
| **Starchy roots** | | | 5.1% | |
| | Cassava tubers | | | 32.0% |
| | Flesh | | | |
| | Skin | | | |
| | White potato tubers | | | 36.8% |
| | Flesh | | | |
| | Skin | | | |
| | Sweet potato tubers | | | 23.2% |
| | Flesh | | | |
| | Skin | | | |
| | *Sum within category* | | | *92.0%* |
| **Sweeteners** | | | 8.6% | |
| | Cane white sugar | | | ? |
| | Beet white sugar | | | ? |
| **Oil crops** | | | 1.9% | |
| | Soybean seeds | | | 29.6% |
| | Groundnut pods | | | 34.2% |
| | Seed | | | |
| | Husk | | | |
| | Sunflower achenes | | | 2.7% |
| | Kernel | | | |
| | Husk | | | |
| | Canola seeds | | | 2.6% |
| | *Sum within category* | | | *69.1%* |
| **Vegetable oils** | | | 8.0% | |
| | Soybean oil | | | 28.5% |
| | Groundnut oil | | | 8.2% |
| | Sunflower oil | | | 13.8% |
| | Canola oil | | | 14.3% |
| | Palm oil | | | 13.2% |
| | | Maize oil | | 2.8% |
| | | Sorghum oil | | ? |
| | | Oil palm kernel oil | | 1.4% |
| | | Cotton oil[b] | | 5.7% |
| | *Sum within category* | | | *>87.9%* |
| **Tree nuts** | | | 0.2% | |
| | Tree nuts | | | (100%) |
| **Pulses** | | | 2.2% | |
| | Pulses | | | (100%) |
| **Vegetables** | | | 1.8% | |
| | Vegetables | | | (100%) |

*Table continues on next page.*

**Table 2.2** (continued)

| Commodity group, category and sub-category | Representing commodity and part of commodity | | Share of *total* | Share of *category* |
|---|---|---|---|---|
| | Products | By-products (and system-external flows) | | |
| **Fruits** | | | 2.6% | |
| | Fruits | | | (100%) |
| **Stimulants** | | | 0.2% | |
| | Stimulants | | | (100%) |
| **Alcoholic beverages** | | | 2.3% | |
| | Barley beer | | | 40.0% |
| ***Animal food*** | | | | |
| **Meat & fat** | | | 8.4% | |
| <u>Ruminant meat</u> | | | | 26.4% |
| | Beef cattle carcass | | | 81%[c] |
| | Lean tissue | | | |
| | Fatty tissue | | | |
| | Bone | | | |
| | | Dairy cattle carcass | | - |
| | | Lean tissue | | |
| | | Fatty tissue | | |
| | | Bone | | |
| <u>Pig meat</u> | | | | 55.2% |
| | Pig carcass-side | | | 100% |
| | Lean tissue | | | |
| | Fatty tissue | | | |
| | Bone | | | |
| <u>Poultry meat</u> | | | | 17.0% |
| | Meat-type chicken carcass | | | ? |
| | Lean tissue | | | |
| | Fatty tissue | | | |
| | Bone | | | |
| | | Leghorn-type chicken carcass | | ? |
| | | Lean tissue | | |
| | | Fatty tissue | | |
| | | Bone | | |
| | *Sum of sub-categories within category* | | | *98.6%* |
| **Offals** | | | 0.3% | |
| | | Beef cattle fifth quarter | | ? |
| | | Dairy cattle fifth quarter | | ? |
| | | Pig fifth quarter | | ? |
| | | Meat-type chicken fifth quarter | | ? |
| **Milk** | | | 5.2% | |
| | Cattle whole milk | | | 88%[d] |
| **Eggs** | | | 1.0% | |
| | Chicken whole eggs | | | 93%[d] |
| | Yolk & white | | | |
| | Shell | | | |
| **Fish & seafood** | | | 0.9% | |
| | | Fish[b] | | |
| ***Sum of categories*** | | | *99.6%* | |

Residues generated at food use ('non-eaten food', 'human feces & urine' and 'respiratory heat') are not included in the table.

*Notes continue on next page.*

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[a] Shares in real system are calculated from the FAOSTAT Food Balance Sheet (global averages for 1992-94, values on ME basis if not otherwise stated). The flows specification in FAOSTAT does not exactly correspond to that of the representing commodities. For cereals and starchy roots, consumption data in FAOSTAT are given for each species as a group (for ‘wheat’, ‘rice’, etc), that is, no specification of processed flows is explicitly given.

[b] System-external related flow (see Section 2.1.3, p. 15).

[c] Refers to *total* (beef *and* dairy) cattle meat as share of total *produced* amount, as opposed to end-used amount, of ruminant meat (on as-is weight basis). Calculated from FAOSTAT, domain Livestock primary.

[d] Refers to share of *produced* amount, as opposed to end-used amount, (on as-is weight basis). Calculated from FAOSTAT, domain Livestock primary.

Besides enabling use of data from FAOSTAT, the representing flows were chosen taking into consideration two aspects: (1) Ability to reflect different preferences and economic standards (purchasing power). (2) Ability to give a representative description with respect to (a) the required production of phytomass products and (b) the generation of by-products and residues.

The chosen structure of *categories* of commodities follows more or less the structure in the FAOSTAT Food Balance Sheets (FBS), with only a few exceptions: (1) The FBS category ‘sugar crops’ was omitted since it makes up only a very small fraction of the food supply (globally about 0.1 percent on ME basis). (2) Omitted was also the category ‘Animal fats’ — in the FPD model, the FBS flows in this category were assumed to be modeled by flows in other categories instead. The categories and sub-categories included in the FPD model covers entirely the real food use (to 99.6 percent, see Table 2.2), and are diversified enough to reflect differences in preferences.

Each category is described by one or more representing *commodities*, which can be either a product or a by-product from a generating sub-system. Some representing commodities are also described by a further level of detail, here referred to as ‘partition’ of commodity — this applies to starchy roots, some of the oil crops and carcasses and eggs. This further level of detail was included if the commodity consists of clearly discernible parts with different composition and if these parts are differently preferred as food. Such a description enables a more accurate representation of the degree of food intake, that is to say, to what extent the end-used flow is actually eaten or not eaten.

For the categories cereals and starchy roots, it was assumed that there exist different preferences for different species of cereals and roots. The types and amounts of by-products generated in the conversion (processing) into cereals products also differentiate between different species of cereals. For these reasons, all major species of cereals and starchy roots were included.

Vegetable oils are a relatively complex part of the vegetable food group, since the types of oil crops products used in production are relatively different in terms of composition and cultivation characteristics. This motivates a relatively large number of representing flows. Soybean, groundnut, sunflower, canola and oil palm are the five most common oil crops globally. Maize and sorghum oil are by-products from maize and sorghum milling, oil palm kernel oil is a by-product from palm oil production, and cotton oil is a by-product from the cotton lint production.

The relatively detailed depiction of oil crops for direct human consumption is not justified alone since it constitutes only a small part of the diet. These oil crops are included as separate flows in the model as a consequence of the depiction of vegetable oils, and therefore this level of detail entails only a slight extra modeling effort.

For ‘alcoholic beverages’ a more detailed description might seem motivated. There are different preferences for different alcoholic beverages and their means of production also differs. However, these differences were neglected since this commodity category makes up only a small part of the human diet.

The same basis for reasoning as for alcoholic beverages was used for all the categories ‘tree nuts’, ‘pulses’, ‘vegetable’, ‘fruits’ and ‘stimulants’. All together they constitute only about 6 to 7 percent (ME basis) of the diet globally. In the FPD model, these categories were represented by pure equivalent-character flows (concept described in Section 2.1.4, p. 17). The flows are the same in food use as in the phytomass production — hence, they remain unchanged in composition throughout the model system.

For the category ‘meat & fat’ it was recognized that there exist different preferences for different types of meat. Versatility in feed use as well as feed conversion efficiency differentiate substantially between ruminants, pig and poultry. In the FPD model, use of ruminant meat is represented by cattle carcass only (beef plus dairy cattle carcass, dairy cattle carcass formally being a by-product from cattle milk production). Use of poultry meat is represented by meat-type chicken carcass (broiler) and leghorn-type chicken carcass, the latter being a by-product from chicken egg production.

The categories ‘milk’ and ‘egg’ were represented by each category’s dominating flow in the real food system, that is, cattle milk and chicken egg, respectively. It should be noted that milk is represented merely as whole-milk (that is, producer milk) — thus, no processed milk flows were included in the food use description. The category ‘fish’ is represented by one single flow of equivalent-character.

Besides these representing commodities, flows representing *residues* in the model are ‘non-eaten food’, ‘respiratory heat’ and ‘human feces & urine’. Thus, all food which is not eaten, is represented by only one single flow, ‘non-eaten food’.

## 2.3 PRODUCTION OF ANIMAL FOOD COMMODITIES

This part of the FPD model represents the conversion of phytomass, and other biomass, to animal food commodities. Its main function is to calculate the *required distribution* of phytomass *products* for use as feed, given the required supply of animal food products.

### 2.3.1 General approach and delimitations

Division into animal sub-systems

In the FPD model, the processes of conversion of biomass to animal food commodities are organized in separate sub-systems. The structure of the sub-systems was determined by the structure of the animal food products included in the food use vector (Table 2.2 above). The following sub-systems are included:

- Cattle milk
- Beef cattle carcass
- Pig carcass
- Chicken egg
- Meat-type chicken carcass

The name of each sub-system refers to the flow which is defined as the *product* from the system.

Basis in the description of the animal sub-systems

In the FPD model, the representation of each of the animal food sub-systems is based on a detailed description of (1) the pools (animals-in-stock) and flows of all major animal categories, (2) the feed energy requirements for each of the animal categories and (3) the feed dry matter intake for each of the categories.

*Pools and flows of animals*

The very foundation in the representation of the animal sub-systems is the description of the pools and flows of animals. In each animal sub-system, the pools and flows are described in separate categories based on the *function* of the animals in the sub-system. In the FPD model it is, as a general rule, differentiated between the following generic categories:[40]

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[40] These animal categories are generic in the sense that animals may belong to more than one of the categories — for instance, the milk cow belongs to both the category ‘reproducers’ and the category ‘producers’. Also, a category may be represented by more than one animal type — for example, the category

*Notes continue on next page.*

- Reproducers (animals producing offspring)
- Producers (animals fed for carcass, milk or egg production)
- Replacers (animals replacing reproducing animals)

In the description of the category ‘reproducers’, only females are included. Males were excluded since only a very small number of males are needed for the reproduction, and their feed requirements are negligible in comparison with that of the entire sub-system. Excluded were also the reproducers in the chicken egg system, that is, the breeding hens which produce pullets intended to be egg-producing hens. In average systems, the feed requirements of these hens are less than one percent of the total.

Each of these animal categories are described by a number of base parameters, among the principal ones are:[41]

- Body liveweight (described on *daily* basis)
- Liveweight gain (*daily* basis)
- Reproduction (offspring production) (yearly basis)
- Milk/egg production (yearly basis)
- Culling rate of reproducing animal (yearly basis)
- Mortality rate (yearly basis)
- Body, milk and egg partition[42] and composition (yearly basis)

From these parameters a complete picture of each of the animal sub-systems is obtained in terms of:

1a The size of the pools of the different animal categories (calculated on mid-year basis, assuming even mortality rate over the year).[43]

1b The flows of animals — *in* to the sub-system (borned/hatched animals), *out* from the sub-system (slaughtered and deceased animals, respectively), and *between the pools* of the animal categories.[44]

2 The generation of commodity (carcass, milk, egg) per *total* number of animals-in-stock in the sub-system (that is, the sum of the pools of categories in the sub-system).[45]

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‘producers’ in the beef cattle sub-system includes separate descriptions of ‘bulls’ and ‘heifers’, respectively.

[41] Of course, not all of the parameters are applicable to all animal categories in all sub-systems.

[42] As mentioned in the preceding section, ‘partition’ refers to description of separate parts — often different in terms of chemical composition — of a commodity. In the FPD model, output from, for instance, animal carcass sub-systems are described in ‘whole body’, which consists of ‘empty body’ and ‘ingesta’ (intestinal content). ‘Empty body’ in turn, consists of ‘carcass’ and ‘fifth quarter’, respectively. Further details on the specifications of these flows are given in Appendix 1.

[43] Normalized per number of reproducing animals in stock.

[44] Normalized per number of reproducing animals in stock and year.

*Feed energy requirements*

Feed energy requirements are calculated with equations which as input parameters have some of the above-listed base parameters (equations are given in Sections 2.3.2 to 2.3.6 below). These give the feed energy requirements for each of the animal categories (calculated on either yearly or life-time basis).

Together with the specifications of the pools and flows (point 1a and 1b), this calculation operation gives the feed energy requirements *per number of animals-in-stock* in the sub-system. In combination with the specifications of the commodities generation (point 2), this also gives the feed energy requirements *per amount of commodity generated* in the sub-system. (Both are calculated on a yearly basis.)

*Feed dry matter intake*

In the FPD model, calculated feed energy requirements are to be fully met by the energy content of the feed dry matter intake, that is, feed dry matter intake is a function of the energy requirements as well as the average energy density of the eaten feed mix.

The description of the feed dry matter includes specification of the share of each feedstuff in the feed mix, and the energy density of each feedstuff. (Which flows that are included as options in the feed mix for each animal sub-system, is given in Table 2.3 Table 2.4 Table 2.5 below.) As a general rule, the specification of the mix of the feed dry matter intake is made separately for each of the animal categories in each sub-system (further details are given in Sections 2.3.2 to 2.3.6 below).

In each of the animal sub-systems, a specific feedstuff, or group of feedstuffs, is treated as a balance post for the feed use for each of the animal categories in the system. This means that, for each of the animal categories, the feed use of this *balancing flow* is automatically adjusted so the energy content of the feed matter intake comply with the calculated feed energy requirements of the animal category.

For all animal categories in the two cattle sub-systems, the balance post is ‘permanent pasture’ (as a group, that is, native and oversown pasture operate jointly as balancing flow). For the pig sub-system, balancing flow is the equivalent-character flow ‘forage-vegetables’. For the chicken egg and meat-type chicken carcass sub-systems, the balance posts are ‘cereals grains’ (as a group). (See Section 2.5, p. 45, for details regarding these flows.)

Allowances in calculated feed energy requirements

In the FPD model, calculated feed energy requirements of the animal sub-systems include minimum requirements for maintenance, growth, lactation, reproduction and other

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[45] Calculated per year.

basic biological functions of the animals. However, the energy required for maintenance can be much larger than its minimum requirement. For instance, temperature stress (heat and cold stress) and activity can significantly rise the maintenance requirement. Therefore, a general allowance for basic activity, temperature effects, and so forth, is included. Besides this basic activity allowance, additional allowances are included for the extra energy expenditures for activity at grazing. (Details are given in Sections 2.3.2 to 2.3.6 below.)

As mentioned in Section 2.1.3 (p. 15), only terrestrial phytomass production induced by consumption of *food services* is included in the FPD model. Therefore, allowances for draft work performed by meat and milk producing ruminants are not included in the model. Neither are animals primarily used for draft purposes, such as camels, horses and mules, part of the model.

For each animal category, all relevant allowances are calculated — with one exception. For the cattle and pig systems, the energy requirements of the parental animal for the synthesis of milk for consumption by the offspring are not included. In the FPD model, the feed matter requirement of the offspring is calculated assuming no suckling of milk. Thus, the feed matter requirement of the entire herd is calculated under the assumption that the offspring consumes all the feed directly, and no feed indirectly in the form of milk synthesized by the parent.

Of course, this is a simplification of real cattle and pig systems, which, especially in their more traditional forms, include a significant suckling period. Since a certain energy loss occurs in the formation of milk, this simplification implies an underestimate of the real feed energy requirements. However, from the perspective of the total feed requirement of the herd, this simplification is likely to be of little significance. First, the amount of feed energy provided by milk is very small compared to the total feed requirement of the growing offspring during its entire lifetime (probably less than 5 percent). Secondly, the energetic efficiency of milk formation is rather high — for pigs, for instance, the efficiency of use of ME for milk production is around 70 percent.[46] The underestimation due to this simplification is not likely to be much larger than 1 percent of total feed energy requirements of the herd.

Other biomass uses included in the description of animal food production

Besides feed, the livestock sector uses significant amounts of biomass for the purpose of bedding in animal confinements. The main function of the bedding material is to absorb the water in the manure, thereby keeping the animals cleaner and more comfortable. The most commonly used bedding material is cereals straw and stover, although many other types of biomass have properties suitable for bedding.

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[46] [Whittemore 1993, p. 339]

The FPD model includes use of cereals straw and stover as bedding material. All flows representing cereals straw and stover in the model, that is, wheat straw, rice straw, maize stover, sorghum stover and barley straw, are included as bedding material options. Required use of cereals straw and stover for bedding is calculated as a function of the generated amount of manure (feces and urine).

The model representation of animal bedding also includes description of the loss of dry matter that occurs during use. This mainly represents the oxidational losses which occur when in place in the animal confinement.

### Other processes included

Most feedstuffs are treated in some way after harvest before offered to the animals. These processes range from simple ones as flaking of cereals grains, to more advanced ones as ensiling for preservation and seasonal storage.

In the FPD model, these activities are formally part of the description for the animal food production. Processes included in the model are those which normally involve dry matter losses or changes in composition:

- Cassava meal production from raw cassava tubers
- Cooking of sweet potato tubers
- Cooking of soybean seeds
- Hay and silage production from fresh grass-legume
- Silage production from whole-cereals
- Silage production from sugar-beet tops
- Meat & bone meal production from carcass fifth quarters
- Fish meal production from fish

The depiction of these processes in the model is very simple and includes only dry matter losses and changes in composition. Other, more simple feedstuff processing is implicit in the model and accounted for through setting nutritive values valid for processed feed. This applies for instance to cereals grains, which are all assumed to be flaked or the like.

### Calculation of generation of by-products

In the FPD model, each feedstuff is specified in terms of its content (or density) of gross energy (GE), digestible energy (DE), metabolizable energy (ME), and in the case of cattle, also net energy (NE). This specification, together with the specification of the share of each feedstuff in the feed mix, enable calculation of the division of the total feed intake into feces, urine, methane, heat and zoomass for each animal category.

For the cattle and pig sub-systems, the generated amount of feces is calculated as the difference between GE and DE of the feed intake. For these sub-systems, the amount of methane generated in enteric fermentation is calculated as a factor of GE of feed intake (‘methane factor’). The amount of urine is calculated as the difference between DE and ME, *minus* the amount of methane as calculated by the methane factor. For poultry, which excrete feces and urine together via a cloaca, the amount of feces and urine are calculated together as the difference between GE and ME of the feed intake (gaseous losses are negligible for poultry[47]). For all animal sub-systems, the amount of respiratory heat equals the amount of ME of the feed intake.

### 2.3.2 Cattle milk

Calculations of energy requirements

Formulas and coefficients used in the FPD model for calculation of energy requirements for dairy cattle are taken from the equations proposed by the Committee on Animal Nutrition at the US National Research Council (NRC) for predicting requirements of energy and other nutrients.[48] In the following, the choices of equations for use in the FPD model will be commented upon only if an element of own estimate is introduced. All requirements are calculated in net energy (NE) terms. (Definitions of different NE terms are given in Appendix 2.)

*Maintenance*

Maintenance requirement for the lactating *cow* is calculated according to:

$$\mathrm{NE_l} = 0.305 \cdot LW^{0.75} \qquad \text{[MJ/day]}$$

For the *replacement heifer*, and *bulls & heifers* according to:

$$\mathrm{NE_m} = 0.360 \cdot LW^{0.75} \qquad \text{[MJ/day]}$$

where

LW: Live weight [kg as-is]

To the values given by these equations — which are valid for penned animals in generally non-stressful environments — a general allowance for basic activity, heat and cold stress, and so forth, of 10 percent is added. A 10 percent increase as general allowance may be on the low side, since basic activity alone may amount to 10 percent of the

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[47] [NRC 1994, p. 4]

[48] [NRC 1989]. Prediction equations are given on pp. 71-77, explanations, comments and original references on pp. 5-9. A new edition of Nutrient Requirements of Dairy Cattle is scheduled for release in 2000. Equations are written in the same fashion, using the same abbreviations, as in the source.

minimum maintenance requirement. Also cold and heat stress can imply increases of the same order of magnitude or more.[49]

The resulting value, here referred to as *base* maintenance requirements, is the default value in the model for the maintenance requirement calculation. Additional allowances are made only for activity at grazing. The magnitude of the grazing allowances are formally treated as input parameters of the model, see the section ‘Estimates of additional energy requirements at grazing’ (p. 76) for values.

### *Gestation*

Gestation requirement is estimated by assuming an average of 33 MJ $\mathrm{NE_l}$ per kg calf birth weight, using data valid for beef cattle (details are given in the section describing the beef cattle carcass sub-system below, p. 35).

### *Lactation*

The net energy requirement for the formation of milk equals the gross energy content of the milk produced.

As mentioned in the preceding section, in the model description of the cattle and pig sub-systems, no milk is consumed by the offspring. Thus, in the cattle milk system no requirements are included for milk consumed by calves (see the section ‘Allowances in calculated feed energy requirements’, p. 28).

### *Growth*

Growth requirement for *heifers*, *large* breed is calculated according to:

$$\mathrm{NE_g} = 0.146 \cdot LW^{0.75} \cdot LWG^{1.119} + 4.184 \cdot LWG \ [\mathrm{MJ/day}]$$

For heifers, *small* breed:

$$\mathrm{NE_g} = 0.188 \cdot LW^{0.75} \cdot LWG^{1.119} + 4.184 \cdot LWG \ [\mathrm{MJ/day}]$$

For *bulls, large* breed:

$$\mathrm{NE_g} = 0.105 \cdot LW^{0.75} \cdot LWG^{1.097} + 4.184 \cdot LWG \ [\mathrm{MJ/day}]$$

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[49] An allowance of 10% is recommended for the usual activity in individual stalls and drylot systems [NRC 1989, p. 6]. Under severe winter conditions, it is recommended to increase the *total* feed allowance (maintenance plus production) by up to 8% for animals that do not have access to dry shelter [Ibid., p. 7]. Heat stress may cause up to 25% increase of maintenance requirements [NRC 1996, p. 10].

For bulls, *small* breed:

$$\mathrm{NE_g} = 0.146 \cdot LW^{0.75} \cdot LWG^{1.097} + 4.184 \cdot LWG\ [\mathrm{MJ/day}]$$

where

LW: Live weight [kg as-is]
LWG: Live weight gain [kg as-is/day]

Calculation of feed energy densities of feedstuff

In the FPD model, the energy content of feedstuffs for dairy cattle is specified in terms of GE, DE, ME, $\mathrm{NE_l}$, $\mathrm{NE_m}$, and $\mathrm{NE_g}$. The DE-value is formally an input parameter from which values of ME and NE are calculated. In the model, ME and NE are calculated according to the equations used in the preparation of the NRC tables of feed composition:[50]

$$\mathrm{ME} = 4.184 \cdot (\text{-}0.45) + 1.01 \cdot DE$$

$$\mathrm{NE_l} = \text{-}4.184 \cdot 0.12 + 0.0245 \cdot \frac{DE}{0.04409}$$

$$\mathrm{NE_m} = 4.184 \cdot \left[ -1.12 + 1.37 \cdot \frac{0.82 \cdot DE}{4.184} - 0.138 \cdot \left( \frac{0.82 \cdot DE}{4.184} \right)^2 + 0.0105 \cdot \left( \frac{0.82 \cdot DE}{4.184} \right)^3 \right]$$

$$\mathrm{NE}_g = 4.184 \cdot \left[ -1.65 + 1.42 \cdot \frac{0.82 \cdot DE}{4.184} - 0.174 \cdot \left( \frac{0.82 \cdot DE}{4.184} \right)^2 + 0.0122 \cdot \left( \frac{0.82 \cdot DE}{4.184} \right)^3 \right]$$

All energy values in MJ/kg DM.

Feed options

A list of those flows which are included as options in the feed mix for the cattle milk system is given in Table 2.3 below.

The share of each feedstuff in the feed mix is specified separately for each of the three major animal categories in this sub-system: milk cows, replacement heifers, and dairy

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[50] Equations are given in NRC [1989, p. 9]. NRC emphasizes that the NE-equations are based on experimental solution set diets with mainly moderate to high digestibility, and that caution should be exercised in use of the equations outside the experimental data range. These issues are further unfolded in Section 3.3.1 (see p. 201).

**Table 2.3** Flows included as feedstuff options for the cattle milk system (and the beef cattle carcass system). Feeds are grouped with respect to major nutritional properties.

| Products | By-products |
|---|---|
| **Concentrate products** | **Non-fibrous by-products**[a] |
| Maize grains | Cassava leaves |
| Sorghum grains | Sugar beet tops (ensiled) |
| Barley grains | Wheat mill run |
| Cassava tubers (raw) | Rice bran |
| Cassava meal | Maize hominy feed |
| | Sorghum hominy feed |
| **Forage products** | Sugar cane molasses |
| Grass-legume hay, temperate species | Sugar beet pulp |
| Grass-legume hay, tropical species | Sugar beet molasses |
| Grass-legume silage, temperate species | |
| Grass-legume silage, tropical species | **Fibrous by-products**[b] |
| Whole-maize silage | Wheat straw |
| | Rice straw |
| **Cropland pasture** | Maize stover |
| Grass-legume, temperate species | Sorghum stover |
| Grass-legume, tropical species | Barley straw |
| | Sugar cane tops & leaves |
| **Permanent pasture** | Soybean stalks & husks |
| Native grass-legume, temperate species | Groundnut stalks |
| Native grass-legume, tropical species | Sunflower stalks & threshed heads |
| Oversown grass-legume, temperate species | Canola stalks & husks |
| Oversown grass-legume, tropical species | Rice hulls |
| | Sugar cane bagasse |
| | |
| | **Protein supplement by-products**[c] |
| | Brewer’s grains |

[a] Feedstuffs with less than 20% of crude fiber (DM basis).
[b] Feedstuffs with more than 20% of crude fiber (DM basis).
[c] Feedstuffs with more than 20% of crude protein (DM basis).

bulls and heifers respectively. The reason for the separate specification is that the nutrient density requirements are distinctly different for these categories, and no one dominates total feed use for the whole sub-system.

### 2.3.3 Beef cattle carcass

Calculations of energy requirements

Formulas and coefficients used in the FPD model for calculation of energy requirements for beef cattle are taken from the equations proposed by the Committee on Animal Nutrition at the US National Research Council (NRC) for predicting requirements of energy and other nutrients.[51] Comments on the choice of equation for use in the FPD

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[51] [NRC 1984]. Prediction equations are given on pp. 38-39, the explanations, comments and original references on pp. 2-5. More recently, a thoroughly revised edition of Nutrient Requirements of Beef Cattle has been published [NRC 1996].

model are made only if an element of own estimate is introduced. All requirements are calculated in net energy (NE) terms. (Definitions of different NE terms are given in Appendix 2.)

*Maintenance*

Maintenance requirement for all animals is calculated according to:

$$\mathrm{NE_m} = 0.322 \cdot LW^{0.75}\ [\mathrm{MJ/day}]$$

where

LW: Live weight [kg as-is]

In the same way as for the cattle milk system, a general allowance for basic activity, heat and cold stress, and so forth, of 10 percent is added to this equation. The resulting value, here referred to as *base* maintenance requirements, is the default value in the model for the maintenance requirement calculation. Additional allowances are made only for activity at grazing. The magnitude of the grazing allowances are formally treated as input parameters of the model (see the section ‘Estimates of additional energy requirements at grazing’ (p. 76) for values).

*Gestation and lactation*

Gestation requirement is estimated by assuming an average of 33 MJ $\mathrm{NE_m}$ per kg calf birth weight.[52]

As mentioned above, in the model description of the cattle and pig sub-systems, no milk is consumed by the offspring. Thus, in the beef cattle system no requirements for lactation are included (see the section ‘Allowances in calculated feed energy requirements,. p. 28).

*Growth*

Growth requirement is calculated assuming no use of hormonal adjuvants.[53] Requirements for *heifers, large-frame* breed are calculated according to:

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[52] NRC gives prediction equations for the daily energy requirements during gestation [NRC 1984, p. 5; NRC 1996, p. 43]. In the latter edition, the pregnancy requirements have been significantly increased. Integrating the daily requirements over the entire gestation period (281 days), using the equation in the latter edition, yields approximately 33 MJ $\mathrm{NE_m}$ per kg birth weight.

[53] The prediction equations given by NRC are valid for animals receiving hormonal adjuvants. NRC [1984, p.4] states, citing Garret [1980], that cattle that do not receive hormonal adjuvants contain 5% more energy per unit gain. Therefore, the NRC’s prediction equations are increased by 5%.

$$\mathrm{NE_g} = 1.05 \cdot 0.254 \cdot LW^{0.75} \cdot LWG^{1.119}\ [\mathrm{MJ/day}]$$

For heifers, *medium-frame* breed:

$$\mathrm{NE_g} = 1.05 \cdot 0.287 \cdot LW^{0.75} \cdot LWG^{1.119}\ [\mathrm{MJ/day}]$$

For *bulls*, *large-frame* breed:

$$\mathrm{NE_g} = 1.05 \cdot 0.183 \cdot LW^{0.75} \cdot LWG^{1.097}\ [\mathrm{MJ/day}]$$

For bulls, *medium-frame* breed:

$$\mathrm{NE_g} = 1.05 \cdot 0.233 \cdot LW^{0.75} \cdot LWG^{1.097}\ [\mathrm{MJ/day}]$$

where

| | |
|---|---|
| LW: | Live weight [kg as-is] |
| LWG: | Live weight gain [kg as-is/day] |

Calculation of feed energy densities of feedstuff

In the FPD model, energy content of feedstuffs for beef cattle is specified on the levels GE, DE, ME, $\mathrm{NE_m}$, and $\mathrm{NE_g}$. The DE value is formally an input parameter from which values of ME and NE are calculated. In the FPD model, ME and NE are calculated according to the equations used in the preparation of the NRC tables of feed composition:[54]

$$\mathrm{ME} = 0.82 \cdot DE$$

$$\mathrm{NE_m} = 4.184 \cdot \left[ -1.12 + 1.37 \cdot \frac{0.82 \cdot DE}{4.184} - 0.138 \cdot \left( \frac{0.82 \cdot DE}{4.184} \right)^2 + 0.0105 \cdot \left( \frac{0.82 \cdot DE}{4.184} \right)^3 \right]$$

$$\mathrm{NE}_g = 4.184 \cdot \left[ -1.65 + 1.42 \cdot \frac{0.82 \cdot DE}{4.184} - 0.174 \cdot \left( \frac{0.82 \cdot DE}{4.184} \right)^2 + 0.0122 \cdot \left( \frac{0.82 \cdot DE}{4.184} \right)^3 \right]$$

All energy values are in MJ/kg DM.

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[54] Equations are given in NRC [1996, p. 4]. NRC emphasizes that the NE-equations are based on experimental solution set diets with mainly moderate to high digestibility, and that caution should be exercised in use of the equations outside the experimental data range. These issues are further unfolded in Section 3.3.1 (see p. 201).

Feed options

Flows included as options in the feed mix for the beef cattle carcass system are the same as those for the cattle milk system, see Table 2.3 (p. 34).

The share of each feedstuff in the feed mix is specified for two animal categories separately: cows and replacement heifers, and bulls and heifers. The nutrient density requirements are distinctly different for the two categories, and no one dominates total feed use for the whole sub-system.

### 2.3.4 Pig carcass

Calculations of energy requirements

Equations and coefficients used in the FPD model for calculation of energy requirements for pigs are mainly from Whittemore.[55] All requirements are calculated in metabolizable energy (ME) terms.

*Maintenance*

Maintenance requirement for all animals is calculated according to:[56]

$$\mathrm{ME} = 0.440 \cdot LW^{0.75} \ [\mathrm{MJ/day}]$$

where

LW: Live weight [kg as-is]

A general allowance for basic activity, heat and cold stress, and so forth, of 15 percent is added to this equation.[57] The resulting value, here referred to as *base* maintenance requirements, is the default value in the model for the maintenance requirement calculation.

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[55] [Whittemore 1993]

[56] This equation remains, according to Whittemore [1993, p. 335], the best-used of all estimates of the energy requirement for maintenance.

[57] The energy cost of cold thermogenesis (cold stress) can be estimated to 0.012-0.018 MJ ME for each kg of metabolic weight and degree below the comfort temperature [Whittemore 1993, p. 336]. This means that an ambient temperature of, for example, 5 degrees below the comfort temperature increases the daily maintenance requirement by about 17%.

*Gestation and lactation*

Requirement for gestation is estimated by assuming 25 MJ ME per born piglet (including stillborn piglets).[58]

This figure includes requirements for development of the mammary tissue. Besides this, no requirements for lactation are included, since in the model description of the cattle and pig sub-systems, no milk is consumed by the offspring (see the section ‘Allowances in calculated feed energy requirements’, p. 28).

*Growth*

Growth requirement for all animals is calculated according to:[59]

$$\text{ME} = 54.6 \cdot W_{protein} + 53.3 \cdot W_{lipid} \qquad [\text{MJ}]$$

where

$W_{protein}$: Protein retained in gain [kg]
$W_{lipid}$: Lipid retained in gain [kg]

Feed energy densities of feedstuff

In the FPD model, energy content of feedstuffs for pigs is specified with respect to GE, DE and ME. All values are stated (in MJ/kg DM).

Feed options

A list of those flows which are included as options in the feed mix for the pig carcass-side system is given in Table 2.4 below.

The share of each feedstuff in the feed mix is specified jointly for all animal categories in the system, that is, the feed mix is the same for the categories sows, replacement gilts

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[58] Total gravid uterus at term contains 85 MJ, mammary tissue approx. 40 MJ, and are deposited with an efficiency (NE/ME) of approx. 50% [Whittemore 1993, p. 339]. Assuming a litter size of 10 piglets, this gives approximately 25 MJ ME per piglet in energy cost for gestation.

[59] [Whittemore 1993, pp. 336-338]. The factors correspond to energetic efficiencies (NE/ME) for protein and lipid retention of 44 and 75% respectively. According to Whittemore, it is likely that the energy cost of tissue turnover is positively related to the rate of turnover and mass of protein tissue. It is believed that the efficiency of protein retention has higher values up to 54% for younger pigs, and lower values down to 38% for heavier pigs of 100 kg or more. However, since these issues are not well quantified, Whittemore concludes that it is forgivable to settle for the single fixed value of 44%.

**Table 2.4** Flows included as feedstuff options for the pig carcass-side system. Feeds are grouped with respect to major nutritional properties.

| Products | By-products & residues |
|---|---|
| **Concentrate products** | **Non-fibrous by-products** |
| Wheat grains | White potato tops |
| Maize grains | Sweet potato tops |
| Sorghum grains | Wheat mill run |
| Barley grains | Rice bran |
| Cassava tubers (raw) | Maize hominy feed |
| Cassava meal | Sorghum hominy feed |
| Sweet potato tubers (raw) | Sugar cane molasses |
| Sweet potato tubers (cooked) | Sugar beet molasses |
| | |
| **Forage products** | **Protein supplement by-products**[a] |
| Forage-vegetables | Soybean meal |
| | Groundnut meal |
| **Protein supplement products**[a] | Sunflower meal |
| Soybean seeds (cooked) | Canola meal |
| Fish meal | Brewer's grains (wet) |
| | Dairy cattle meat & bone meal |
| | Beef cattle meat & bone meal |
| | Meat-type chicken meat & bone meal |
| | Cotton meal |
| | |
| | **Food residues** |
| | Non-eaten food |

[a] Feedstuffs with more than 20% of crude protein (DM basis).

and growing swines respectively. This is a reasonably acceptable approach since (1) the nutrient density requirements are only slightly different for sows and swines, and (2) the feed use of the whole system is dominated by that of swines (around 80 percent of total feed in average systems).

### 2.3.5 Chicken egg

Calculations of energy requirements

Formulas used in the FPD model for calculation of energy requirements for chicken eggs production are taken from equations proposed by Larbier and Leclercq.[60] All requirements are calculated in metabolizable energy (ME) terms.

*Maintenance*

Maintenance requirement for the laying *hen* is calculated according to:[61]

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[60] [Larbier & Leclercq 1994]

[61] Larbier & Leclercq [1994, p. 65] list several equations proposed for estimating energy requirements of the laying hen. The equations for maintenance, egg production and growth used in the FPD model for the

*Notes continue on next page.*

$$\mathrm{ME} = 0.565 \cdot LW^{0.75} \ [\mathrm{MJ/day}]$$

For the laying hen *pullet* according to:[62]

$$\mathrm{ME} = 0.418 \cdot LW^{0.75} \ [\mathrm{MJ/day}]$$

where

LW: Live weight [kg as-is]

A general allowance for basic activity, heat and cold stress, and so forth, of 5 percent is added to these equations.[63] The resulting value, here referred to as *base* maintenance requirements, is the default value in the model for the maintenance requirement calculation.

*Egg production*

Requirement for egg production is calculated according to:[64]

$$\mathrm{ME} = 1.68 \cdot E_{egg} \ [\mathrm{MJ}]$$

where

$E_{egg}$: Energy content (gross) of eggs produced [MJ]

*Growth*

Growth requirement for the laying *hen* is calculated according to:[65]

$$\mathrm{ME} = 1.20 \cdot E_{lwg} \ [\mathrm{MJ}]$$

where

$E_{lwg}$: Energy content (gross) of gain [MJ]

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laying hen are those suggested by Grimbergen [1974]. (The Grimbergen reference is not stated in the reference list in Larbier & Leclercq [1994] and is therefore not given in the reference list of this thesis.)

[62] This is one of the two equations suggested for broilers [Larbier & Leclercq 1994, p. 153].

[63] This modest allowance was chosen since the effect of ambient temperature seems to be rather low, for example in comparison with pigs. For instance, a decrease in ambient temperature from 20°C to 15°C increases the maintenance requirements for laying hens by approximately 7% (using formula in NRC [1981], cited in NRC [1994, p. 24]).

[64] The factor 1.68 means that the assumed efficiency (NE/ME) for egg production is 60%.

[65] The factor 1.20 means that the assumed efficiency (NE/ME) for body tissue retention for the hen is 83%.

**Table 2.5** Flows included as feedstuff options for the chicken egg system (and the meat-type chicken carcass system). Feeds are grouped with respect to major nutritional properties.

| Products | By-products |
|---|---|
| **Concentrate products** | **Non-fibrous by-products** |
| Wheat grains | Wheat mill run |
| Maize grains | Rice bran |
| Sorghum grains | Maize hominy feed |
| Barley grains | Sorghum hominy feed |
| | |
| **Protein supplement products**[a] | **Protein supplement by-products**[a] |
| Soybean seeds (cooked) | Soybean meal |
| Fish meal | Groundnut meal |
| | Sunflower meal |
| | Canola meal |
| | Brewer's grains (wet) |
| | Dairy cattle meat & bone meal |
| | Beef cattle meat & bone meal |
| | Pig meat & bone meal |
| | Cotton meal |

[a] Feedstuffs with more than 20% of crude protein (DM basis).

Growth requirement for the *pullet* is calculated according to:[66]

$$\text{ME} = 59.1 \cdot W_{protein} + 53.5 \cdot W_{lipid}\ [\text{MJ}]$$

$W_{protein}$: Protein retained in gain [kg]
$W_{lipid}$: Lipid retained in gain [kg]

## Feed options

A list of those flows which are included as options in the feed mix for the chicken egg system is given in Table 2.5 above.

The share of each feedstuff in the feed mix is specified jointly for the animal categories laying hens and pullets. Analogous to the pig sub-system, the nutrient density requirements are only slightly different for hens and pullets, and the feed use of the whole system is dominated by that of hens (85 to 90 percent of total feed in average systems).

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[66] [Larbier & Leclercq 1994, p. 63]. The factors in the equation correspond to energetic efficiencies (NE/ME) for protein and lipid retention of 40% and 74% respectively. According to Larbier & Leclercq [1994], the efficiency of protein retention are between 40% and 60%, the generally more realistic value being 40%. For lipid retention, the efficiency is, on average, 60%, 75% or 90% depending on the substrate (amino acids, carbohydrates or lipids respectively); thus, for diets based on cereals, the efficiency is usually around 75%.

### 2.3.6 Meat-type chicken carcass

Calculations of energy requirements

Formulas used in the FPD model for calculation of energy requirements for chicken eggs production are taken from equations suggested in Larbier and Leclercq.[67] All requirements are calculated in metabolizable energy (ME) terms.

*Maintenance*

Maintenance requirement for the breeding *hen* is calculated according to:[68]

$$\mathrm{ME} = 0.549 \cdot LW^{0.653} \; [\mathrm{MJ/day}]$$

For the *replacement pullet* and *broilers* according to:[69]

$$\mathrm{ME} = 0.418 \cdot LW^{0.75} \; [\mathrm{MJ/day}]$$

where

LW: Live weight [kg as-is]

A general allowance for basic activity, heat and cold stress, and so forth, of 5 percent is added to these equations.[70] The resulting value, here referred to as *base* maintenance requirements, is the default value in the model for the maintenance requirement calculation.

*Egg production*

Requirement for egg production is calculated according to:[71]

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[67] [Larbier & Leclercq 1994]

[68] Larbier & Leclercq [1994, p. 66] list two equations proposed for estimating energy requirements of broiler breeders. The equations for maintenance, egg production and growth used in the FPD model for the breeding hen are those suggested by Connor [1980] assuming 20°C ambient temperature. (The Connnor reference is not stated in the reference list in Larbier & Leclercq [1994] and is therefore not given in the reference list of this thesis.)

[69] This is one of the two equations suggested for broilers [Larbier & Leclercq 1994, p. 153].

[70] As is the case with leghorn chickens, the effect of ambient temperature seems to be rather low. A decrease in ambient temperature from 20°C to 15°C increases the maintenance requirements for breeding hens by approximately 7%, using the formula given by Connor [1980] cited in Larbier & Leclercq [1994, p. 66] (The Connnor reference is not stated in the reference list in Larbier & Leclercq [1994] and is therefore not given in the reference list of this thesis.) No data were found regarding the effect of the environment for broilers, but we assumed that the effect of temperature for hens is likely to be valid also for broilers.

[71] The factor 13.2 corresponds to an efficiency (NE/ME) for egg tissue retention of about 48%.

$$\mathrm{ME} = 13.2 \cdot W_{egg}\ [\mathrm{MJ}]$$

where

$W_{egg}$: Eggs produced [kg]

*Growth*

Growth requirement for the breeding *hen* is calculated according to:[72]

$$\mathrm{ME} = 13.1 \cdot LWG\ [\mathrm{MJ}]$$

where

LWG: Live weight gain [kg as-is/day]

Growth requirement for the *replacement pullet* is calculated according to:[73]

$$\mathrm{ME} = 59.1 \cdot W_{protein} + 53.5 \cdot W_{lipid}\ [\mathrm{MJ}]$$

For *broilers* according to:[74]

$$\mathrm{ME} = 60.3 \cdot W_{protein} + 46.1 \cdot W_{lipid}\ [\mathrm{MJ}]$$

where

$W_{protein}$: Protein retained in gain [kg]
$W_{lipid}$: Lipid retained in gain [kg]

Feed options

Flows included as options in the feed mix for the meat-type chicken system are the same as those for the chicken egg system, see Table 2.5 (p. 41).

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[72] The factor 13.1 corresponds to an efficiency (NE/ME) for body tissue retention for the hen of about 79%.

[73] This is the same equation as the one used for growth of leghorn-type chickens (see Section 2.3.5).

[74] This is one of the two equations suggested for broilers [Larbier & Leclercq 1994, p. 153]. The factors correspond to efficiencies (NE/ME) for protein and lipid retention of 39% and 84% respectively. Thus, compared to the equation used for the other animals, efficiency for lipid retention is assumed to be somewhat higher.

The share of each feedstuff in the feed mix is specified jointly for all animal categories, that is, the ration is the same for the categories breeding hens, replacement pullets and broilers respectively. Analogous to the pig sub-system, the nutrient density requirements are only slightly different for hens and broilers, and the feed use of the whole system is dominated by that of broilers (about 90 percent of total feed in average systems).

## 2.4 PRODUCTION OF CONVERTED VEGETABLE FOOD COMMODITIES

This part of the model represents the conversion of phytomass products to vegetable food commodities. Its main function is to calculate the *required distribution* of phytomass products for use as feedstock, given the required supply of vegetable food products.

As is the case with animal food production, the structure of sub-systems was determined by the structure of the animal food products included in the food use vector (Table 2.2, p. 22). The production of converted vegetable food commodities is represented by the following sub-systems, the name of each sub-system referring to the flow which is defined as the *product* from the system:

- Wheat straight flour
- White rice
- Maize grits, meal & flour
- Sorghum grits, meal & flour
- Cane white sugar
- Beet white sugar
- Soybean oil
- Groundnut oil
- Sunflower oil
- Canola oil
- Palm oil
- Barley beer

From a mass and energy balance point of view, the processes involved here are rather simple. Basically, there is only one major feedstock for each system. The nature of the processes can be described as *extracting* and refining a specific, wanted component in the feedstock (starch, sucrose, oil, etc). The barley beer sub-system is an exception from this, since it involves an actual *conversion* of carbohydrate-rich substrate into ethanol.

In the FPD model, the depiction of the processes is simple and consists mainly of yield variables describing the extent of transformation of the feedstock into other flows. Determining yield parameters are stated on dry matter basis mainly. Added to this are composition parameters characterizing the input and output flows. There is only one feedstock option included for each of the sub-systems.

For some of the sub-systems, the yield variable determining the major transformation in the process is expressed as *rate of extraction* (or recovery) of a specific component in the feedstock. This construction is used in the sugar and oil sub-systems.

In the cane and beet sugar sub-systems, raw sugar yield is expressed as a share of the amount of *sucrose* in the feedstock (that is, cane stems and beet roots respectively). Analogously, in the oil sub-systems, oil yield is expressed as a share of the amount of *lipid* in the feedstock (soybean seeds, groundnut seeds, sunflower kernels, canola seeds, and oil palm fruit).

By-products from the processes are — except for the barley beer sub-system — those parts of the feedstock which remain after the wanted components have been extracted. Thus, the amount of by-products generated is determined by the yield variables and the feedstock composition and partition parameters.

## 2.5 PRODUCTION OF PHYTOMASS

This part of the FPD model represents the production and growth of crops, and other phytomass used in the food system, such as pastures. Its main function is to calculate required total (above-ground) generation of phytomass, given the required supply of phytomass products.

### 2.5.1 General approach and delimitations

General characteristics in representation

As mentioned in the introductory section, the FPD model describes the required terrestrial phytomass production induced by human food use. For all phytomass except underground crops (starchy roots, sugar beet), the up-stream boundary of the model is *above-ground* phytomass production. For the underground crops, the phytomass production of the *whole plant* is included.

Since the output of the model is the required phytomass production, the model does not deal with *how* the phytomass is produced. Thus, the model system does not include the actual process of photosynthesis and dry matter production.

This means that the descriptions of the phytomass production included in the FPD model are simple and consist only of a few variables. However, the number of phytomass flows included is relatively large.

### Representing flows

The flows representing phytomass production in the FPD model are shown in Table 2.6 below. Also shown are estimates of the significance of these representing flows in the real food system.

The representing flows were chosen taking into consideration that they are to be able to reflect different climatic and biogeochemical conditions for plant growth and production. However, as regards edible-type crops, the choice of the representing flows was essentially determined by the representing flows in the end-use vector (Table 2.2, p. 22).

The phytomass flows are divided into different *categories*, which belong to three different *groups* (Table 2.6). Together these categories cover the major plant types used in the food system.

Each category is described by one or more representing *products,* and in the case of the edible-type crops group, also by one or more representing *by-products*. Analogous with the case in food use, some representing products are also described by a further level of detail, referred to as ‘partition’ of product. Such a description enables a more accurate representation of the degree of food intake, that is to say, to what extent the end-use flow is actually eaten or not eaten. It also gives a more accurate representation of the processes of production of converted vegetable food; the yields of products and by-products in the conversion processes can be described by a further level of detail.

As mentioned in the introductory section, the main approach in the construction of the FPD model was the real-character depiction approach (see Section 2.1.4, p. 17). However, contrary to this, quite a large number of the flows representing the phytomass production have a clear equivalent-character. Within the edible-type crops group, this applies to the representing products ‘tree nuts’, ‘pulses’, ‘vegetable’, ‘fruits’ and ‘stimulants’. These were chosen as representing flows in the food use; in the phytomass production, the flows are the same, that is, these have the same composition throughout the model system. Note that no representation of by-products was included for these categories.

Within the groups of animal forage crops and pasture, almost all representing flows are equivalent-character flows. The major reasons for this reliance on equivalent-character rather than real-character depiction were (1) that the numbers of species and sub-species being used within these plant groups are relatively large, and (2) that the relative importance of the different species and sub-species is not regularly monitored by collection of statistics and is, therefore, far from being well known.

The number of species and sub-species in use is particularly large for grasses and legumes. In forage production, cropland pasture, overseeding of pastures and the like, at least several tens of groups of (domesticated) species are in use in the real system. In

**Table 2.6** Vector of representing flows in production of phytomass in the FPD model. Significance of some of the flows is indicated by their share in the real system.[a]

| Plant group and category | Representing product | Representing by-product | Share of *group* | Share of *category* |
|---|---|---|---|---|
| ***Edible-type crops*** | | | | |
| **Cereals** | | | 63% | |
| | Wheat grains | | | 27% |
| | | Wheat straw | | |
| | Rice grains[b] | | | 29% |
| | | Rice straw | | |
| | Maize grains | | | 30% |
| | | Maize stover | | |
| | Sorghum grains | | | 3.6% |
| | | Sorghum stover | | |
| | Barley grains | | | 6.3% |
| | | Barley straw | | |
| | *Sum within category* | | | *96%* |
| **Starchy roots** | | | 5.7% | |
| | Cassava tubers | | | 40% |
| | Flesh | | | |
| | Skin | | | |
| | | Cassava leaves | | |
| | | Cassava tops excl. leaves | | |
| | White potato tubers | | | 30% |
| | Flesh | | | |
| | Skin | | | |
| | | White potato tops | | |
| | Sweet potato tubers | | | 23% |
| | Flesh | | | |
| | Skin | | | |
| | | Sweet potato tops | | |
| | *Sum within category* | | | *93%* |
| **Sugar crops** | | | 14% | |
| | Sugar cane stems | | | 85% |
| | | Sugar cane tops & leaves | | |
| | Sugar beet roots | | | 15% |
| | | Sugar beet tops | | |
| | *Sum within category* | | | *100%* |
| **Oil crops**[c] | | | 9.8% | |
| | Soybean seeds | | | 46% |
| | | Soybean stalks & husks[d] | | |
| | Groundnut pods | | | 10% |
| | Seed | | | |
| | Husk | | | |
| | | Groundnut stalks | | |
| | Sunflower achenes | | | 7.5% |
| | Kernel | | | |
| | Husk | | | |
| | | Sunflower stalks & threshed heads[e] | | |
| | Canola seeds | | | 11% |
| | | Canola stalks & husks[f] | | |

*Table continues on next page.*

**Table 2.6** (continued)

| Plant group and category | Representing product | Representing by-product | Share of *group* | Share of *category* |
|---|---|---|---|---|
| | Oil palm fruit bunches | | | 16% |
| | Clean fruit | | | |
| | Non-fruit part | | | |
| | | Oil palm leaves | | |
| | | Oil palm trunks | | |
| | *Sum within category* | | | *90%* |
| **Tree nuts** | | | 0.2% | |
| | Tree nuts | | | |
| **Pulses** | | | 1.8% | |
| | Pulses | | | |
| **Vegetables** | | | 1.7% | |
| | Vegetables | | | |
| **Fruits** | | | 3.4% | |
| | Fruits | | | |
| **Stimulants** | | | 0.1% | |
| | Stimulants | | | |
| ***Sum of categories*** | | | *99.7%* | |
| ***Animal forage crops*** | | | | |
| **Grass-legume** | | | | |
| | Grass-legume, temperate species | | | |
| | Grass-legume, tropical species | | | |
| **Whole-cereals** | | | | |
| | Whole-maize | | | |
| **Other animal forage** | | | | |
| | Forage-vegetables | | | |
| ***Pasture*** | | | | |
| **Cropland pasture** | | | | |
| | Grass-legume, temperate species | | | |
| | Grass-legume, tropical species | | | |
| **Permanent pasture** | | | | |
| | Native grass-legume, temperate species | | | |
| | Native grass-legume, tropical species | | | |
| | Oversown grass-legume, temperate species | | | |
| | Oversown grass-legume, tropical species | | | |

The designation ‘grass-legume’ refers to mixtures of grasses and legumes, as well as pure swards of either grasses or legumes.

[a] Shares in real system are own estimates based on FAOSTAT (global averages for 1992-94, values on dry weight basis).

[b] Refers to rice in husk (paddy).

*Notes continue on next page.*

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[c] Numbers for the oil crops category refer to shares of total production of oil crops, *excluding* the fiber-related oilseeds (seed cotton, linseed and hempseed). Together these oilseeds make up roughly 10 percent of the total oil crops production (dry weight basis).

[d] Includes stalks and husks from threshed pods.

[e] Includes stalks and threshed heads (that is, the residue remaining after that the achenes have been separated from the heads).

[f] Includes stalks and husks from threshed pods.

permanent grasslands, which more or less are dominated by native species, the number of species is certainly far larger than that.

The approach chosen in the FPD model to handle this large diversity can be considered as a minimum one: In each category, grass-legume is represented by at least two separate flows, one 'temperate', and one tropical'. A reason for this division is the fact that there exist some general differences between temperate and tropical species.[75]

Another equivalent-character flow in the forage crops group is 'forage-vegetables', which may call for some explanations since it is not a common feedstuff. In the FPD model, 'forage-vegetables' is intended to represent vegetables used in pig production. Vegetables, and feed products other than the conventional ones (that is, cereals, starchy roots, etc), are used extensively in pig production in some regions, especially in East and South East Asia. In China, for instance, vegetables grown for pigs is reported to contribute roughly 10 percent of the total feed energy supply for the whole livestock sector.[76]

### 2.5.2 Cultivation and harvest of phytomass

The depiction in the FPD model of the production of edible-type crops and animal forage crops is simple. Besides composition parameters it basically includes the following variables:

- Partition of dry matter production
- Recovery rate of products and by-products
- Use of cultivation products as seed
- Use of cultivation by-products for mulching

The partition variable refers to the partition of the plant dry matter into 'product' (such as, grain) and 'by-product' (such, as straw) respectively. Thus, this variable is applica-

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[75] For instance, the digestibility of tropical grasses for ruminants is lower than that of temperate grasses. This is in part due to the growth characteristics of the tropical grasses under high-temperature regimes as well as their anatomy [Kretschmer JR & Pitman 1995, p. 286].

[76] [Simpson et al. 1994, p. 365] (year-average for 1989-91, ME basis). The corresponding cultivated area is reported to be 6.4 million ha (p. 258).

ble to the edible-type crops only (see Table 2.6 above). Essentially, the variable is equivalent to the commonly used parameter ‘harvest index’.

The recovery rate refers to the share of generated phytomass made available for further use within or outside the food system. In practical terms, ‘recovered’ essentially corresponds to plant material being cut and gathered (and normally, but not necessarily, removed from field) during harvest. However, as recovered phytomass is counted also plant material being eaten by animals grazing in field after harvest (this applies mainly to straw and other crop by-products).

As a general rule, in the FPD model, use of seeds for sowing is described as an internal use of the product in the crop sub-system (expressed as share of the amount of product generated, on dry matter basis). Exceptions are those cases where seeds, for inherent biological reasons, must be produced in a cycle external to the actual crop producing cycle (applies, for example, to sugar beet). In these cases, no description of requirements of seeds is included.

In the FPD model, use of cultivation by-products (or ‘crop by-products’) for mulching includes two types of use; in both cases, the main purposes are soil conservation and amelioration. (1) Crop by-products *left in field* to decompose, described as an internal use within the crop sub-system (expressed as share of the amount of crop by-product recovered). (2) Crop by-products *distributed to field* from another crop sub-system. This type of use was included only for the tuber (sugar beet, starchy roots) and vegetable production sub-systems. As options for this use were included cereals straw and stover, that is, all flows representing cereals straw and stover in the FPD model (wheat straw, rice straw, maize stover, sorghum stover and barley straw) are included as mulching material options. Required use of cereals straw and stover for bedding is calculated as a function of the generated amount of crop product generated (on dry matter basis).

### 2.5.3 Production and grazing of phytomass

The depiction in the FPD model of the production and grazing of pasture is very simple. As shown in Table 2.6 above, there are only six different flows representing pasture phytomass. Besides the composition parameters, there is only one variable included, ‘pasture utilization’.

In the FPD model, ‘pasture utilization’ refers to the amount of pasture *eaten*, divided by the amount of pasture *generated* (that is, pasture growth) above ground, calculated on a yearly basis.[77] This variable is similar to the concepts of efficiency of grass utilization used in literature; however, variations in the exact definitions of these utilization effi-

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[77] In the formal terminology of the FPD model, the amount of pasture eaten is equivalent with the amount ‘supplied’ that is, formally ‘pasture utilization’ equals ‘recovery rate’ (see Section 2.1.6, p. 19, for definitions of these concepts). The amount eaten is also equivalent with the amount ‘distributed’, that is, distribution losses and trade are, from a formal point of view, zero for the pasture flows.

ciency concepts occur, which means that they are not necessarily directly comparable to the variable used in the FPD model.

Naturally enough, in the real system, growth and use of pastures are far more complex than what the simple depiction in the FPD model suggests. The large diversity of species, for instance, was mentioned above. Therefore, this part of the model merits some comments regarding the interpretation of the model descriptions.

### Permanent pasture

Permanent pastures, considered in a wide sense, comprise a large variety of grasslands and grazing systems.

On the one end, we have grasslands with significant elements of woody vegetation, consisting of native species only and receiving no improvement practices. Non-herbage plant mass, such as browse,[78] constitute a substantial part of the livestock's feed intake. In its more simple forms, animals are allowed to move more or less freely, without any particular grazing strategy or vegetation management. In an economic perspective, not only services such as animal food are produced from such mixed pastures but also, for instance, fuelwood. These types of permanent pasture systems border to forestland grazing systems.

On the other end, we have grasslands entirely dominated by herbage, in particular grasses and legumes, with a large occurrence of improved species (high-yielding, more palatable), which receive improvement practices such as liming, fertilizing, seeding, irrigating and control of weed and bush growth. Timing and duration of grazing activities are normally carefully controlled and occur within fenced areas. This type of systems resemble those of cropland pastures by its relatively high management intensity per unit area.

For permanent pasture, the FPD model includes representation of two different systems, designated 'native' and 'oversown' respectively. Each system is represented by two different flows of grass-legume species groups, 'temperate' and 'tropical'. (See Table 2.6 above.)

#### *Native*

'Native grass-legume' represents phytomass produced and used in permanent pasture systems of a kind closer to the first one of the two type-examples described above. Thus, 'native permanent pasture', represents grazing systems which, in the real system, may contain substantial elements of woody, non-herbage vegetation. Moreover, the feed

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[78] 'Browse' refers to shoots, leaves and twigs of shrubs and woody plants, as well as fruits, pods, and the like.

consumed by the grazing livestock may be made up of non-herbage plant mass to a considerable extent.

This means that the interpretation of the model representation in this case is far from straightforward. First, in the FPD model, the feed flow consists of grass-legume, whereas in the real system, it may be composed of a large number of different types of feedstuffs. Thus, the flow ‘native permanent pasture’ in the model should not just be interpreted as grass-legume —rather, as grass-legume *plus* other grazed feedstuffs, such as browse. Second, the significant occurrence of woody, non-edible vegetation in the real system means that the ‘pasture utilization’ variable in the FPD model should not be interpreted as in the customary way. In principle, pasture utilization does not refer to the *total* above-ground plant growth, that is, including all kinds of vegetation, but only to the *edible* plant mass, that is, herbage, or consumable parts of non-herbage vegetation, such as browse. This means that the calculated required phytomass production associated with intake of ‘native permanent pasture’ should essentially be interpreted as an equivalent-value. (These issue are further dealt with in the discussion following the application of the model — see the section ‘Feed use’, p. 207 sq., and the section ‘Phytomass appropriation’, p. 214.)

### *Oversown*

‘Oversown grass-legume’ represents phytomass produced and used in permanent pasture systems of a kind closer to the second one of the two type-examples described above, that is, the more capital-intensive one.

Since this kind of systems is more homogenous and more clearly defined (little vegetation other than grass-legume, few other uses than grazing, etc), compared to ‘native’, this representation is less of equivalent-character, that is to say, it is closer to the real system.

### Cropland pasture

Cropland pastures are legume and/or grass swards grown and grazed on land suitable for production of crops other than forages.

This kind of systems is even more clearly defined then improved permanent pastures, and its representation does not entail any particular problems besides those with the large number of species used.

## 2.6 DISTRIBUTION, TRADE & STORAGE

This element of the FPD model represents distribution, trade and storage of all non-dissipated flows occurring in the model system.[79] Its main function is to calculate required *supply* of products from phytomass production and conversion processes within a particular region, given a required *distribution* of products within that region.

The depiction in the model mainly includes variables for *losses* during distribution & storage, and variables for *net-import* between regions.

'Losses' refers to both dry matter losses (dissipation), and economic damages, that is, damages that make the flow unfit for use as feedstock or commodity. Loss variables for all non-dissipated flows, including by-products and residues, are part of the model.

The trade variable 'net-import' expresses to what extent the required supply of a particular product within a region is met by net-import from another region. The model does not contain specification of trade between all eight regions, that is to say, it is not specified from which region(s) the net-import to a particular region occurs.[80] Trade of by-products and residues is not included in the model.

## 2.7 ASSIGNMENT AND USE OF INTERNAL BY-PRODUCTS AND RESIDUES

As described in Section 2.1 (p. 13), a main feature of the FPD model is its comprehensive description of all major by-products and residues in the food system. This description involves all significant process steps in generation, handling and use, and is based on mass and energy balances over each of these processes.

Many of these by-products and residues may be of use for various purposes within the food system, for example as feed for animals. In the real system, such *internal* uses of by-products and residues do occur to a considerable extent. However, quite often the use clearly falls below the available amount. We see at least two reasons for this.

First, there are limitations due to the prevailing technological and economic conditions. For example, a crucial factor for the economics of the internal use is the geographical

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[79] For obvious reasons, dissipated flows, such as heat and gases, are not of relevance in this context.

[80] This means that the model does not differentiate between the region-domestically produced flow and the corresponding imported flow. For the sum of the imported and the domestic flow, the chemical composition of the latter is used since, in most cases, this is the dominating one of the two. This means that in cases where the composition of the imported flow is different from the domestic one, mass and energy balances are not fully maintained. However, if the differences in chemical composition are small, or the trade flow amounts to a small share of total supply, the losses in mass and energy balance consistency are small.

pattern of producers and users. This applies in particular to by-products with relatively low economic value, such as cereals straw and stover.

Second, there are competing, alternative uses of the by-products and residues in other systems than the food system. For instance, in many non-industrial regions, there is a substantial use of crop by-products and manure as fuel. Also, use of these by-products as materials (as building materials, as raw material, etc) is significant in many regions.

In the FPD model, such limitations for internal use, that is, use within the food system, are represented by the by-products & residues assigning variables. These assignment variables express limitations in the internal use of by-products and residues with respect to technological and economic restrictions as well as competing uses. The amount assigned for a certain purpose expresses the amount *maximally* available for this purpose. This amount is not to be confused with the amount *actually used*, which may be lower than the amount assigned due to circumstances in the using activity. Thus, the assignment variable expresses only the *prerequisites* for making by-products and residues *available* for a certain activity.

# 3 BIOMASS TURNOVER IN THE FOOD SYSTEM 1992-94

The purpose of this chapter is to present an estimate of the biomass metabolism in today’s food system. The principal background to and the major reasons for carrying out this estimate were described in Chapter 1. The main issues that this study is intended to answer are:

- What is the total appropriation of terrestrial phytomass for the purpose of human food? How large is it in relation to other societal uses biomass?
- What is the relative importance of different phytomass categories in this respect? For instance, how large amount of phytomass comes from grassland compared to cropland? How important are cereals?
- How efficient is the use of the appropriated phytomass? How much of it ends up as food eaten? How large are the differences in efficiencies between individual food commodities?
- What is the relative influence of different food commodities on the phytomass appropriation? Which food commodity end-uses induce the largest phytomass appropriation?
- Which influence has trade on the regional phytomass appropriation?
- Which difference does internal use of by-products, such as crop residues, make to lessen the demand of phytomass production?
- How much of usable by-products and residues does the food system deliver as surplus?
- Are there significant differences between regions in the respects mentioned above?

The FPD model, described in the previous chapter, was the major tool in the study of the food system’s biomass metabolism. In essence, this study is a mass and energy balance analysis of the terrestrial food-driven phytomass production and its derivatives, including zoomass. This mass and energy balance was achieved by means of the FPD model.

The study includes all terrestrial above-ground phytomass production induced by food end-use, including pasture and animal forage crops. For underground crops, such as tubers, the whole plant phytomass is included. Although related to the food system, this study does *not* include phytomass required for draft work performed by draft animals or other livestock.

Formally, the study refers to year-average for the time period 1992-1994. An average for several years was chosen in order to reduce possible yearly variations which have no relevance to the intentions of this study. Due to data limitations, however, not all data used in the study refer to this specific time period. Therefore, it is more adequate to denote the study’s time reference point as the early 1990s.

Necessary model input data were to a great extent not available directly in the literature. Therefore, a large part of the work in performing this study was dedicated to prepare model input data from the data actually available. This preparatory work produced figures which, in some cases, in themselves are interesting results. This kind of results is presented in the corresponding sub-sections of Section 3.1 below.

In the first section of this chapter, we describe data sources and procedures for preparing data to the particular form required for the FPD model. In the following section, we present major results from the model calculation. In the last section, we discuss accuracy, significance and relevance of these results.

## 3.1 DATA SOURCES, DATA PREPARATION AND CALCULATION PROCEDURES

The purpose of this section is to specify data sources, assumptions made and calculation procedures used in the study. Basically, there is one section describing each principal part of the model system. There is also one section dealing with the internal assignment of by-products and residues generated in the food system.

In this study, data sources are a combination of FAOSTAT[81] data and other sources. Most of the other data sources were retrieved by carrying out searches in data bases, among others CAB Abstract. Largely, the data were of secondary or tertiary kind.

The effort to retrieve data, besides those data provided through FAOSTAT, varied between the different areas of the study. First priority was given to obtain data on those parts of the system which were believed to be the main determining factors in the system: productivity and efficiency of animal food production, animal feed use, internal use of by-products and residues, as well as harvest indices for crops. Less intensive efforts to retrieve data were made for production of converted vegetable food commodities and grazing. The least efforts were made for the other areas of the study. In part, this variation in data collection efforts was also due to the fact that some of the data were more or less directly available from FAOSTAT. This applies to data on food end-use per capita, trade, and distribution and storage losses.

The most important source of data was FAOSTAT. In a number of ways, this study’s estimates of the biomass flows in the food system relied most substantially on this database. For example, FAOSTAT was the sole basis for the values on food end-use per capita (Section 3.1.1 below) and the values on trade and distribution & storage losses (Section 3.1.5, p. 98) used in this study. It was also a main keystone for the assumptions on the productivity and feed energy requirements of the animal food systems, as well as for the estimates of some elements of the animal feed use (see Section 3.1.2, p. 66). To

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[81] FAOSTAT is a statistical database provided by the Food and Agriculture Organization of United Nations (FAO). Excerpts from FAOSTAT are available at http://apps.fao.org. The FAOSTAT PC-disks version, released in 1996, was used in this study.

some extent, FAOSTAT was also relied on for the estimates on the efficiency in the vegetable food processing (Section 3.1.3, p. 89).

It might be argued that the fruitfulness of such a considerable reliance to FAOSTAT is doubtful since, indeed, FAOSTAT is not a database without errors and pitfalls.[82] In fact, we experienced that ourselves in this study. The FAOSTAT figures we used were data on PC disks released in 1996. However, in this release, the Food Balance Sheet (FBS) domain did not have figures for all elements for the 15 countries of the former USSR (exceptions were food per capita supply, among others). Complete data for these countries (for the year 1992 and onwards) were included in the FBS domain first in the 1998 release.[83] Unfortunately, this did not come to our knowledge until at a rather late stage, and there were no time for remaking the model calculations using the 1998 release, or a more recent release, of FAOSTAT data.[84] Since the former USSR comprised some relatively large countries, it is clear that this entails a most considerable loss in significance of the results of this study. The influence on the results for specific system parts and regions is further discussed in the section 'Impact of revisions and accuracy of FAOSTAT data' (p. 179).

The errors of FAOSTAT, and the lack of explanatory information accompanying the statistics, are indeed arguments against relying heavily on FAOSTAT data. However, in our opinion, there are also some general arguments in favor. FAOSTAT is the sole worldwide and publicly available database for agriculture, for one thing. To achieve a basis for deviating from FAOSTAT would require a data-gathering effort far beyond the scope of this study. Moreover, a consistent matching with FAOSTAT data makes the model calculation easier to verify or refute by others — thus, it makes the model calculation more transparent. The value of the latter was, unfortunately, substantially diminished on account of the missing data for the former USSR.

In most cases, data were not available for the particular regional structure used in the FPD model. When compiling region-specific values from FAOSTAT, values from only a limited number of countries in each region were included. These selected countries, 83 in number in comparison with the world total of about 220, make up 95 percent of the total world population, and between 87 to 99 percent on a regional basis, see Table 3.1. This range in representation was considered high enough to produce region-specific values with reasonable accuracy.

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[82] Smil [1999b] points out several sources of errors in the FAO statistics on crop production; for example, this statistics do not take into account home gardens and backyard plots. In Smil [1994] are given examples of sources of errors in the FAOSTAT Food Balance Sheets. For example, it is claimed that nearly 70% of all figures used in constructing national balance sheets are estimated in FAO's Rome headquarters, while only 30% are supplied directly by the member states.

[83] Details regarding the revision were obtained through personal communication with E. Gillin, Statistics Division, Economic and Social Department, FAO (November 20, 1999).

[84] It may be noted that at the time of our purchase of the 1996 release of the statistics, FAO did not bother to include any information regarding the missing data for former USSR.

**Table 3.1** Regional structure in this study.[a]

**East Asia**
*83-countries (99%):*
Cambodia
China
Hong Kong
Indonesia
Japan
Korea DPR
Korea Rep.
Malaysia
Myanmar/Burma
Philippines
Thailand
Viet Nam
*Other countries:*
Laos
Mongolia
Singapore
(+ 3 small states)

**East Europe**
*83-countries (91%):*
Belarus
Bulgaria
Czech Rep.
Greece
Hungary
Poland
Romania
Russian Federation
Ukraine
Yugoslavia
*Other countries:*
Albania
Bosnia-Herzegovina
Croatia
Estonia
Latvia
Lithuania
Macedonia, FYR
Moldova Rep.
Slovakia
Slovenia

**Latin America & Caribbean**
*83-countries (87%):*
Argentina
Brazil
Chile
Colombia
Cuba
Ecuador
Guatemala
Mexico
Peru
Venezuela
*Other countries:*
Bolivia
Costa Rica
Dominican Rep.
El Salvador
Haiti
Honduras
Jamaica
Nicaragua
Panama
Paraguay
Puerto Rico
Uruguay
(+ 24 small states)

**North Africa & West Asia**
*83-countries (88%):*
Algeria
Egypt
Iraq
Israel
Morocco
Saudi Arabia
Sudan
Syrian Arab Rep.
Tunisia
Turkey
Yemen
*Other countries:*
Armenia
Azerbaijan
Georgia
Jordan
Lebanon
Libyan Arab Rep.
Oman
United Arab Emirates
(+ 6 small states)

**North America & Oceania**
*83-countries (97%):*
Australia
Canada
United States of America
*Other countries*
New Zealand
Papua New Guinea
(+ 24 small states)

**South & Central Asia**
*83-countries (99%):*
Afghanistan
Bangladesh
India
Iran
Kazakhstan
Nepal
Pakistan
Sri Lanka
Uzbekistan
*Other countries:*
Kyrgyzstan
Tajikistan
Turkmenistan
(+ 2 small states)

**Sub-Saharan Africa**
*83-countries (88%):*
Angola
Burkina Faso
Cameroon
Côte d'Ivoire
Dem. Rep. of the Congo
Ethiopia
Ghana
Kenya
Madagascar
Malawi
Mali
Mozambique
Niger
Nigeria
Somalia
South Africa
Uganda
United Rep. Tanzania
Zambia
Zimbabwe

**Sub-Saharan Africa (ctd)**
*Other countries:*
Benin
Burundi
Central Afric Rep.
Chad
Congo
Eritrea
Guinea
Lesotho
Liberia
Mauritania
Rwanda
Senegal
Sierra Leone
Togo
(+ 13 small states)

**West Europe**
*83-countries (91%):*
Belgium
France
Germany
Italy
Netherlands
Portugal
Spain
Sweden
United Kingdom
*Other countries:*
Austria
Denmark
Finland
Ireland
Norway
Switzerland
(+ 11 small states)

Countries listed under the heading '83-countries' are those which were used for compilation of region-specific values from FAOSTAT. Percentage numbers refer to the degree of representation, in terms of share of each region's population, by those countries (see text for further explanations).

[a] Throughout this study, the categories 'industrial regions' and 'non-industrial regions' are used as a label of groups of regions. (These designations may also be interpreted as 'high-income' and 'low-income',

*Notes continue on next page.*

respectively.) North America & Oceania and West Europe were included among the industrial regions and the other regions, except East Europe, among the non-industrial regions. East Europe was considered as transitionary with respect to industrialization and income, and is not classified among any of the groups.

### 3.1.1 Population and food use per capita

Population

Values on population were prepared directly from FAOSTAT (see Table 3.2).

**Table 3.2** Population in this study.

| | East Asia | East Europe | Latin America & Caribb. | North Africa & West Asia | North America & Oceania | South & Central Asia | Sub-Saharan Africa | West Europe |
|---|---|---|---|---|---|---|---|---|
| Total population | 1 864 | 355 | 465 | 309 | 314 | 1 325 | 536 | 371 |

Average in millions for the years 1992-94. Compiled from FAOSTAT.

Food end-use per capita

As described in Section 2.2.1 (p. 20), the FPD model includes both the variables ‘food intake per capita’ and ‘food end-use per capita’. Food intake refers to the amount of food actually eaten, whereas food end-use basically refers to the amount of food supplied on the wholesale level.

As values for food end-use per capita we used the values on ‘per caput supply’ in the FAOSTAT Food Balance Sheets (FBS). The structure of the food use vector in the FPD model (that is, the flows which represent food use in the FPD model, see Table 2.2, p. 22) is similar to the structure of flows in the FBS — however, they are not altogether identical. Therefore, to some extent, the values on per capita supply in the FBS had to be interpreted and translated into model end-use values. In Table 3.3 a partial list of these resulting model end-use values is given.

In the interpretation of the FBS data into model end-use values, the *main* principle was to use the stated value in the FBS on *per capita supply* in *metabolizable energy* (ME) for the *corresponding* flow in the FPD model.

For all commodity *categories*, except ‘meat & fat’, ‘milk’ and ‘fish & seafood’ (see further below), in the FPD food use vector, ME values on end-use per capita were taken directly from the ME values for the corresponding category in the FBS. Hence, for the FPD categories ‘cereals’, ‘starchy roots’, ‘sweeteners’, ‘oil crops’, 'vegetable oils’, 'tree nuts’, ‘pulses, ‘vegetables’, ‘fruits’. stimulants’, ‘alcoholic beverages’ and ‘offals’,

**Table 3.3** Selection of values on food end-use per capita in this study.

| Commodity | Unit | East Asia | East Europe | Latin America & Carib. | North Africa & W. Asia | North America & Oc. | South & Central Asia | Sub-Saharan Africa | West Europe |
|---|---|---|---|---|---|---|---|---|---|
| **All commodities** | ME | 11.0 | 13.2 | 11.7 | 12.5 | 15.1 | 9.9 | 9.1 | 14.3 |
| | GE | 12.8 | 15.9 | 14.0 | 14.9 | 18.6 | 11.4 | 11.2 | 17.6 |
| | DW | 240 | 290 | 250 | 280 | 320 | 220 | 220 | 300 |
| | AW | 520 | 920 | 630 | 610 | 1 050 | 410 | 510 | 1 120 |
| *All vegetable commodities* | ME | 89% | 72% | 82% | 90% | 67% | 93% | 94% | 68% |
| Cereals | ME | 64% | 43% | 38% | 58% | 22% | 66% | 47% | 25% |
| Wheat | ME | 17% | 40% | 14% | 43% | 17% | 26% | 7.2% | 22% |
| Rice | ME | 40% | 1.2% | 10% | 5.4% | 2.0% | 34% | 7.8% | 1.4% |
| Maize | ME | 6.7% | 1.4% | 14% | 6.0% | 2.5% | 2.8% | 24% | 1.3% |
| Sorghum | ME | 0.5% | 0.1% | 0.0% | 3.7% | 0.0% | 3.2% | 8.5% | 0.0% |
| Starchy roots | ME | 4.8% | 6.8% | 4.0% | 2.0% | 2.9% | 1.8% | 20% | 4.3% |
| Cassava | ME | 0.8% | 0.0% | 2.1% | 0.1% | 0.0% | 0.4% | 18% | 0.0% |
| White potato | ME | 0.9% | 6.8% | 1.7% | 1.9% | 2.8% | 1.2% | 0.6% | 4.3% |
| Sweet potato | ME | 3.1% | 0.0% | 0.2% | 0.0% | 0.1% | 0.1% | 1.3% | 0.0% |
| Sweeteners | ME | 4.3% | 11% | 17% | 9.2% | 17% | 8.8% | 4.3% | 11% |
| Vegetable oils | ME | 5.5% | 6.5% | 11% | 10% | 13% | 7.0% | 7.8% | 14% |
| Alcoholic beverages | ME | 2.1% | 3.9% | 2.5% | 0.3% | 4.4% | 0.2% | 2.3% | 6.0% |
| Other vegetable com.[a] | ME | 7.8% | 4.9% | 10% | 10% | 9.2% | 9.3% | 12% | 9.4% |
| *All animal commodities* | ME | 11% | 28% | 18% | 9.8% | 33% | 7.5% | 6.1% | 32% |
| Meat & fat | ME | 6.5% | 10% | 9.0% | 3.2% | 17% | 1.6% | 3.1% | 14% |
| | AW | 28 | 57 | 48 | 20 | 110 | 7.2 | 13 | 81 |
| Ruminant | ME | 0.8% | 3.8% | 4.7% | 2.0% | 6.5% | 1.2% | 2.0% | 3.9% |
| | AW | 4.0 | 23 | 26 | 12 | 46 | 5.5 | 8.6 | 26 |
| Pig | ME | 4.7% | 5.3% | 1.8% | 0.0% | 5.3% | 0.1% | 0.5% | 7.5% |
| | AW | 18 | 24 | 7.1 | 0.0 | 27 | 0.4 | 1.5 | 37 |
| Poultry | ME | 1.0% | 1.4% | 2.5% | 1.2% | 4.9% | 0.2% | 0.6% | 2.3% |
| | AW | 6.1 | 10 | 16 | 8.1 | 40 | 1.3 | 2.9 | 18 |
| Offals | ME | 0.2% | 0.4% | 0.4% | 0.2% | 0.4% | 0.1% | 0.2% | 0.4% |
| | AW | 2.1 | 4.6 | 4.3 | 2.1 | 5.2 | 1.1 | 1.7 | 5.8 |
| Milk | ME | 1.0% | 14% | 7.2% | 5.4% | 13% | 5.2% | 1.9% | 15% |
| | AW | 14 | 250 | 110 | 88 | 270 | 68 | 22 | 290 |
| Eggs | ME | 1.3% | 1.5% | 1.0% | 0.6% | 1.3% | 0.3% | 0.3% | 1.4% |
| | AW | 9.7 | 13 | 7.6 | 4.5 | 13 | 1.8 | 1.7 | 14 |
| Fish & seafood[b] | ME | 1.6% | 0.9% | 0.8% | 0.4% | 0.8% | 0.3% | 0.6% | 1.5% |
| | AW | 20 | 14 | 11 | 5.6 | 15 | 3.8 | 6.4 | 25 |

For ‘all commodities’ the ME and GE values are given in MJ/capita & *day*, and the dry weight (DW) and the as-is weight (AW) values in kg/capita & *year*. For all other flows stated, the ME values are given as *share* (in percent) of the total ME per capita (that is, of the ME of ‘all commodities’). The as-is weight of each of the animal food commodities is the mass (in kg as-is/capita & year), *of the representing model flow*, corresponding to the ME end-use specified in the table. Thus, for ‘milk’ and ‘eggs’, the weight values refer to the weight of cattle whole (producer) milk and chicken whole egg respectively (composition is specified in Table A1.II, Appendix 1). For ‘ruminant meat’, the as-is weight refers to the weight of *beef cattle* carcass; for ‘pig meat’, to the weight of pig *carcass-side*; for ‘poultry meat’, to the weight of *meat-type chicken* carcass — for the *average* composition of these flows in each region (as

*Notes continue on next page.*

further described in Section 3.1.2 below, partition and composition of individual animals vary considerably — see also the definitions and values on composition of carcasses in Appendix 1.)

[a] Includes oil crops, tree nuts, pulses, vegetables, fruits and stimulants.

[b] System-external input (see Section 3.1.7, p. 103).

the regional ME values on end-use per capita in this study are identical to the compiled regional ME values on per capita supply in the FBS.

For the *representing commodities* in the FPD food use vector, the *relative proportions within each category* are equivalent to those of the corresponding commodities in the FBS. Since there are fewer commodities representing each category in the FPD food use vector than there are commodities belonging to each category in the FBS, the value in this study on end-use per capita for an individual representing commodity is higher than for the corresponding commodity in the FBS. However, the *relative* proportions on ME basis between the representing commodities within each category in the food use vector, are the same as the *relative* proportions on ME basis between the corresponding commodities in the FBS.

To further describe this, let us consider the category ‘cereals’. In the FPD food use vector, cereals are represented by four flows: ‘wheat straight flour’, ‘white rice’, ‘maize grits', 'meal & flour’ and ‘sorghum grits, meal & flour’. In this study, the *relative* proportions of the ME end-use values for these four flows are the same as the *relative* proportions of the ME values for ‘wheat’, ‘rice’, maize’ and ‘sorghum’ in the FBS.

The corresponding applies to the commodity categories ‘starchy roots’, ‘sweeteners’, ‘oil crops’, ‘vegetable oils’ and ‘meat & fat’ — in the latter case, however, on *as-is weight* basis instead of ME basis (see below). (It should also be noted that because of the construction of the FDP model, the value of end-use per capita in this study of the sub-category ‘ruminant meat’ corresponds to the *sum* of the weight values in the FBS for ‘bovine’ and ‘sheep/goat’ meat.)

The above-mentioned main principle was diverged from in the following cases:

- Milk end-use values were matched with *production* values (from FAOSTAT ‘Livestock Primary’) instead of the per capita supply values in the FBS.
- Meat & fat end-use values were matched with the *as-is weight* values instead of the ME values in the FBS.
- The FBS flow ‘animal fat, raw’ was represented by the FPD flows in the category ‘meat & fat’
- The FBS flows ‘fish, body oil’ and ‘fish, liver oil’ were represented by the FPD flow ‘fish & seafood’.

In the FDP model, milk end-use is represented by one flow, ‘whole milk’, that is, milk at the producer (farm) level. In contrast, the FBS contains several milk commodities of processed kind, such as milk ready-to-drink, butter, ghee and cream. Milk processing into products such as butter and cheese involves considerable losses, mainly in the form of generation of various by-products, such as whey. At the most, such losses amount to roughly 70 percent on a dry matter basis. Using the ME value in the FBS on milk supply per capita as ME value for the milk end-use in the FPD model would, therefore, give as a result that the model underestimates the production of whole milk. In order to avoid such an underestimate, the milk end-use per capita in the FPD model was set so that accordance was obtained with the level of *production of whole milk* in each region. As level of production on whole milk was taken the data in the FAOSTAT data collection 'Livestock Primary' (in the domain 'Agricultural Production').

The values on end-use of meat & fat in the FPD food use vector were matched with the values in the FBS on supply per capita in *as-is weight* instead of ME for reasons similar to the case with milk. In the FBS, the primary unit for the data is as-is weight. As a general rule, data on meat are expressed in terms of carcass weight. The ME values in the FBS are produced by applying ME content factors for each commodity in the balance sheet. For commodities which are not consumed in the form in which they are presented in the FBS — for instance, commodities which are further processed before consumption — these ME factors reflect both the ME content of the product actually consumed and the extent and characteristics of the processing. For carcass, for instance, the ME factor reflects the degree of consumption of lean and fatty tissue respectively. This means that the ME factors may diverge substantially from those valid for the *actual ME density* of the primary commodity as displayed in the FBS. Since the FPD model represents meat end-use by carcass, we assumed that a matching against the weight values instead of ME values in the FBS would produce more accurate model estimates of the meat end-use.

The same apply to other commodities which are subject to processing involving losses or changes in composition and where the corresponding representing flows in the FPD model are not processed flows. Some oil crops and pulses, for instance soybean, are to a great extent processed into more refined products. In this study, such possible processing were implicitly taken into account by using the same ME factors as those in the FBS. This was done for the FPD flows representing the categories 'tree nuts', 'pulses', 'vegetables', 'fruits', 'stimulants', and 'fish & seafood' (see Table 2.2, p. 22). For these flows, the *global average* ME factor in the FBS (on *as-is weight* basis) for the corresponding flow was used in all regions (ME values are given in Appendix 1). This means that the values on the *production* of these flows in the FPD model reproduce the values of production of corresponding flows in the FBS (on a *global, as-is weight* basis).

In this study, the FBS flow 'animal fat, raw' was entirely interpreted as a part of the carcass. The end-use of raw animal fat was represented by ruminant carcass and pig carcass, but not poultry carcass, assuming that raw animal fat production from poultry is negligible. This interpretation is probably not quite accurate, since at least some raw animal fat rather is a by-product to the carcass, given the carcass definitions customary in many regions. We discuss this issue further in the section ‘End-use per capita and level of production’ (p. 188).

Finally, the fish oil flows in the FBS were included under the FPD flow ‘fish & seafood’ since the FPD model does not contain any description of fish processing.

### Food intake per capita

There exist much less data on actual intake of food per capita than for supply per capita, mainly because of the fundamental difficulties and costs for achieving such data. In fact, for the majority of the world population, the actual food intake is not known with satisfactory accuracy.[85] These circumstances are the chief reasons behind the fact that essentially all statistics on food consumption refer to the supply at the wholesale level, and not to the actual food intake.

Due to this lack of data, as values on food intake per capita we used estimates of daily *food energy requirements* instead of data on true food intake. Such physiological energy requirements can be calculated in detail from values on weight, height, activity levels, pregnancy allowances and so forth. In this study, however, no more than rough estimates for each region were used. As a general figure for the industrial regions North America & Oceania and West Europe, the national average for Sweden was taken.[86] Values for other regions were adjusted so that the total global value agreed with the global average calculated by the World Hunger Program.[87] This simple approach was considered satisfactory since the driving variable in the FPD model is end-use; the level of intake only affects the division between the residues ‘non-eaten food’ and ‘human

**Table 3.4** Assumed food intake per capita in this study.

| | Unit | East Asia | East Europe | Latin America & Carib. | North Africa & W. Asia | North America & Oc. | South & Central Asia | Sub-Saharan Africa | West Europe |
|---|---|---|---|---|---|---|---|---|---|
| Total intake (total for all commodities) | ME | 8.4 | 9.2 | 8.7 | 9.0 | 9.3 | 8.1 | 7.9 | 9.3 |
| Total intake as share of total end-use (average for all commodities) | ME basis | 0.76 | 0.70 | 0.74 | 0.72 | 0.61 | 0.81 | 0.87 | 0.65 |
| | DM basis | 0.72 | 0.65 | 0.69 | 0.68 | 0.55 | 0.78 | 0.79 | 0.58 |

Total food intake per capita in MJ ME per capita and day. The values on share of end-use on DM basis were calculated in the FPD model.

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[85] [Smil 1994, pp. 260-261]

[86] The average energy requirement for the entire Swedish population amounted to 9.3 MJ ME/capita & day (in 1980) [Becker & Jonsson 1985].

[87] The World Hunger Program prepared estimates on physiological energy requirements for approximately 130 countries, obtaining a global mean of 8.4 MJ ME/capita & day (Bender [1993] quoted in Smil [1994]).

feces & urine' respectively (see Section 2.2.1, p. 21). The resulting regional values on total food intake per capita, and on total intake as share of total end-use, are shown in Table 3.4.

These values of energy requirements provided the basis for the assumed values on *total* intake per capita only, that is, the intake of the sum of *all* food commodities. Assumptions on the intake for each *separate* food flow were based on studies on food losses on retail and consumer levels, complemented with own simplifying assumptions.[88]

**Table 3.5** Assumed intake of separate commodities and parts of commodities in this study.

| Commodity and commodity part | All regions excluding Sub-Saharan Africa | Sub-Saharan Africa |
|---|---|---|
| Cereals | 1.00 | 1.00 |
| Starchy roots flesh | 1.00 | 1.00 |
| Starchy roots skin | 0 | 0 |
| Sweeteners | 1.00 | 1.00 |
| Vegetable oils | 0.90 | 0.90 |
| Alcoholic beverages | 1.15 | 1.10 |
| Oil crops seeds & kernels | 1.15 | 1.10 |
| Tree nuts, pulses and stimulants | 1.15 | 1.10 |
| Vegetables and fruits | 1.10 | 1.10 |
| Carcass lean tissue | 1.15 | 1.10 |
| Carcass fatty tissue | 0.85 | 0.90 |
| Offals | 1.15 | 1.10 |
| Milk | 0.90 | 0.95 |
| Egg yolk & white | 1.05 | 1.05 |
| Fish & seafood | 1.15 | 1.10 |

Values refer to intake as share of end-use *relative to the average share* as stated in Table 3.4 above. All values are on DM basis, except those for 'tree nuts, pulses and stimulants', 'vegetables', 'fruits', 'offals' and 'fish' which are on ME basis. Oil crops husks, carcass bones and egg shells have the value zero. (See Table 2.2, p. 22 for details regarding partition of food commodities.)

The assumed values for this study are shown in Table 3.5. Owing to the poor data basis, we did not find any basis for assuming large differences between the different flows. Thus, in order to avoid unsupported discrimination of any of the flows, we chose a more careful approach, assuming rather small differences. Neither did we find that there was

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[88] Kantor et al. [1997] estimated food loss on retail, food service and consumer levels in the USA in 1995. Losses of processed foods (such as processed fruit and vegetables), dry foods (such as dry pulses), and meat and fish were estimated to be substantially lower (about 15% units lower, on edible supply basis) than for other foods. These values formed the basis for the assumptions on intake as share of end-use in this study. In addition, for meat, we assumed a lower intake of fatty tissue relative to lean tissue since fatty tissue is less preferred. We also assumed a slightly lower relative intake of vegetable oils since it is likely that a larger relative loss occurs when used in frying and similar.

any ground for assuming different values for each region. The slightly different values for Sub-Saharan Africa are merely a consequence of that region's high average intake relative to end-use.

Since the FPD model includes specification of the chemical composition of each flow, the diet at intake and end-use can be described in terms of nutritive components. In order to give a rough picture of some nutritive aspects of the diets in each region, values on intake by major nutrients were calculated, see Table 3.6. It should be observed that these values are our estimates based on the stated end-use per capita and the assumed composition values and, more importantly, our assumptions on the food intake per capita in each region.

**Table 3.6** Estimated values on food intake by nutrient.

| Nutrient | Unit | East Asia | East Europe | Latin America & Carib. | North Africa & W. Asia | North America & Oc. | South & Central Asia | Sub-Saharan Africa | West Europe |
|---|---|---|---|---|---|---|---|---|---|
| Protein | DW | 59 | 73 | 58 | 59 | 73 | 51 | 44 | 75 |
| | ME | 12% | 14% | 11% | 11% | 13% | 11% | 9.4% | 14% |
| Vegetable protein | DW | 41 | 34 | 30 | 45 | 23 | 42 | 35 | 26 |
| | ME | 70% | 46% | 53% | 76% | 31% | 82% | 80% | 35% |
| Animal protein | DW | 18 | 39 | 28 | 14 | 50 | 8.9 | 9.2 | 49 |
| | ME | 30% | 54% | 47% | 24% | 69% | 18% | 20% | 65% |
| Fat | DW | 34 | 59 | 53 | 45 | 83 | 30 | 31 | 84 |
| | ME | 15% | 24% | 23% | 18% | 33% | 13% | 15% | 33% |
| Carbohydrate | DW | 350 | 320 | 330 | 370 | 270 | 360 | 350 | 270 |
| | ME | 71% | 60% | 64% | 70% | 50% | 76% | 74% | 48% |
| Alcohol | DW | 4.7 | 9.7 | 5.8 | 0.7 | 11 | 0.4 | 4.6 | 15 |
| | ME | 1.6% | 3.1% | 1.9% | 0.2% | 3.5% | 0.2% | 1.7% | 4.7% |

Values calculated by means of the FPD model for the assumed values on end-use per capita (Table 3.3) and intake per capita (Table 3.4 and Table 3.5) and composition (Table A1.II, Appendix 1). Dry weight (DW) values are given in gram/capita & day. ME values are given as *share* of the *total ME* intake per capita (Table 3.4), except for vegetable and animal protein which are given as share of *total protein ME*.

## Nutrient densities data

All values on composition, such as, GE, human ME, and so forth, of all flows in this study are given in Appendix 1. Most of the composition values pertaining to food commodities were taken from standard tables of food composition.[89]

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[89] For example, Holland et al. [1991].

Generation and recovery of residues

As we described in Section 2.2.1 (p. 21), the amount of residues generated from food use is in essence determined by the values of the end-use, intake, and composition. The only variable of significance remaining to be quantified is the recovery rate for the generated residues (for definition of ‘recovery rate’, see Section 2.1.6, p. 19). For both non-eaten food and human feces & urine, the recovery rate was set equal to 90 percent. This is only a very rough figure, based on the simple assumption that some losses always occur, which means that not all residues can be entirely recovered.

### 3.1.2 Production of animal food

Owing to the rather detailed modeling of the animal food sector, this section is more comprehensive than other sections. It contains two major parts. The first one deals with estimates of the *productivity* of the animal food sub-systems, as well as with estimates of the *feed energy requirements* corresponding to these productivity estimates. The second part deals with estimates of the *required intake of feed matter* complying with the estimated feed energy requirements. In the end of the section, there are three smaller parts dealing with processing of feeds, use of litter for animal bedding, and generation and recovery of by-products including methane from enteric fermentation.

As already mentioned in the beginning of this chapter, this study does not include phytomass required for draft work performed by draft animals or other livestock. Possible levels on feed use for draft power are briefly touched upon in the section ‘Feed use’ (p. 213).

Productivity and specific feed energy requirements

This section leads up to estimates of *specific* feed energy requirements, here defined as the feed energy requirements per *unit of commodity generated*, for each animal food sub-system included in this study. These estimates of the specific feed energy requirements were made with the FPD model, and were based on matching with available FAOSTAT data on animal food productivity.

Grazing significantly increases the maintenance energy requirement as compared to animals in confinement. This section also includes estimates of the extra energy expenditures at grazing for different pasture qualities.

*Productivity and efficiency data*

Generally speaking, data on animal food productivity and efficiency are limited, and in many cases also ambiguous and inadequate (the latter was briefly illustrated in Section 1.2, p. 5). Studies of efficiency on a system level, that is, including all relevant inputs and outputs for all animal categories, are extremely rare, especially on the international level. The majority of data available with some bearing on efficiency refer to more basic productivity parameters. This deficiency of adequate data on efficiency was a major reason behind the relatively large effort in this study to achieve consistent estimates of the specific feed energy requirements for different animal sub-systems as well as different regions.

**Table 3.7** Productivity parameters available in FAOSTAT for animal sub-systems included in this study.[a] Average per year for 1992-1994.

| Livestock group | East Asia | East Europe | Latin America & Carib. | North Africa & W. Asia | North America & Oc. | South & Central Asia | Sub-Saharan Africa | West Europe |
|---|---|---|---|---|---|---|---|---|
| **Cattle** | | | | | | | | |
| Production of milk per number of *dairy cows* in stock | 2 227 | 2 403 | 1 108 | 1 036 | 6 685 | 976 | 429 | 5 248 |
| Offtake (number slaughtered per number of cattle in stock) | 16% | 39% | 17% | 19% | 34% | 9,2% | 14% | 36% |
| Average carcass weight all slaughtered animals | 182 | 171 | 194 | 141 | 290 | 126 | 137 | 278 |
| Production of carcass per number of cattle in stock | 29.7 | 67.0 | 32.9 | 26.2 | 99.5 | 11.6 | 18.6 | 101 |
| Production of milk per number of cattle in stock | 130 | 940 | 142 | 375 | 619 | 180 | 71.2 | 1 141 |
| **Pig** | | | | | | | | |
| Offtake (number slaughtered per number of pigs in stock) | 106% | 107% | 63% | 114% | 161% | 96% | 80% | 157% |
| Average carcass weight all slaughtered animals | 74 | 78 | 68 | 62 | 82 | 42 | 48 | 85 |
| Production of carcass per number of pigs in stock | 78.4 | 82.8 | 43.2 | 70.6 | 132 | 40.7 | 38.0 | 134 |
| **Poultry** | | | | | | | | |
| Production of carcass per number of poultry in stock | 2.34 | 2.70 | 4.66 | 3.20 | 7.56 | 1.58 | 1.99 | 7.06 |
| Production of eggs per number of poultry in stock | 3.76 | 3.91 | 2.59 | 2.30 | 2.61 | 2.49 | 1.84 | 5.26 |

Values on annual basis. All values in kg as-is, except offtake (percent). According to FAOSTAT explanatory notes, cattle and pig meat production figures refer to dressed carcass, excluding offals and slaughter fat. For poultry meat, values are given in ready-to-cook weight. Milk production figures relate to production of whole fresh milk, excluding milk sucked by young animals.

[a] These figures are directly available, or may be directly calculated, from data in the 1996 release of the PC-version of FAOSTAT, which was used in this study. It should be observed that additional productivity data are accessible at the current on-line version of FAOSTAT (available at http://apps.fao.org), among others, egg production per laying chicken hen, and carcass weight for meat-type chicken (broiler) — these additional data were not taken into consideration in this study.

The FAOSTAT data collection ‘Livestock Primary’ (domain ‘Agricultural Production’) contains data over the total number of animals of each major animal category, that is, the total stock of animals. It also contains data on the produced amount of meat, milk and eggs. For some animal categories, the number of animals slaughtered is also given. From these figures, values on offtake, carcass weight, and production per head (that is, the production per number of animals in stock) for the animal sub-systems related to those included in this study were calculated, see Table 3.7.

*Estimates of productivity*

As we described in Section 2.3.1 (p. 26), the FPD model contains a detailed description, in a set of ‘base parameters’, of the characteristics of each principal animal category in each animal sub-system. For each animal sub-system, these descriptions enable calculation of the number of animals in stock and the number of animals slaughtered, corresponding to a certain level of production (of carcass and/or milk or egg). Thus, for each set of values on the base parameters, offtake and carcass weight, as well as production per head in the sub-system can be calculated.

In this study, the model values on offtake, carcass weight and production per head for the model animal sub-systems were *exactly matched* with those compiled from FAOSTAT for the analogous animal systems, that is, the values in Table 3.7. This means that the values on the base parameters were tuned so that the values on offtake, carcass weight and production per head in the model agreed with those of FAOSTAT. By this matching procedure, for each animal sub-system and region, a uniform link was obtained between the productivity statistics pertaining to the region and the estimate of the specific feed energy requirements for the region.

Obviously, different combinations of values on the base parameters for each of the sub-systems may give identical values on offtake, carcass weight and production per head. Therefore, data were gathered regarding normal ranges of the base parameters in the different regions. Figures from a variety of sources were used for assuming values within appropriate ranges for each animal sub-system and region.[90] The exact values were settled in the tuning procedure with the FAOSTAT values. In Table 3.8 below, a list of the resulting values on the major base parameters is shown.

For cattle, separate data for dairy and beef cattle were not available in FAOSTAT. Therefore, the tuning of the base parameters for the ‘cattle milk’ sub-system and the

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[90] The following references were the most important in terms of extent and level of detail. Simpson et al. [1994, pp. 186, 203, 240, 359], as well as Simpson & Li [1996], give detailed information of the Chinese livestock systems, and were used as major sources for the East Asia region. OTA [1992, p. 138] contains performance data for the U.S. and was used as one of the sources for North America & Oceania. SNV [1997, pp. 109-126] contains detailed descriptions of performance of livestock systems in Sweden, and was used as a major source for West Europe. Payne [1990, pp. 216, 264, 314, 689] gives many examples of representative values for livestock performance in tropical regions, and was used as a major source for Latin America & Caribbean, Sub-Saharan Africa and South & Central Asia. Kassam et al. [1991, pp. 67-91] include extensive data on herd performance for livestock systems in Eastern Africa (Kenya) — we assumed that these data were approximately valid for the non-industrial regions in general. For the regions East Europe and North Africa & West Asia, values were chosen so that the best possible consistency between production-per-head values and determining parameters was achieved in comparison with the values for the other regions.

**Table 3.8** Estimates of major productivity parameters for animal food production in 1992-94 (used in this study). The estimates comply with the productivity values in Table 3.7.[a]

| Animal sub-system and parameter | East Asia | East Europe | Latin America & Carib. | North Africa & W. Asia | North America & Oc. | South & Central Asia | Sub-Saharan Africa | West Europe |
|---|---|---|---|---|---|---|---|---|
| **Cattle milk** | | | | | | | | |
| Cow mature liveweight (kg) | 400 | 480 | 300 | 300 | 620 | 320 | 270 | 550 |
| Cow mortality (number dead/year & number of cows in stock) | 1.5% | 1.0% | 1.5% | 1.5% | 1.0% | 2.0% | 2.0% | 1.0% |
| Milk yield (kg/cow & year) | 2 100 | 2 403 | 11 08 | 1 036 | 6 685 | 1 200 | 429 | 5 248 |
| Calves weaning rate (calves weaned/cow & year) | 0.55 | 0.85 | 0.50 | 0.50 | 0.90 | 0.40 | 0.45 | 0.90 |
| Replacement heifer mortality (number dead/born calf) | 5.0% | 3.0% | 5.0% | 5.0% | 3.0% | 10% | 10% | 3.0% |
| Replacement heifer age at first calving (months) | 40 | 24 | 40 | 40 | 24 | 50 | 44 | 24 |
| Bull mortality (number dead/born calf) | 7.0% | 3.0% | 7.0% | 7.0% | 3.0% | 15% | 15% | 3.0% |
| Bull liveweight at slaughter (kg) | 390 | 290 | 450 | 320 | 480 | 280 | 300 | 460 |
| Bull average growth rate form birth to slaughter (kg liveweight gain/day) | 0.23 | 0.59 | 0.33 | 0.28 | 0.72 | 0.099 | 0.17 | 0.90 |
| Partition and composition quality of animals[b] | Low | Medium | Low | Low | High | Low | Low | High |
| Carcass yield, average all animals (of empty body, as-is basis)[c] | 51% | 60% | 51% | 51% | 63% | 51% | 51% | 63% |
| **Beef cattle carcass** | | | | | | | | |
| Cow mature liveweight (kg) | 280 | 550 | 310 | 310 | 550 | 250 | 280 | 550 |
| Cow mortality (number dead/year & number of cows in stock) | 1.5% | 1.0% | 1.5% | 1.5% | 1.0% | 2.0% | 2.0% | 1.0% |
| Calves weaning rate (calves weaned/cow & year) | 0.45 | 0.90 | 0.50 | 0.50 | 0.90 | 0.40 | 0.45 | 0.90 |
| Replacement heifer mortality (number dead/born calf) | 5.0% | 3.0% | 5.0% | 5.0% | 3.0% | 10% | 10% | 3.0% |
| Replacement heifer age at first calving (months) | 40 | 24 | 40 | 40 | 24 | 50 | 44 | 24 |
| Bull mortality (number dead/born calf) | 7.0% | 3.0% | 7.0% | 7.0% | 3.0% | 15% | 15% | 3.0% |
| Bull liveweight at slaughter (kg) | 430 | 320 | 500 | 360 | 530 | 310 | 340 | 510 |
| Bull average growth rate form birth to slaughter (kg liveweight gain/day) | 0.25 | 0.66 | 0.36 | 0.31 | 0.80 | 0.11 | 0.18 | 1.0 |
| Partition and composition quality of animals[b] | Low | Medium | Low | Low | High | Low | Low | High |
| Carcass yield, average all animals (of empty body, as-is basis)[c] | 51% | 60% | 52% | 52% | 64% | 51% | 51% | 64% |

*Table continues on next page.*

**Table 3.8** (continued)

| Animal sub-system and parameter | East Asia | East Europe | Latin America & Carib. | North Africa & W. Asia | North America & Oc. | South & Central Asia | Sub-Saharan Africa | West Europe |
|---|---|---|---|---|---|---|---|---|
| **Pig carcass** | | | | | | | | |
| Sow mature liveweight (kg) | 160 | 160 | 140 | 160 | 220 | 140 | 140 | 220 |
| Sow mortality (number dead/year & number of sows in stock) | 4.0% | 4.0% | 5.0% | 4.0% | 4.0% | 5.0% | 5.0% | 4.0% |
| Piglets weaning rate (piglets weaned/sow & year) | 13.0 | 13.0 | 11.0 | 13.0 | 16.0 | 11.0 | 11.0 | 17.0 |
| Swine mortality (number dead/weaned piglet) | 7.0% | 7.0% | 10% | 7.0% | 5.0% | 10% | 10% | 5.0% |
| Swine liveweight at slaughter (kg) | 100 | 110 | 100 | 87 | 110 | 62 | 71 | 110 |
| Swine average growth rate form birth to slaughter (kg liveweight gain/day) | 0.35 | 0.38 | 0.20 | 0.32 | 0.56 | 0.20 | 0.18 | 0.56 |
| Partition and composition quality of swine[d] | Medium | Medium | Low | Medium | High | Low | Low | High |
| Carcass yield, average all animals (*carcass-side*, of empty body, as-is basis)[e] | 62% | 62% | 59% | 62% | 65% | 59% | 59% | 65% |
| **Chicken egg** | | | | | | | | |
| Hen mature liveweight (kg) | 1.4 | 1.4 | 1.5 | 1.4 | 1.7 | 1.3 | 1.3 | 1.7 |
| Hen mortality (number dead/year & number of hens in stock) | 10% | 10% | 7.0% | 10% | 5.0% | 10% | 10% | 3.0% |
| Egg yield (kg/hen & year) | 9.5 | 10.0 | 11.5 | 9.5 | 16.5 | 7.0 | 6.5 | 17.5 |
| **Meat type chicken carcass** | | | | | | | | |
| Chicks production rate (chicks produced/breeding hen & year) | 84 | 110 | 130 | 84 | 150 | 70 | 70 | 160 |
| Broiler mortality (number dead/chick produced) | 10% | 10% | 7.0% | 10% | 5.0% | 10% | 10% | 4.0% |
| Broiler liveweight at slaughter (kg) | 2.0 | 2.0 | 2.0 | 2.0 | 2.1 | 1.3 | 2.0 | 1.9 |
| Broiler average growth rate from birth to slaughter (kg liveweight gain/day) | 0.022 | 0.025 | 0.029 | 0.021 | 0.039 | 0.014 | 0.016 | 0.047 |
| Partition and composition quality of broiler[f] | Medium | Medium | Medium | Medium | High | Low | Low | High |
| Carcass yield, average all animals (eviscerated carcass, of whole body, as-is basis) | 68% | 68% | 68% | 68% | 73% | 63% | 63% | 73% |

All weight numbers are as-is values. Assumed values on composition of milk and egg are given in Table A1.II, Appendix 1. Specifications of how carcass is defined in each animal sub-system are presented in the section ‘Specification and composition of carcass’, Appendix 1. Values on whole body partition for the different animal quality-types, as well as corresponding carcass composition, are shown in Table A1.I, Appendix 1.

[a] Except for the ‘cattle milk’ and ‘beef cattle carcass’ sub-systems in East Asia and South & Central Asia, see text for explanations.

[b] For the systems with ‘high’ animals quality, the bulls are of ‘high-quality’ type, whereas the cows and the heifers are of ‘medium-quality’ type (see Table A1.I, Appendix 1). For the systems with ‘medium’ and ‘low’ animals quality, all animal categories are of ‘medium-quality’ and ‘low-quality’ type respectively.

*Notes continue on next page.*

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[c] Empty body weight is whole body liveweight minus the weight of the intestinal contents. Intestinal contents amounts typically to 10% (as-is basis) of the whole body liveweight.

[d] In all cases, the sow is of 'medium-quality' (see Table A1.I, Appendix 1).

[e] Empty body weight is whole body liveweight minus the weight of the intestinal contents. Intestinal contents amounts typically to 5% (as-is basis) of the whole body liveweight.

[f] In all cases, the breeding hen is of 'medium-quality' (see Table A1.I, Appendix 1).

'beef cattle carcass' sub-system were coordinated so that the *average* values on offtake, carcass weight and production of carcass and milk per head for these two sub-systems complied with those of 'cattle' in FAOSTAT.[91] The production of milk per dairy cow was set to exactly the same value as in FAOSTAT.

For poultry, data on offtake and carcass weights for chickens were not specified in FAOSTAT, nor was egg production per laying hen included.[92] Therefore, in the same manner as for cattle, the base parameters for the 'chicken egg' and 'meat-type chicken carcass' sub-systems were tuned jointly so that the average values on production of egg and carcass per head agreed with those of 'poultry' in FAOSTAT.

For two regions, East Asia and South & Central Asia, the procedure for cattle diverged to some extent from the one described above. In these regions, the occurrence of buffalo is substantial. In East Asia, the buffalo stock amounts to 39 million head, to be compared with the cattle stock of 130 million head; in South & Central Asia, the buffalo stock is 100 million head and the cattle stock 270 million head. Particularly in South & Central Asia, the contribution to the food supply from the buffalo system is substantial — buffalo meat production amounts to 25 percent of total ruminant meat (cattle meat roughly 45 percent, the remainder sheep and goat meat), and the milk production is nearly equally distributed between the cattle and buffalo systems.

Buffalo systems are comparable with cattle systems in terms of digestive system, liveweights, reproduction and growth rates, and so forth. Therefore, for these two regions, the values of the base parameters of the two cattle sub-systems were tuned so that their average values on offtake, carcass weight and production of milk and carcass per head agreed with those in FAOSTAT for cattle *and* buffalo as *average*.[93] In this way, a

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[91] In this tuning procedure, *dairy* bulls & heifers were, as a general rule, assumed to have lower slaughterweights and liveweight gains than *beef* bulls & heifers within the same region (both 10% lower). In addition, *heifers* were assumed to have 20% lower slaughterweights and 10% lower liveweight gains than *bulls*. Carcass yields were, for both beef and dairy, assumed to be approximately 10% lower for heifers, and about 20% lower for cows, than for bulls. For both dairy and beef cattle, the mortality rates of heifers for meat production (that is, heifers besides the replacement heifers) were assumed to be equal to those of bulls (Further specifications of cattle whole bodies and carcasses are given in Appendix 1.)

[92] This applied to the 1996 release of the FAOSTAT PC-version which we used in this study. Additional information is available at the current on-line version of FAOSTAT, see comment in Table 3.7 above.

[93] For East Asia, meat and milk production per head for the combined system cattle-plus-buffalo was 12-13% lower than for the cattle system. For South & Central Asia, meat production per head was 13%

*Notes continue on next page.*

partial compensation for the relatively low representatives of the cattle systems in these regions was achieved without having to introduce additional animal food sub-systems in the model. The issue of the representativeness of the cattle sub-systems is critical for the significance of the results and is further dealt with in the discussion section (see the section ‘Productivity and specific feed energy requirements’, pp. 183 sq.).

*Estimates of base energy requirements*

The FPD model includes equations for estimating the feed energy requirements for *each animal category* in each animal sub-system (presented in Sections 2.3.2 to 2.3.6 above). The feed energy requirements for the *whole sub-system* are determined by these energy equations and the values on the base parameters of the sub-system. For each animal sub-system, these feed energy requirements are calculated per number of animals in stock in the sub-system (that is, per head), as well as per amount of commodity generated in the sub-system — the latter here referred to as the *specific* feed energy requirements for the sub-system.

Table 3.9 shows the estimated values on feed energy requirements per amount of commodity generated, calculated for those values on the base parameters as specified in Table 3.8. Note that the values shown in the table refer to the *base* energy requirements, which means that for the cattle sub-systems, extra energy requirements for grazing are *not* included. The level of energy expenditures at grazing are dealt with in the subsequent section (p. 76).

These values in Table 3.9 on the specific feed energy requirements reflect the feed *conversion efficiency* of each of the animal food sub-systems, that is, the efficiency of the conversion of feedstuff into animal food commodities. Due to differences in, for example, terms of the feed energy units (NE, ME, etc), and the partition and composition of the commodities generated, comparisons of the feed conversion efficiency between the animal sub-systems are not straightforward.

One way to obtain a platform for consistent comparisons of the feed conversion efficiencies between systems with different feed energy units is to calculate the amount of feed required to cover the energy requirements assuming the *same feed* for all sub-systems. If also the output, that is, the amount of commodity generated, is consistently expressed in a quantity uniform to that of the feed use, comparable values on the conversion efficiencies are obtained. This kind of concept might be designated *feed-equivalent* or *feed-neutral* conversion efficiency.

Such conversion efficiencies were calculated for the estimated values on specific feed energy requirements in this study, assuming a feed ration of 100 percent *maize grains*. The major reason to choose maize as the feed equivalent was that in principle, maize

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higher, and milk production per head 36% higher than for the cattle system. The influence on system efficiency is roughly half of these figures, see note in Table 3.10.

grains are acceptable as feed for all the animal systems included here. Maize is also the most widely used of all dried feedstuffs. Naturally, many other feedstuffs would be possible as a basis for comparison. As quantity for the efficiency concept, we chose *gross energy*. Another relevant alternative could be dry weight. In our opinion, however, gross energy is more appropriate since energy is a major limiting factor in the process of animal metabolism. The resulting values on these feed-equivalent conversion efficiencies are given in Table 3.10 below. In Figure 3.1 and Figure 3.2, a selection of these efficiency values are illustrated.

**Table 3.9** Estimated values in this study on feed energy requirements per amount of commodity generated. Calculated from the values on productivity in Table 3.8.[a]

| Commodity | Unit | East Asia | East Europe | Latin America & Carib. | North Africa & W. Asia | North America & Oc. | South & Central Asia | Sub-Saharan Africa | West Europe |
|---|---|---|---|---|---|---|---|---|---|
| Cattle milk & cow carcass (MJ per kg whole milk & carcass as-is)[b] | $NE_l$ | 8.2 | 8.2 | 11 | 12 | 5.3 | 11 | 23 | 5.6 |
| | $NE_m$ | 2.3 | 1.3 | 1.9 | 2.0 | 1.1 | 2.5 | 5.4 | 1.3 |
| | $NE_g$ | 0.46 | 0.45 | 0.30 | 0.32 | 0.50 | 0.32 | 0.70 | 0.52 |
| Dairy bulls & heifers carcass (MJ per kg carcass as-is) | $NE_m$ | 187 | 47 | 143 | 130 | 53 | 344 | 211 | 41 |
| | $NE_g$ | 22 | 14 | 24 | 21 | 16 | 19 | 20 | 16 |
| Beef carcass (MJ per kg carcass as-is) | $NE_m$ | 288 | 141 | 236 | 262 | 109 | 479 | 352 | 103 |
| | $NE_g$ | 25 | 19 | 28 | 23 | 23 | 20 | 21 | 23 |
| Pig carcass (MJ per kg carcass-side as-is) | ME | 86 | 84 | 131 | 86 | 65 | 115 | 123 | 64 |
| Eggs & hen carcass (MJ per kg whole egg & carcass as-is)[c] | ME | 43 | 42 | 39 | 43 | 32 | 53 | 56 | 30 |
| Meat-type chicken carcass (MJ per kg eviscerated carcass as-is) | ME | 60 | 56 | 51 | 61 | 42 | 72 | 77 | 38 |

For values on partitioning and composition of produced outputs (milk, carcasses, eggs) see Appendix 1. For all cattle sub-systems, the values refer to *base energy* requirements, that is, extra energy expenditures for activity at grazing are not included. Note that for calculating total feed requirement for any of the cattle sub-systems, each of the net energy categories has to be covered.

[a] For dairy cattle, the growth requirement equations for *large* breed (p. 32) were used in East Europe, North America & Oceania, and West Europe. In all other regions, the equations for *small* breed were used. Analogously, for beef cattle, the growth requirement equations for *large-frame* breed (p. 35) were used in East Europe, North America & Oceania, and West Europe. In all other regions, the equations for *medium-frame* breed were used.

[b] Dairy heifers above those required for replacement of the dairy cow, as well as dairy bulls are, strictly speaking, not necessary parts of the cattle milk system. Therefore, dairy cow & replacement heifer, and dairy bulls & heifers respectively are here treated separately. This means that the feed energy requirement values for production of milk and cow carcass include feed energy for cow and replacement heifer. The amount of cow carcass produced as compared to total output (cow carcass plus milk) is relatively low — it amounts to 1-2% on as-is weight basis, and 4-7% on GE basis, except for Sub-Saharan Africa which has somewhat higher values owing to low milk yield (about 3 and 9% respectively).

[c] The amount of leghorn-type chicken carcass (culled hen carcass) in relation to total output (hen carcass plus eggs) is slightly higher than in the case of cattle milk; it amounts to 5-7% on as-is weight basis, and 8-11% on GE basis.

**Table 3.10** Maize-equivalent conversion efficiencies corresponding to the specific feed energy requirements estimated in this study. Values are consistent with the values in Table 3.8 and Table 3.9.[a]

| Animal sub-system and commodity | East Asia | East Europe | Latin America & Carib. | North Africa & W. Asia | North America & Oc. | South & Central Asia | Sub-Saharan Africa | West Europe |
|---|---|---|---|---|---|---|---|---|
| **Cattle milk & dairy cow carcass**[b] | | | | | | | | |
| Milk plus lean & fatty tissue | 13% | 15% | 11% | 10% | 21% | 10% | 5.2% | 19% |
| **Dairy bulls & heifers carcass**[c] | | | | | | | | |
| Lean tissue | 0.95% | 3.3% | 1.2% | 1.3% | 3.2% | 0.56% | 0.86% | 3.7% |
| Lean and fatty tissue | 2.1% | 6.3% | 2.5% | 2.8% | 5.5% | 1.2% | 1.9% | 6.5% |
| **Beef carcass** | | | | | | | | |
| Lean tissue of carcass | 0.69% | 1.4% | 0.80% | 0.75% | 1.7% | 0.44% | 0.58% | 1.8% |
| Lean and fatty tissue of carcass | 1.5% | 2.8% | 1.8% | 1.7% | 3.2% | 0.96% | 1.3% | 3.4% |
| **Pig carcass** | | | | | | | | |
| Lean tissue of carcass-side | 4.6% | 4.7% | 2.8% | 4.6% | 6.4% | 3.2% | 3.0% | 6.4% |
| Lean and fatty tissue of carcass-side | 12% | 13% | 8.3% | 12% | 16% | 9.5% | 8.9% | 16% |
| **Eggs & laying hen carcass** | | | | | | | | |
| Yolk & white of egg, and lean & fatty tissue of hen carcass | 13% | 13% | 14% | 13% | 17% | 11% | 10% | 18% |
| **Meat-type chicken carcass** | | | | | | | | |
| Lean tissue of eviscerated carcass | 5.1% | 5.5% | 6.0% | 5.0% | 7.6% | 4.1% | 3.8% | 8.3% |
| Lean and fatty tissue of eviscerated carcass | 11% | 12% | 13% | 11% | 15% | 9.3% | 8.7% | 17% |

Values refer to the GE (HHV) content of the amount of commodity (or commodities) generated, expressed as share of the GE (HHV) content of the feed used, that is, actual intake of feed. The commodity GE content refers to the GE content of those commodity parts which are stated in the table. (For values on partition and composition of commodities, see Appendix 1.) Feed use is calculated as the amount of maize grains required to completely meet the estimated specific feed energy requirements (Table 3.9). With the exception of the cattle milk sub-system (see separate notes below), commodities generated and feed used refer to commodities output and feed use, respectively, for *all* animal categories in each sub-system. (For values on energy densities of maize grains, see Table A1.II, Appendix 1.)

[a] As described in the previous section, the model input parameters for the cattle sub-systems for East Asia and South & Central Asia were matched with the FAOSTAT productivity data for the cattle and buffalo systems combined. Thus, the values in this table deviate from the corresponding values for the cattle systems considered alone. For East Asia, the maize-grain-equivalent efficiency for beef carcass is roughly 7% lower than the value given in this table; for milk plus cow carcass, the efficiency is about 0.4 percent lower. For South & Central Asia, the efficiency for beef carcass is about 8% higher than the value shown in this table, and for milk plus cow carcass roughly 12% higher.

[b] Commodities generated include whole milk, and lean and fatty tissue of the dairy cow carcass. Feed use includes use of feed for the lactating cow, and for the replacement heifer from birth to first calving.

[c] Commodity parts generated include lean and fatty tissue respectively of the dairy bulls & heifers carcass. Feed use includes use of feed for the dairy bulls & heifers from birth to slaughter.

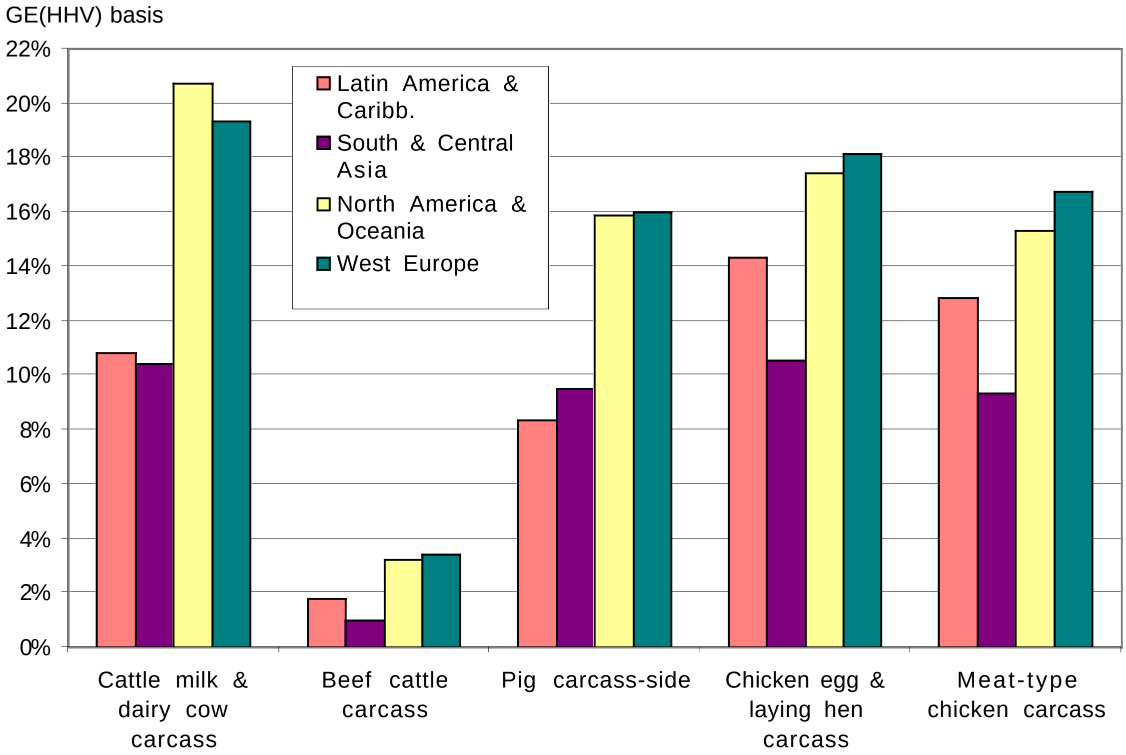

**Figure 3.1** Maize-equivalent conversion efficiency of animal food systems in this study. Refers to lean and fatty tissues of carcass commodities (see text and Table 3.10 for further explanations).

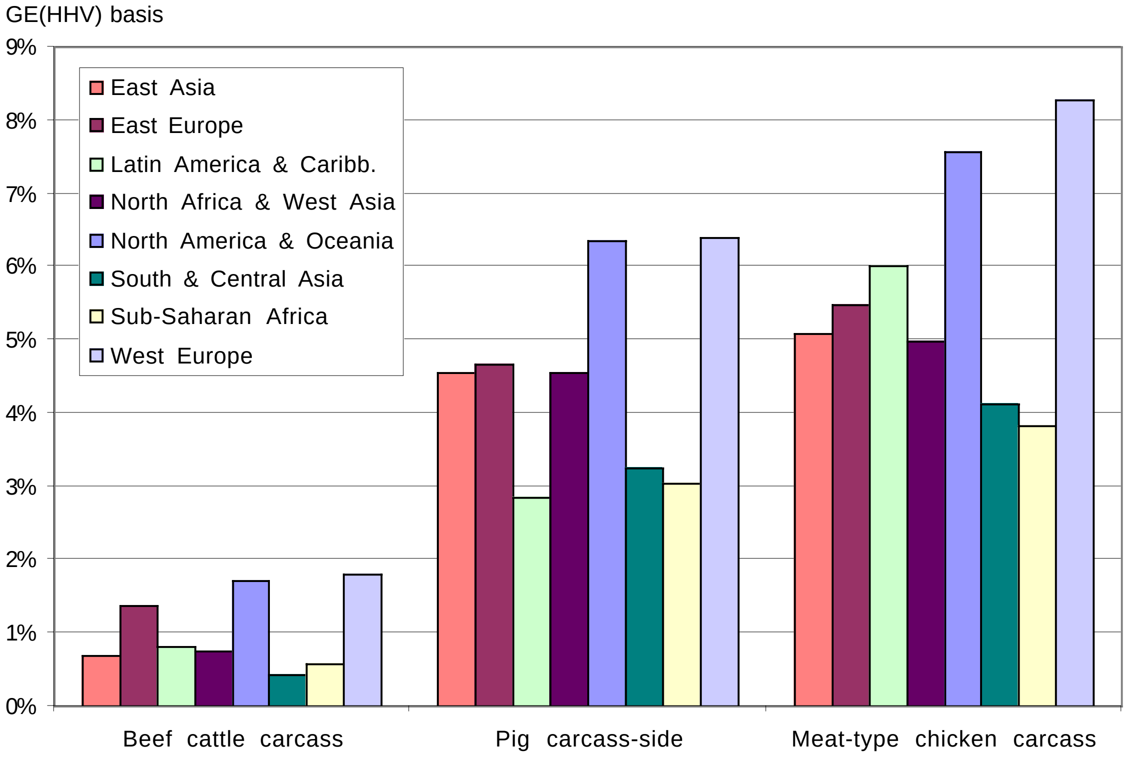

**Figure 3.2** Maize-equivalent conversion efficiency for major meat systems in this study. Output refers to the lean tissue only in the carcass (see text and Table 3.10 for further explanations).

We want to emphasize that the feed-equivalent conversion efficiency indeed is no more than an equivalent-measure. In real systems, the nutritive value of the ration — that is, the content of different nutrients such as energy, protein, etc, in the ration — has a significant influence on the productivity performance of the system. The productivity levels for each sub-system and region are by no means valid for the nutritive content of a 100 percent maize grain ration. The only nutritive aspect that actually is fulfilled in the feed-equivalent measure is energy. In practice, a pure maize grain ration would imply severe deficiency of many nutrients, notably protein for pig and poultry, and also severe excess of starch in the case of cattle systems.

The point with the concept of feed-equivalent conversion efficiency, despite its obvious imperfections, is that comparisons based on this concept in principle are less discriminatory than comparison based on the *actual feed* ration. This applies particularly to comparisons between on the one hand ruminants, and on the other monogastrics (pigs) and poultry. Generally speaking, normal rations for beef cattle (such as grasses and legumes) have a relatively low content of *available* energy (that is, of ME or NE) per unit of feed, whereas normal rations for pigs and poultry (such as cereal grains) have a relatively high content of available energy. This means that an efficiency comparison based on the actual feed ration is somewhat discriminative against the cattle system — since there is, in part, a difference in efficiency which is only due to the content of available energy of the feed.

In the results section of this chapter, values are given on actual conversion efficiencies, that is, feed conversion efficiencies calculated for the *average feed rations* estimated in this study (see, for example, pp. 123, 163 sq.). Comments and discussion on productivity and efficiency are given in the sections ‘Productivity and specific feed energy requirements’ (p. 180), and ‘Efficiency and specific biomass use’ (p. 231).

### *Estimates of additional energy requirements at grazing*

Energy expenditure for work by grazing animals is influenced by numerous factors including herbage quality and availability, topography, weather, distribution of water and genotype. The US National Research Council (NRC) reports, citing a review of available literature, that the increase in maintenance energy requirements of grazing cattle as compared to penned cattle may be 10 to 20 percent under the best grazing conditions and about 50 percent for cattle in extensive, hilly pastures where animals walk considerable distances to preferred grazing areas and water.[94] These general data were used as a basis for a rough estimate of allowances for the additional energy expenditures at grazing. We assumed that pastures with native species entail greater energy expenditures than oversown pastures, and that oversown pastures in turn entail larger energy expen-

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[94] [NRC 1996, p. 11]

ditures than cropland pastures.[95] The resulting estimate for each pasture category is shown in Table 3.11.

**Table 3.11** Assumed values in this study on additional energy requirements for activity at grazing.

| Pasture type | All regions |
|---|---|
| Permanent pastures, native | 0.20 |
| Permanent pastures, oversown | 0.15 |
| Cropland pastures | 0.10 |

Values are expressed as share of the *base* maintenance requirement (on $NE_m$ basis). Note that the base maintenance requirement corresponds to the maintenance requirement for penned animals *plus* a 10% general allowance (see Sections 2.3.2, p. 31, and 2.3.3, p. 34).

## Feed use

The productivity estimates in the preceding section gave estimated *specific* feed *energy* requirements *per commodity unit generated* for each of the animal sub-systems. The next step in the calculation procedure in this study was to estimate the corresponding *total* use of feed *dry matter* as well as the *feed mix* (that is, the share of each feedstuff in the feed mix) for each animal category and sub-system.

In this study, the estimates of feed use were based on *complete feed balances* with respect to energy, calculated in the FPD model. This means that for each animal sub-system in each of the eight regions, the energy content of the feed intake complied with the estimated feed energy requirements. These feed balances were achieved by performing an iterative adjustment of the feed mixes in the model so that as little deviation as possible was obtained compared with available data, particularly those regarding feed use; the calculations included matching and tuning with available *feed use data*, and to some extent also with *nutrient density requirements data*. Since feed use data in most cases were available only for the whole livestock sector, the feed balance calculations also involved *allocation principles* for the assumptions on the feed use in the separate animal sub-systems and animal categories.

In the subsequent sections, more detailed descriptions follow for each of these parts. In the last section, a summary description of the principal features of the feed balance calculations is given.

### *Feed use data*

In general, national statistics on feed use have a very partial coverage. Normally, only commercial — mostly dried — crop products, such as cereals grains, root crops meals

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[95] NRC [1989, p. 7] suggests that maintenance allowances, *in addition to* a 10% basic activity allowance, may be increased by 10% for good pasture and up to 20% for sparse pastures.

and oil crops seeds, are included. Only occasionally, statistics on feed use comprise all major feed categories, including on-farm produced forages (such as hay and silage), grazed feed, and by-products and residues. In addition, feed use data are in most cases given in ambiguous or inadequate units, such as, weight including water (as-is weight). This lack of adequate data was one principal reason for carrying out the relatively detailed estimate of feed use in this study.

The FAOSTAT Food Balance Sheets (FBS) contain data on feed use for most edible-type crops, among which cereals, starchy roots, pulses, and oil crops are the most significant ones. The FBS do not, however, include the feed categories animal forage crops, pasture, or by-products. The data in the FBS refer to the total feed use of the whole livestock sector — thus, there is no specification given for separate animal systems. The only unit in which the data are presented is as-is weight.

For the feed categories included in the FBS, the estimates of feed use were entirely based on the feed use data in the FBS. For all other feed categories, that is, animal forage crops, pastures, and by-products and residues, estimates of feed use were based on a variety of other sources.[96] These data from other sources were used as points of departure for assuming values within reasonable ranges for each feedstuff and region. In general, the geographic areas referred to in these sources did not coincide with the regional structure used in this study. The type of data employed from these sources was, therefore, either feed use as *share of total feed use* (that is, share in average feed mix), or feed use as *share of total production or supply* (that is, share of generated or available amount used as feed). The latter kind of data was the most frequently available in literature.

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[96] Simpson et al. [1994, pp. 363-365, 460-465] give detailed data on the use of all types of feed in the Chinese livestock sector, both as share of generated amount and as share in feed mix, and was the principal source for East Asia. Their figures on use of conversion by-products (cereal brans, oil meals, etc) as feed were adopted as reference values also for other non-industrial regions, since few other comprehensive and consistently organized studies on this topic were available. Lee [1988] gives data on use of animal forage crops, pasture and crop by-products in several European countries and the former USSR, and was a major source for East Europe and West Europe. Glenn [1992] and Nordblom [1988] give information on use of major feed categories, including crop by-products (but not conversion by-products) in a number of North African and West Asian countries; these were used as major sources for the North Africa & West Asia region. NASS [1997] contains statistics on feed use in the USA, divided into ‘concentrates’, ‘harvested roughage’ and ‘pasture’; it was assumed that non of these includes by-products. McIntire et al. [1992, p. 126] give some examples on use of crop by-products as feed in Sub-Saharan Africa. Their figures were adopted as reference values also for other non-industrial regions. Janssens [1990] contains detailed data on use of all types of feed in EC-10 (in 1986/1988), and was the principal source for the West Europe region. Kosaka [1990] contains data on use of conversion by-products in Japan; these figures were used as reference values for the industrial regions North America & Oceania and West Europe. Various sources containing figures on feed mixes and use of by-products as feed were: [Bakrie 1996, Diarra & Bosma 1988, El Naga 1985, McDowell 1988, Tareque 1996, Upadhyay 1996, Verma & Jackson 1984]. A recent study [Renard 1997], containing information on feed use — in particular of crop by-products — in different regions, was not possible to include in the estimates since we received information about it at too late a stage. However, comparisons of the results in this study were made with some of the data reported in that study (see the section ‘Feed use, p. 191 sq.).

Unfortunately, most sources lacked essential descriptions of how these shares are derived. For data on feed use as share of the generated amount and alike, it is often not clearly specified whether the share refers to the total amount *generated*, or to the amount *supplied* (that is, the amount harvested), or to the amount *distributed* (that is, the amount available for use after that storage losses have been accounted for). Frequently, the data given only refer to the amount "available", normally meaning a rough estimate of the amount that possibly *could* be used as feed. In a like manner, for data on share in feed mix, the unit for which the shares in feed mix are calculated is often not specified (for example, as-is weight, dry weight, DE, ME or other energy units are conceivable alternatives). Despite these shortcomings, this kind of data was usable to some extent, especially for making assumptions on the use of by-products and residues as feed.

### *Nutrient density requirements data*

For achieving a certain animal productivity target, the feed eaten by an animal needs to have a certain nutrient density per dry matter unit. An animal has a limited capacity for intake of dry matter per unit time and since a certain animal productivity requires a certain intake of nutrients per unit time, particularly of energy and proteins, the feed dry matter intake must have a certain density of these nutrients. In practice, this issue is, at least in industrial countries, normally handled by using standard ration guidelines based on productivity targets and assumed dry matter intake.

However, factors that regulate voluntary feed intake are complex and are not fully understood.[97] Animals do not simply eat as much as they can; the intake is adjusted depending on a number of circumstances, such as physiological factors, environmental factors and management and dietary factors. For growing-finishing cattle and lactating dairy cows, dry matter intake as share of body weight may vary up to a factor of two.[98] Therefore it is difficult to predict voluntary feed intake with accuracy.

In addition to these fundamental difficulties, studies on these issues for lower productivity levels, as those prevailing in non-industrial regions, are rare. We did not find data on relationships regulating dry matter intake for such productivity levels. Despite this, assumptions on nutrient density requirements were formulated for the *cattle* subsystems, see Table 3.12. The estimate of these nutrient density requirements were based on data from NRC, complemented with own basic assumptions.[99]

These assumptions were made with the limited purpose to obtain indications of the likely proportions in the feed mixes for the cattle systems in each region. Due to the

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[97] [NRC 1987]

[98] [NRC 1989, NRC 1996]

[99] NRC [1996, pp. 220-228] and NRC [1989, pp. 81-87] give typical values on dry matter intake in relation to body weight, live weight gain, milk yield and energy density of feed. Extrapolation from these values, combined with own observations in this study on apparent relationships between feed energy density and productivity, constituted the basis for the estimate for productivity levels lower than those in the NRC reports.

above-described uncertainties, the guideline values on the nutrient density requirements were subordinated to the data on feed use, that is, the values on the nutrient densities of the feed mixes in the model did *not* have to comply with the guideline values. Rather, the calculations were aimed at obtaining as little deviation from the nutrient density guideline as possible for each animal category. In order to give a picture of the degree of deviation, also the nutrient density values of the assumed feed mixes in this study are shown in Table 3.12. Comments on the differences between guideline and outcome are given in the section ‘Feed use’ (p. 191 sq.).

**Table 3.12** Nutrient density requirements roughly consistent with the estimated productivity values in Table 3.8, and the outcome in this study for the assumed feed mixes.

| Animal sub-system and category | Unit | Status | East Asia | East Europe | Latin America & Carib. | North Africa & W. Asia | North America & Oc. | South & Central Asia | Sub-Saharan Africa | West Europe |
|---|---|---|---|---|---|---|---|---|---|---|
| Dairy cow | $NE_l$ | Guideline | 5.0 | 5.1 | 4.6 | 4.5 | 6.3 | 4.6 | 4.2 | 6.1 |
| | | *Outcome* | *4.7* | *5.1* | *4.3* | *4.7* | *6.9* | *4.6* | *4.2* | *6.4* |
| Dairy replacer | $NE_m$ | Guideline | 4.0 | 4.7 | 3.9 | 3.9 | 5.1 | 3.8 | 3.8 | 4.9 |
| | | *Outcome* | *3.7* | *4.7* | *3.7* | *4.1* | *5.4* | *3.8* | *3.7* | *5.2* |
| Dairy bulls & heifers | $NE_m$ | Guideline | 4.0 | 4.9 | 4.3 | 4.1 | 5.4 | 3.6 | 3.8 | 6.0 |
| | | *Outcome* | *3.7* | *4.9* | *4.1* | *4.3* | *6.9* | *3.6* | *3.7* | *6.3* |
| Beef cow & replacer | $NE_m$ | Guideline | 3.6 | 4.8 | 3.7 | 3.7 | 4.8 | 3.4 | 3.6 | 4.8 |
| | | Outcome | 3.4 | 4.8 | 3.6 | 3.9 | 5.1 | 3.5 | 3.5 | 5.1 |
| Beef bulls & heifers | $NE_m$ | Guideline | 4.1 | 5.2 | 4.3 | 4.2 | 5.6 | 3.6 | 3.9 | 6.3 |
| | | *Outcome* | *3.8* | *5.2* | *4.1* | *4.4* | *7.2* | *3.7* | *3.7* | *6.6* |
| Pig | ME | Guideline | | | | | 14-15 | | | 14-15 |
| | | *Outcome* | *12.0* | *13.2* | *13.2* | *(14.1)* | *15.1* | *11.4* | *10.6* | *14.4* |
| | Prot. | Guideline | | | | | 18-21% | | | 18-21% |
| | | *Outcome* | *15.9%* | *14.7%* | *18.4%* | *(18.0%)* | *20.7%* | *18.7%* | *13.4%* | *19.7%* |
| Egg | ME | Guideline | | | | | 12.5-13.5 | | | 12.5-13.5 |
| | | *Outcome* | *14.4* | *13.9* | *14.1* | *13.4* | *13.6* | *12.0* | *13.7* | *13.0* |
| | Prot. | Guideline | | | | | 17-20% | | | 17-20% |
| | | *Outcome* | *14.4%* | *13.8%* | *18.7%* | *17.6%* | *20.8%* | *20.1%* | *14.8%* | *20.3%* |
| Chicken | ME | Guideline | | | | | 14-15 | | | 14-15 |
| | | *Outcome* | *14.5* | *13.8* | *14.1* | *14.0* | *14.0* | *12.2* | *13.7* | *13.8* |
| | Prot. | Guideline | | | | | 21-24% | | | 21-24% |
| | | *Outcome* | *15.9%* | *14.7%* | *21.7%* | *18.9%* | *23.7%* | *20.7%* | *15.2%* | *23.3%* |

Energy densities are given in MJ/kg DM, and protein densities in percent of total DM.

For *pig* and *poultry*, no nutrient density requirements were formulated with the exceptions of the industrial regions North America & Oceania and West Europe. There were mainly two reasons for this. Firstly, the variations in nutrient density are, at least for normal rations in industrial countries, much smaller than is the case for ruminants. Secondly, the feed allocation procedure used in this study (described in the subsequent section) overrides other factors determining the proportions in the feed mixes for pig and poultry.

*Allocation principles*

As mentioned above, feed use data are often given for livestock as an entire group — that is, normally, there is no specification of the feed use for separate animal systems, nor for individual animal categories within different systems. To make use of such livestock-sector feed use data in this study, the data had to be interpreted into feed use for separate animal sub-systems and categories. This interpretation was expressed in a number of ‘allocation principles’.

The principles for allocation of *products* were made following hierarchies mainly based on overall nutrients requirements and feed suitability with respect to the character of the digestive system of each of the animal species considered. In addition, for *internally generated by-products and residues*, the allocation was guided by availability and quality of the substituted product flow. To some extent, particularly within each cattle sub-system, the allocation was also guided by nutrient density requirements as specified in Table 3.12 above.

For *cereals products*, first priority was given to the egg and chicken meat systems since the requirements of these systems are less flexible than are those for other systems. Next in priority was the pig system, then the dairy and beef cattle systems. For *starchy roots products* priority was given to the pig system, then the cattle systems. For *protein supplement products* (oil crops, pulses, fish) equal priority was given to the egg, chicken meat and pig systems (the cattle systems were not considered here since protein supplement products were not included as feed options for cattle in the FPD model).

*Non-fibrous cereals milling by-products*[100] were treated as a substitute to *cereals* and the allocation followed the same hierarchy as cereals. If the total feed use of *cereals products* according to the FBS was not sufficient to cover the estimated requirements of the egg and chicken meat systems, priority was given to these two systems before the pig and cattle systems. Allocation was then made *equally* between the egg and chicken meat systems, measured as share of feed mix for each system and for all non-fibrous cereals milling by-products *together*. If there were not cereals products sufficient for the egg, chicken meat *and* the pig system, priority was given to these three systems before the cattle systems. Allocation was made equally between the three sub-systems, measured as share of feed mix for each system and for all non-fibrous cereals milling by-products together. Finally, if there were sufficient cereals products for the egg, chicken and pig systems together, the non-fibrous cereals milling by-products were allocated equally between *all five* animal sub-systems, measured as share of feed mix for each of the sub-systems.

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[100] In this study, flows representing this category are ‘wheat mill run’, ‘rice bran’, ‘maize hominy feed’ and ‘sorghum hominy feed’.

Most *other non-fibrous by-products* were solely allocated to cattle[101] and some solely to pig,[102] more for the sake of modeling simplicity than strict feed suitability. In contrast, *molasses*[103] was treated as a substitute to *cereals products* and followed the same principle for allocation as non-fibrous cereals milling by-products: priority was given to pig before cattle. If there were sufficient of cereals products for the egg, chicken and pig systems, molasses was equally allocated between the pig, beef cattle and dairy cattle systems, measured as share of feed mix for each systems. *Non-eaten food* was allocated exclusively to pig production since this feed type is more suitable to pigs than to cattle and poultry.

As regards *protein supplement by-products,*[104] first priority was given to the egg, chicken meat, and pig systems since these systems require rations with higher protein content than the cattle systems. These by-products were allocated *equally* between the egg, chicken meat, and pig systems, measured as share of feed mix of each system and for all protein supplement by-products *together*. If a surplus remained when recommended levels of protein in rations had been reached, a part of this surplus (brewer’s grains) was allocated to dairy cattle. Brewer’s grains was the only protein supplement by-product included as feed option for the cattle sub-systems. Since this flow is small in comparison with other protein-rich by-products this implied that the protein supplement by-products were, in practice, allocated merely to the egg, chicken and pig systems.

*Fibrous by-products*[105] were allocated to the dairy and beef cattle systems as these by-products are not suitable as feed for pig and poultry. These by-products were allocated *equally* between the two cattle systems, measured as share of ration for each system and for all fibrous by-products *together*.

For all products and by-products, allocation *within* each *cattle* sub-system was made with regard to the assumed nutrient density guidelines above (Table 3.12). Each product and by-product was allocated to the animal category with the energy density requirement closest to the energy density value of the feed. The difference between each animal category within dairy and beef, as regards the *total* share of all non-fibrous by-products and all fibrous by-products respectively, was intended to be as small as possible — however, without producing *unequal* deviation from the energy density guideline value for each animal category.

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[101] Cassava leaves, sugar beet tops and sugar beet pulp.

[102] Sweet potato tops and white potato tops.

[103] Sugar cane molasses and sugar beet molasses.

[104] As protein supplement by-products are counted those with a crude protein content exceeding 20% (DM basis). In this study, these are oil crops meals, meat & bone meals, brewer’s grains, and cotton meal (the latter being a system-external input, see Section 3.1.7, p. 103).

[105] As fibrous by-products are counted those with a crude fiber content exceeding 20% (DM basis). In this study, these are cereals straw and stover, oil crops straw and stalks, cane tops & leaves, and rice hulls and cane bagasse.

*Feed nutrient densities data*

All values on composition of the flows included in this study are given in Appendix 1. For a large number of the feedstuffs, such as the cereals grains and starchy roots, the variation in nutritive value is rather small, and a considerable fraction of the composition values for these flows are based directly on standard references, such as the NRC tables of feed composition.[106] However, for some flows — particularly crop by-products, such as cereals straw, and forages, such as grasses and legumes — the variations in nutritive value may be most substantial. This applies in particular to permanent pastures. Since permanent pasture is a principal phytomass category, especially in the non-industrial regions, the data basis for the energy density values assumed is described in more detail below (see the section ‘Feed energy density of pasture’, p. 97).

As described above in Sections 2.3.2 and 2.3.3, all DE, ME and NE data for cattle feedstuffs in the FPD model are consistent with the equations used in the preparation of the NRC tables of feed composition (given on p. 33 and p. 36, respectively). Comments on the accuracy of these equations are given in the discussion section below (see the section ‘Feed use’, p. 201).

*Estimates of feed use — the feed balance calculations*

The estimates of feed use in this study — the feed balance calculations — were performed under a number of stipulations and considerations, of which the major ones have been presented above. Here we want to give a summary description of the principal features of the feed balance calculations, specified for each major feed category. Further details of the data sources, tendencies, and tradeoffs in the feed balance calculations in each region are given in the section ‘Feed use’ (pp. 192 sq.).

1) For the feed categories *included in the FBS*, the model values on total feed use were *exactly matched* with the values in the FBS. This means that, for each region, the feed mix for each animal category was tuned so that the model values for each of these feed categories as regards the *total feed* use (that is, the sum for all five animal sub-systems) agreed with the values for the corresponding feed categories in the FBS.[107]

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[106] [NRC 1989, NRC 1994, NRC 1996, NRC 1998]

[107] This tuning procedure was made for the FBS categories ‘cereals’, ‘starchy roots’, ‘oil crops’ and ‘fish, seafood’. There are a number of flows in the FBS, with a stated use as feed, which are not included as feed options in the FPD model. In most cases, the stated feed use of these flows is insignificant and was therefore neglected. In two cases, compensation was made by increasing the use as feed, to a corresponding extent on a DM basis, for one or several flows of those actually included in the FPD model: Use of *sugar crops* as feed was modeled by feed use of cereals, and *pulses* by feed use of oil crops (soybeans). In both these cases the amounts were very small compared to total feed use. The only significant feed use reported in the FBS which was not included, or compensated for, in the FPD model was milk. However, its use as feed amounted to no more than approximately 1% of the feed use for cereals (globally, on DM basis). The subject of feed use representation is further discussed in the section ‘Feed use’ (pp. 207 sq.).

Besides the stipulation of compliance with the calculated feed energy requirements, this tuning was made under the restriction of the allocation principles. Furthermore, the allocation of these feedstuffs *within* each of the *cattle* systems (that is, the allocation between the cows, replacement heifers, and growing bulls & heifers) was made under consideration of the nutrient density values.

2) For the feed categories *not* included in the FBS, that is, animal forage crops, pastures, and by-products and residues, model values on feed use were not matched with those of any particular source, although the data in some sources had a decisive influence on the assumptions for some of the regions (see footnote 96, p. 78). Hence, in contrast to the case for the feeds included in the FBS, we had no consistent basis for the estimates in each region. Therefore, for these flows, the estimates of feed use relied on a mixture of different data and relations:

    a) For *by-products and residues*, a general basis for the assumptions on feed use was the relatively comprehensive description in the FPD model of the generation, handling and use of all major by-products and residues in the food system. This description enabled estimates of the feed use in relation to use for other purposes than feed, and more importantly, in relation to the amount produced and available. To a considerable extent, the estimates of *total feed* use relied on general assumptions on use as *share of generated* amounts and *distributed* amounts (values are given in Table 3.20, p. 102). The estimates of total feed use also relied on data on share in feed mix — to a lesser extent, however, than the share of generated and distributed products. The estimates of feed use for each animal sub-system and animal category were steered by the allocation principles, including consideration of the nutrient density guidelines.

    b) For *animal forage crops, cropland pasture* and *permanent pasture,* the estimates were based on various feed use data, mainly data referring to share in feed mix for total livestock or for total ruminant sector (major sources given in footnote 96). For the cattle sub-systems and categories, the assumptions regarding the feed mixes also relied on (1) tuning between mainly forage crops (grass-legume) and permanent pastures under consideration of the nutrient density values, and (2) tuning between the cropland-related feeds (forage crops and cropland pasture) and the permanent-grassland related feeds (permanent pasture) under consideration of the production per unit area for these two groups of phytomass (see Figure 3.71, p. 245).

For the feed categories included in the FBS, this study is not much more than a reproduction of the values in the FBS so far as the *total* use as animal feed is concerned, that is, the total use for the whole animal food sector. What this study does provide in addition to that is a simple estimate of the distribution of this total feed use between the separate animal sub-systems.

In contrast, for the feed categories animal forage crops, pasture, and by-products and residues, the estimated feed use is essentially to regard as a result of this study. For these categories, the feed use is an outcome of the matching and tuning with different data, performed under the stipulation that the calculated feed energy requirements are to be complied with. Therefore, the feed use of these categories is presented as results (see Section 3.2.2, p. 135).

Use of litter for bedding

Besides the feed use, also use of litter for bedding in animal confinements was included in this survey of biomass flows in the animal food sector. As described in Section 2.3.1 (p. 29), cereals straw and stover is the only option included in the FPD model for use as bedding material.

In this study, assumed values on specific use of litter per amount of manure generated were based on only a few data sources.[108] From these sources, very rough figures were estimated (Table 3.13). The zero values for the cattle systems in the region South & Central Asia were chosen due to the extraordinary conditions in that region. They should be interpreted that no reasonable values on litter use could be identified, rather than as an estimate of the real litter use. The background to choosing the value zero, and the implications of this choice for the results, are further dealt with in the discussion section below (mainly pp. 197 sq., p. 211, and p. 215).

In the FPD model, the required use of litter for bedding is calculated by multiplying the specific litter use values with the amount of manure (feces plus urine) generated (calculated on a dry matter basis). For obvious reasons, we assumed no litter use for cattle manure generated at grazing on pastures or at post-harvest grazing of crop by-products in field (that is, grazing of stubble and alike). Thus, the specific litter use values in Table 3.13 for the cattle sub-systems were applied to manure generated at intake of *all feedstuff categories except pastures* and, to some extent, *fibrous by-products* (for speci-

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[108] The most useful source on this topic was SNV [1997, pp. 109-117], which gives detailed data on current and future bedding practices in Swedish cattle systems. This reference was the major basis for assumptions on litter use for the cattle sub-systems in the industrial regions North America & Oceania and West Europe. For deep-bedded systems, in which manure is accumulated on the stall floor, SNV states values corresponding to a use of 2 kg straw per kg manure (on DM basis); the mix of manure and straw having a DM content of 25-30%. Since deep-bedded systems are those that require the largest amounts of litter, this value can be considered as an upper limit of the specific litter requirements for cattle. Current use in industrial countries is much lower. Typical specific litter use values for Sweden are 0.6-0.7 kg straw per kg manure (DM basis) for beef cattle systems, and about 0.2 for dairy cattle systems (counted on entire herd respectively, DM basis). In both beef and dairy cattle systems, growing-finishing bulls & heifers are normally reared on slatted floors without bedding. For the non-industrial regions, the litter use values for cattle were based on simple assumptions. For all animal categories, we have chosen 1.0 kg straw per kg manure (DM basis) as a standard value, that is, half of that for deep-bedded systems. For pig and poultry, less data were available. In comparison with cattle, the dry matter density of pig and poultry manure are higher, and therefore the specific litter requirements are generally lower. In industrial countries, growing pigs are nowadays mostly reared in non-bedded systems. On the contrary, in non-industrial countries animal bedding in pig production is common — Smil [1983, p. 180] reports that in East Asia straw demand for pig production is vigorous. As standard value on specific litter use for pig manure we have chosen 0.6 kg straw per kg manure (DM basis). For poultry, we assumed slightly higher litter use in industrial regions than in non-industrial ones. In industrial countries, animals are with few exceptions kept in confinements. In contrast, in non-industrial countries, backyard production systems, in which the animals freely scavenge for seeds, spilled grains and various residues, are still common.

fication of cattle feed categories, see Table 2.3, p. 34). The specific litter use for manure related to intake of fibrous by-products was calculated as a ratio of the specific litter use in Table 3.13. These ratios were only rough and generalized assumptions regarding the extent of crop by-products being fed to animals in confinement, based on general knowledge on the production systems in the different regions. For North America & Oceania and West Europe the ratio was set equal to 83 percent, for East Europe to 55 percent, and for all other regions to zero.

**Table 3.13** Assumed specific litter use for animal bedding in this study.

| Animal sub-system and category | East Asia | East Europe | Latin America & Carib. | North Africa & W. Asia | North America & Oceania | South & Central Asia | Sub-Saharan Africa | West Europe |
|---|---|---|---|---|---|---|---|---|
| **Cattle milk** | | | | | | | | |
| Dairy cow | 1.00 | 0.75 | 0.75 | 1.00 | 0.50 | 0 | 1.00 | 0.25 |
| Dairy repl. heifer | 1.00 | 0.75 | 0.75 | 1.00 | 0.50 | 0 | 1.00 | 0.50 |
| Dairy bulls & heifers | 1.00 | 0.50 | 0.75 | 1.00 | 0 | 0 | 1.00 | 0 |
| Average all animals | 1.00 | 0.71 | 0.75 | 1.00 | 0.41 | 0 | 1.00 | 0.26 |
| **Beef cattle carcass** | | | | | | | | |
| Beef cow | 1.00 | 1.00 | 0.75 | 1.00 | 1.00 | 0 | 1.00 | 1.00 |
| Beef repl. heifer | 1.00 | 0.75 | 0.75 | 1.00 | 0.50 | 0 | 1.00 | 0.50 |
| Beef bulls & heifers | 1.00 | 0.50 | 0.75 | 1.00 | 0 | 0 | 1.00 | 0 |
| Average all animals | 1.00 | 0.82 | 0.75 | 1.00 | 0.49 | 0 | 1.00 | 0.51 |
| **Pig carcass-side** | | | | | | | | |
| All animals | 0.60 | 0.20 | 0.60 | 0.60 | 0.10 | 0.60 | 0.60 | 0.10 |
| **Chicken egg** | | | | | | | | |
| All animals | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 |
| **Meat-type chicken carcass** | | | | | | | | |
| All animals | 0.15 | 0.30 | 0.30 | 0.15 | 0.30 | 0 | 0 | 0.30 |

Values refer to the amount of litter (in the FPD model, cereals straw and stover) used per the amount of feces and urine generated by animals in confinement (see text for further explanations). Values on DM basis.

The model depiction of animal bedding also includes description of the dry matter loss for the bedding material that occurs during use, that is, the oxidational losses that occur when in place in the confinement. Only a very simple assumption was made for this loss — for all regions, the dry matter loss during use was uniformly set equal to 20 percent.

### Feed processing

Feed treatment processes for purposes of conservation and nutrient-enhancement are also part of the FPD model (see Section 2.3.1, p. 30). Processes included are drying (hay-making) and ensiling of grass-legume, as well as ensiling of whole-cereals and sugar-beet tops to mention the most important. Processing of crop by-products, such as cereals straw, for nutrient-enhancement purposes was not taken into consideration, although this occurs in some regions, such as East Asia.[109]

Generally speaking, data regarding the performance of these processes in different regions are rare. For all hay-making and ensiling processes in all regions, the dry matter loss in the processes were uniformly assumed to be 20 percent, that is, 20 percent of the organic matter of the feedstock is oxidized or otherwise lost during the entire process from the *harvest* (that is, cutting in field) to the actual *intake* of the processed feedstuff. This figure was based on only a few data sources.[110]

Generation and recovery of by-products

As we described in Section 2.3.1 (p. 30), the amounts of by-products generated from animal food production are essentially determined by the input variables for productivity and the feed composition values. Besides these parameters, variables in the FPD model for which values have to be stated are the recovery rates of manure (for definition of 'recovery rate', see Section 2.1.6, p. 19), and the emission factors for methane from enteric fermentation.

Values on manure recovery rates were based on simple assumptions — no deeper analysis was made of the variations, for instance, between different manure handling systems or in the degree of collection of manure from pastures. For manure generated at grazing, recovery rates were set equal to zero in all regions — thus, we assumed no collection of manure from pastures. For all other cattle feedstuffs, except the category fibrous by-products, we assumed 90 percent as a flat value of the recovery rate for all animal sub-systems in all regions (for specification of cattle feedstuffs, see Table 2.3, p. 34).

For fibrous by-products, slightly more diversified values were chosen, since such by-products are consumed both by being provided to animals in confinements (or similar) as well as by grazing directly in field (after harvest). The recovery rates of manure related to intake of crop by-products were based on rough assumptions regarding the extent of crop by-products being fed to animals in confinement, relying on general knowledge on the production systems in the different regions. For North America and West Europe, we assumed a manure recovery rate of 75 percent, for East Europe 50 percent, and for all other regions the recovery rate was set equal to zero.

For methane generated at enteric fermentation, values were chosen in correspondence with the methane emission factors suggested by the IPCC's program on greenhouse gas

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[109] [Simpson et al. 1994]

[110] Church [1991, p. 72] states a range of 11-44% DM loss for grass hay, and 24-49% for legume hay in the USA; Bolsen [1995, p. 171] reports 7-40% as a general DM loss range for silage in the USA, and SNV [1997] assumed 20% DM loss to be a representative value for hay and silage in Sweden today, as well as in scenarios in that study for the Swedish agriculture in 2021.

inventories.[111] Since these factors are no more than rules of thumb this approach gives only approximate figures on the methane production. Table 3.14 presents the methane factors used.

**Table 3.14** Assumed methane emission factors in this study.

| Animal sub-system and feedstuff | All regions |
|---|---|
| **Cattle milk and beef cattle carcass** | |
| Concentrate products[a] | 4.0% |
| Harvested-conserved forage[b] | 6.0% |
| Pasture | |
| Cropland pasture | 6.0% |
| Native permanent pasture | 6.5% |
| Oversown permanent pasture | 6.0% |
| Non-fibrous by-products | |
| Cassava leaves, sugar beet tops | 6.0% |
| Maize hominy feed, sorghum hominy feed | 4.0% |
| Other[c] | 5.0% |
| Fibrous by-products | |
| Maize stover, sorghum stover | 7.0% |
| Sugarcane tops & leaves, groundnut stalks | 6.5% |
| Other[d] | 7.5% |
| **Pig carcass-side** | |
| Concentrate products[e] | 0.6% |
| Forage products[f] | 0.9% |
| Protein supplement products | 0.6% |
| Non-fibrous by-products | |
| Potato tops | 1.3% |
| Maize hominy feed, sorghum hominy feed | 0.6% |
| Other | 0.9% |
| Protein supplement by-products[g] | 0.6% |
| Non-eaten food | 1.3% |

Values refer to the GE content of the amount of methane generated as share of the GE content of the feed intake (HHV basis). Further specifications of feedstuffs, besides the notes below, are given in Table 2.3 (p. 34) and Table 2.5 (p. 41).

[a] Cereals grains, cassava tubers and cassava meal.

[b] Grass-legume hay, grass-legume silage and whole-cereals silage.

[c] Wheat mill run, rice bran, molasses and sugar beet pulp.

[d] Cereals straw other than rice straw, oil crops straw other than groundnut stalks, rice hulls, and sugarcane bagasse.

[e] Cereals grains, cassava meal and potato tubers.

[f] Forage-vegetables.

[g] Oil crops meals, brewer’s grains, meat & bone meal and cotton meal.

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[111] [Houghton et al. 1996, pp. 4.16-17, 4.35]

### 3.1.3 Production of converted vegetable food

Conversion efficiency

Overall, there are relatively little data available on yields of products and by-products for processes converting crops to vegetable food commodities. The FAOSTAT Food Balance Sheets (FBS) contain data which in combination enable calculation of rough estimates of process yields. However, most of those data are not adequate enough to function as a consistent basis for more detailed estimates of the performance of these processes on a country or region basis.

**Table 3.15** Values in this study on a selection of major product yield parameters for production of vegetable food commodities.

| Commodity category and commodity | All regions | East Asia | East Europe | Latin America & Carib. | North Africa & W. Asia | North America & Oc. | South & Central Asia | Sub-Saharan Africa | West Europe |
|---|---|---|---|---|---|---|---|---|---|
| **Cereals commodities**[a] | | | | | | | | | |
| Wheat straight flour | | 0.78 | 0.78 | 0.78 | 0.78 | 0.73 | 0.78 | 0.78 | 0.73 |
| White rice | | 0.71 | 0.71 | 0.71 | 0.71 | 0.71 | 0.71 | 0.71 | 0.71 |
| Maize grits, meal & flour | | 0.79 | 0.79 | 0.79 | 0.79 | 0.69 | 0.79 | 0.79 | 0.69 |
| Sorghum grits, meal & flour | | 0.79 | 0.79 | 0.79 | 0.79 | 0.69 | 0.79 | 0.79 | 0.69 |
| **Sweeteners**[b] | | | | | | | | | |
| Sucrose recovery, sugar cane stems | 0.83 | | | | | | | | |
| Sucrose recovery, sugar beet roots | 0.88 | | | | | | | | |
| **Vegetable oils**[c] | | | | | | | | | |
| Lipid recovery, soybean seeds | 0.95 | | | | | | | | |
| Lipid recovery, groundnut seeds | 0.90 | | | | | | | | |
| Lipid recovery, sunflower kernels | 0.90 | | | | | | | | |
| Lipid recovery, canola seeds | 0.95 | | | | | | | | |
| Lipid recovery, stripped oil palm fruit bunches | 0.95 | | | | | | | | |
| **Other** | | | | | | | | | |
| Barley beer[d] | 0.51 | | | | | | | | |

All values on DM basis. For values on partition and composition of products and feedstocks, see Table A1.II, Appendix 1.

[a] Values refer to yield of the stated products as share of wheat grains, rice grains (paddy), maize grains and sorghum grains respectively.

[b] Values refer to the amount of sucrose recovered into *raw sugar* as share of the amount of sucrose in the stated feedstock.

*Notes continue on next page.*

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[c] Values refer to the amount of lipid recovered into *refined oil* as share of the amount of lipid in the stated feedstock.

[d] Value refers to yield of barley beer as share of barley grains.

Generally speaking, for vegetable food processing, the variation in conversion efficiency between, for instance, different mills, is relatively small. Particularly in comparison with animal food production, the conceivable range in conversion efficiency may be considered as minor. Basically speaking, the reason for these limited differences in efficiency is the essentially ‘extracting’ character of the processes (see Section 2.4, p. 44).

In this study, therefore, we took a rather simple approach for the assumptions on conversion efficiencies for vegetable food commodities. For all sub-systems, except the cereals milling systems, we assumed identical values in all regions for each system. The slightly more detailed description for cereals milling processes was chosen due to their relatively large magnitude in comparison to other vegetable food sub-systems.

The estimates of process yields for the cereals milling sub-systems were based on a combination of data compiled from the FBS and other sources.[112] For other vegetable products, a variety of sources were used for estimating the process yields.[113] Table 3.15 presents assumed values for a selection of the principal variables determining conversion efficiency in production of converted vegetable food commodities.

As can be seen in Table 3.15, values are stated for all processes in all regions, although each process is actually not occurring in each region. The reason for this is to enable inter-regional comparisons of region-inherent efficiencies, and analysis of the relative importance influence of trade flows. In cases where a particular model sub-system has

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[112] The ME values in the FBS are produced by applying ME content factors for each commodity included in the balance sheets. When commodities are not consumed in the primary form in which they are presented in the FBS – as is the case with the cereals commodities – these ME factors reflect both the ME content of the product actually consumed, as well as the extent and characteristics of the conversion process. By dividing the ME factors for each region with assumed values on ME content of the products actually consumed, rough estimates of the process yields were obtained for each region. In addition to the FBS data, Matz [1991, pp. 498-502] and Pomeranz [1987, pp. 156-157, 382, 392-393] gave figures, representative mainly for industrial countries, on process yields for wheat, rice and maize. These figures were taken into consideration for the regions North America & Oceania and West Europe. For sorghum the same values as for maize were used in North America & Oceania and West Europe, since the grains of these crops are similar in structure and composition.

[113] Boucqué & Fiems [1988] present yields data on several processes of interest from the perspective of use of the by-products generated (among others, wheat and rice milling, sugar-beet processing, soybean oil, canola oil, and beer production). Relatively detailed process data on sugar-cane processing are given by Singh & Solomon [1995, pp. 20-21] and Paturau [1989, p. 10]; on sugar-beet processing by Bichels [1988], and on palm oil production by Sauerborn & Germer [1998] and Olie & Tjeng [1974, p. 48]. Various yields data are given by Waldroup & Smith [1989, p. 247] (soybean oil), Downey & Röbbelen [1989, p. 359] (canola oil), Gascon et al. [1989, p. 492] (palm oil), and Parra & Escobar [1985] (brewer’s grains). Simpson et al. [1994, App. 12.1] give yields data for several by-products (molasses, beet pulp, oil meals and brewers grains) valid for Chinese process standards.

no counterpart in the real system — such as palm oil production in West Europe — the values describing the model system are to be regarded as no more than equivalent-values (or default-values), included merely for enabling the above-mentioned comparisons and analyses. (Rationale and concepts for this are further unfolded in the section ‘Extent and mix of phytomass appropriation’, p. 111.)

Generation and recovery of by-products

The amounts of by-products generated from vegetable food processing are entirely determined by the input variables for process yield in combination with the feedstock partition and composition values. Hence, no additional values need to be stated. A complete list of composition and partition values for feedstocks, products and by-products is given in Appendix 1.

### 3.1.4 Production of phytomass

Cultivation of crops

In general, statistics on crop production is limited to production data of commercial, mostly dried, crop products within the group edible-type crops (crop groups are specified in Table 2.6, p. 47). FAOSTAT, for example, contains data on the production of products for all major edible-type crops. However, FAOSTAT does not include by-products of edible-type crops, nor animal forage crops.

As we described in Section 2.5.2 (p. 49), the FPD model description of crop production is simple — basically, it includes only variables essential for calculating the required above-ground production of crops, as well as the amount of crop by-products supplied. These variables are phytomass dry matter partition and recovery rates, and internal uses of crop products and by-products for purposes of seeding and mulching.

*Dry matter partition and recovery rates*

For dry matter partition — or if using the prevailing term, ‘harvest index’ — and recovery rates, there are no data compiled on a regular basis. Besides harvest index, published data related to these parameters are frequently expressed as a ‘residue multiplier’, which describes the crop residue yield in relation to the yield of the particular product (grain, tuber etc). However, in many cases published figures on residue multipliers lack essential descriptions of how they are derived. For instance, it is often not clearly specified whether the multiplier is based on dry weights, or as-is weights (for example, in field), or on a combination of these. In particular when it comes to crops with a high water content — such as sugar cane, and starchy roots and tubers — omission of the weight basis renders figures of little value. Lack of specification whether the residue multiplier refers to total *produced* amount (for instance, standing plant mass in field) or to *harvested* amount (for example, cut and removed from field), and how these amounts are measured, is another common source of ambiguity. For instance, different cutting

**Table 3.16** Assumed partition (harvest index) of crops in this study.

| Crop category and crop | East Asia | East Europe | Latin America & Carib. | North Africa & W. Asia | North America & Oc. | South & Central Asia | Sub-Saharan Africa | West Europe |
|---|---|---|---|---|---|---|---|---|
| ***Cereals*** | | | | | | | | |
| **Wheat** | | | | | | | | |
| Grain | 0.40 | 0.40 | 0.40 | 0.40 | 0.45 | 0.37 | 0.30 | 0.50 |
| Straw | 0.60 | 0.60 | 0.60 | 0.60 | 0.55 | 0.63 | 0.70 | 0.50 |
| **Rice** | | | | | | | | |
| Grain[a] | 0.50 | 0.45 | 0.45 | 0.45 | 0.45 | 0.40 | 0.40 | 0.45 |
| Straw | 0.50 | 0.55 | 0.55 | 0.55 | 0.55 | 0.60 | 0.60 | 0.55 |
| **Maize** | | | | | | | | |
| Grain | 0.25 | 0.35 | 0.25 | 0.25 | 0.45 | 0.22 | 0.22 | 0.45 |
| Stover | 0.75 | 0.65 | 0.75 | 0.75 | 0.55 | 0.78 | 0.78 | 0.55 |
| **Sorghum** | | | | | | | | |
| Grain | 0.25 | 0.35 | 0.25 | 0.25 | 0.45 | 0.22 | 0.22 | 0.45 |
| Stover | 0.75 | 0.65 | 0.75 | 0.75 | 0.55 | 0.78 | 0.78 | 0.55 |
| **Barley** | | | | | | | | |
| Grain | 0.40 | 0.40 | 0.40 | 0.40 | 0.45 | 0.35 | 0.35 | 0.45 |
| Straw | 0.60 | 0.60 | 0.60 | 0.60 | 0.55 | 0.65 | 0.65 | 0.55 |
| ***Starchy roots*** | | | | | | | | |
| **Cassava** | | | | | | | | |
| Tuber | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 |
| Top[b] | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 |
| **White potato** | | | | | | | | |
| Tuber | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 |
| Top | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 |
| **Sweet potato** | | | | | | | | |
| Tuber | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 |
| Top | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 |
| ***Sugar crops*** | | | | | | | | |
| **Sugar cane** | | | | | | | | |
| Stem | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 |
| Top & leaves | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 |
| **Sugar beet** | | | | | | | | |
| Root | 0.60 | 0.65 | 0.60 | 0.60 | 0.65 | 0.60 | 0.60 | 0.65 |
| Top | 0.40 | 0.35 | 0.40 | 0.40 | 0.35 | 0.40 | 0.40 | 0.35 |
| ***Oil crops*** | | | | | | | | |
| **Soybean** | | | | | | | | |
| Seed | 0.45 | 0.40 | 0.40 | 0.40 | 0.45 | 0.40 | 0.40 | 0.45 |
| Stalk & husks | 0.55 | 0.60 | 0.60 | 0.60 | 0.55 | 0.60 | 0.60 | 0.55 |
| **Groundnut** | | | | | | | | |
| Pod[c] | 0.45 | 0.45 | 0.40 | 0.40 | 0.45 | 0.40 | 0.40 | 0.45 |
| Stalk | 0.55 | 0.55 | 0.60 | 0.60 | 0.55 | 0.60 | 0.60 | 0.55 |
| **Sunflower** | | | | | | | | |
| Achene[d] | 0.30 | 0.35 | 0.30 | 0.30 | 0.35 | 0.30 | 0.30 | 0.35 |
| Stalk & threshed heads | 0.70 | 0.65 | 0.70 | 0.70 | 0.65 | 0.70 | 0.70 | 0.65 |
| **Canola** | | | | | | | | |
| Seed | 0.30 | 0.35 | 0.30 | 0.30 | 0.35 | 0.30 | 0.30 | 0.35 |
| Stalk & husks | 0.70 | 0.65 | 0.70 | 0.70 | 0.65 | 0.70 | 0.70 | 0.65 |

*Table continues on next page*

**Table 3.16** (continued)

| Crop category and crop | East Asia | East Europe | Latin America & Carib. | North Africa & W. Asia | North America & Oc. | South & Central Asia | Sub-Saharan Africa | West Europe |
|---|---|---|---|---|---|---|---|---|
| **Oil palm** | | | | | | | | |
| Fruit bunch | 0.40 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 |
| Leaves | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 |
| Trunk | 0.10 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |

Values refer to partition of dry matter production into each stated part (DM basis). For cereals, sugar cane and oil crops except groundnut, the values refer to share of above-ground production, for the remaining ones to share of whole-plant production. All values refer to the actual in-field dry matter partitioning at the time of harvest — leaves that have been detached during growth, or other plant mass shed before harvest, are not included in the ratios. For values on composition and further partitioning (of starchy root tubers, groundnut pod, sunflower achene, and oil palm fruit bunch), see Table A1.II, Appendix 1.

[a] Refers to rice grains in hulls (paddy).

[b] Includes attached leaves. For values on partitioning between leaves and top excluding leaves, see Appendix 1.

[c] Includes seed and husk.

[d] Includes kernel and husk.

heights and shedding of senescent plant mass can give large variances for the quota between product and residue, and lead to major difficulties in interpreting the presented data[114].

However, some sources were found which in combination with own estimates gave a basis for rough estimates of harvest indices and recovery rates in each region.[115] The chosen values on *harvest index* are shown in Table 3.16 above.

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[114] [Smil 1983, pp. 164 sq.] and [Hay 1995].

[115] Kossila [1984] gives figures on residue multipliers for all major categories of crops specified for 7 world regions, the regional structure being similar to the one used in this study. This reference was the most useful source, although it lacked clear specification of the basis of its figures. Simpson et al. [1994, app. 12.1], contains residue multipliers for a large number of crops valid for China, and was the major source for East Asia. Hay [1995] compiled representative values of harvest index for major crops in different parts of the world, mainly industrial countries. Similarly, Kertesz [1984] presents a compilation of harvest index values for a large number of cereals varieties, applicable mainly to West European cultivation standards. Some sources contain figures (harvest index mainly) for separate crops and countries, and were taken as fairly representative value for the crop and country in question: McIntire et al. [1992, p. 126] (sorghum—Nigeria and Ethiopia), Alexander [1985, pp. 45-46] (“standard cane”), Singh & Solomon [1995, p. 215] (sugarcane—India), Cheva-Isarakul [1990] (soybean, groundnut—Thailand), Hartley [1988, p. 151] (oil palm—Malaysia, Nigeria). Many sources were found containing results from harvest index studies at research stations, experimental plots and alike; these values were not taken as representative but were useful as reference points for each crop [Bekele et al. 1992, Bhardwaj & Bhagsari 1991, Calderini et al. 1995, Hrustic et al. 1991, Jedel & Helm 1994, Mishra et al. 1992, Osaki 1995a, Osaki 1995b, Prihar & Stewart 1991, Ramanujam & Lakshmi 1984, Reddy et al. 1995, Roberts et al. 1993, Sharma & Varshney 1995, Smith 1993]. The effect of cutting height on residue recovery rates was based on Staniforth [1979, p. 40]. Very few data were found on variations in harvesting practices in different regions and their influence on residue recovery rates; however, some reference points were found in Edwards [1991] and Weiss [1983].

As can be seen in Table 3.16, values are stated for all crops in all regions, although each crop is actually not grown in each region. As already mentioned in Section 3.1.3, the reason is to enable inter-regional comparisons of region-inherent efficiencies, and analysis of the relative importance of the influence of trade flows. In cases where a particular model sub-system has no counterpart in the real system — such as oil palm production in West Europe — the values describing the model system are to be regarded as no more than equivalent-values (or default-values), included merely for enabling the above-mentioned comparisons and analyses.

A partial list of the assumed values for *recovery rates* are given in Table 3.17. Recovery rates for those crop flows not displayed in the table were assumed to be close to 100 percent. (For definition of 'recovery' and 'recovery rate', see Section 2.1.6, p. 19.) In the cases of crop by-products, also plant material eaten by animals grazing in field after harvest is included in 'recovery'. It should be observed that all these values on recovery rates are no more than rough estimates, and they are to be interpreted with caution.

**Table 3.17** Selection of assumed values of recovery rates for crop products and by-products in this study.

| Crop category and crop | East Asia | East Europe | Latin America & Carib. | North Africa & W. Asia | North America & Oc. | South & Central Asia | Sub-Saharan Africa | West Europe |
|---|---|---|---|---|---|---|---|---|
| **Cereals** | | | | | | | | |
| Cereals straw & stover | 0.80 | 0.75 | 0.80 | 0.80 | 0.70 | 0.90 | 0.90 | 0.70 |
| **Sugar crops** | | | | | | | | |
| Sugar crops tops & leaves | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 |
| **Oil crops** | | | | | | | | |
| Soybean stalk & husk | 0.80 | 0.75 | 0.80 | 0.80 | 0.70 | 0.90 | 0.90 | 0.70 |
| Groundnut stalks | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 |
| Sunflower stalk & threshed heads | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 |
| Canola stalk & husk | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 |
| **Grass-legume** | | | | | | | | |
| Grass-legume, temp. & trop. species | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 |
| **Whole-cereals** | | | | | | | | |
| Whole-maize | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 |

Values refer to the amount of plant mass recovered as share of the amount of plant mass generated (on DM basis).

For crop by-products, assumptions on recovery rates were directly coordinated with those on assignment for use as feed (see Table 3.20, p. 102). In accordance with the assumptions on assignment, we assumed that recovery rates of crop by-products were generally higher in the non-industrial regions than in the industrial ones.

*Internal uses for seeding and for soil conservation and mulching*

Values on internal use of crop products as seeds were taken from FAOSTAT Food Balance Sheets (global average for 1992-94 was used in all regions). Use as seeds ranges between 1 to 8 percent depending on the type of crop (measured as share of the amount of new product generated on dry-weight basis).

In the FPD model, internal use of crop by-products for soil conservation and mulching includes both by-products *left in field* to decompose (all crop production), and *externally supplied* cereals straw and stover used as mulch (in production of tubers and vegetables only). The values used in this study are hardly more than qualified guesses since very little data were found on this topic.[116] Thus, the values were determined by very simple assumptions.[117] The main reason for including them, despite the poor data basis, was the ambition in this study to obtain a complete picture of all principal types of by-products use within the food system.

*Relations between temperate and tropical phytomass flows*

In the FPD model, the cultivated grasses and legumes, as well as the pastures, are represented by two separate flows, ‘temperate’ and ‘tropical’ (see Section 2.5.1, p. 45).

In this study, the relation between ‘temperate’ and ‘tropical’ was given a *uniform* value *within each region* for all the applicable phytomass flows, that is, for cultivated-harvested grass-legume (forage crops), cropland pasture, native permanent pasture, and oversown permanent pasture (see Table 2.6, p. 47). The relation ‘temperate’/‘tropical’ was set equal to 50/50 for East Asia, 100/0 for East Europe, 30/70 for Latin America & Caribbean, 80/20 for North Africa & West Asia, 90/10 for North America & Oceania, 30/70 for South & Central Asia, 25/75 for Sub-Saharan Africa and 100/0 for West Europe.

These values are very rough assumptions based on general knowledge of the character of the regions — thus, no particular source or approach was used for making these assumptions. These divisions into ‘temperate’ and ‘tropical’ should, therefore, primarily be regarded as a maneuver to enhance the internal consistency of the grass-legume categories within each region, rather than as an estimate of the actual extension of these species groups in each region.

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[116] Smil [1983, pp. 174-177] gives examples on utilization shares of rice straw and other crop residues for Taiwan, China, as well as some other countries. Edwards [1991] states such figures for the UK. The figures from Taiwan indicate that the amount of straw used as mulch can be as high as 20% of supply, whereas the figures for UK point at a utilization level on 3-4% of supply. In both Taiwan and the UK, the dominating use of straw and stover is mushroom composting.

[117] For cereals straw and stover, and soybean straw, the amount ‘left in field’ was set equal to zero for all regions except North America & Oceania (5% of the amount ‘recovered’). For all other crops, the amount left in field was set equal to zero. Externally supplied straw and stover was calculated as share of product generated on DM basis. For cassava tuber and sweet potato tuber, mulch use was set equal to 10% in all regions. For vegetables, mulch use was set equal to 100% in all regions.

## Production and grazing of pasture

As we noted in Section 2.5.3 (p. 50), the grazing sector consists of a great variety of systems. The number of different plant species involved is very large, the intensity per unit area varies considerably, and grazing is often combined with other land-use activities within the same area.

The description in the FPD model is, however, very simple. In essence, the representation of the grazing sector is based on equivalent-character depiction (see Section 2.1.4, p. 17). This equivalent-character entailed difficulties when choosing values on the model parameters, since data from a wide range of different species and systems had to be taken into consideration. Thus, the chosen values in this study are averages over wide intervals.

### *Pasture utilization*

For pasture consumption (that is, the actual intake of pasture by animals), data produced on a regular basis exist in many industrial countries. In contrast, for pasture production (that is, pasture growth) and pasture utilization (the quota between intake and growth), there are only sporadic data, and data pertaining to countries or regions are very rare.

**Table 3.18** Assumed values on pasture utilization in this study.

| Pasture type | East Asia | East Europe | Latin America & Carib. | North Africa & W. Asia | North America & Oc. | South & Central Asia | Sub-Saharan Africa | West Europe |
|---|---|---|---|---|---|---|---|---|
| Cropland pasture | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 |
| Permanent pasture, native | 0.48 | 0.50 | 0.46 | 0.49 | 0.50 | 0.46 | 0.46 | 0.50 |
| Permanent pasture, oversown | 0.52 | 0.55 | 0.52 | 0.54 | 0.54 | 0.52 | 0.51 | 0.55 |

Values refer to the intake of plant mass as share of the above-ground growth of *edible* plant mass (on DM basis, annually) (See Section 2.5.3, pp. 50 sq., as well as p. 214, for definition and comments on the pasture utilization concept.) The values shown in the table are averages for the defined relations between 'temperate' and 'tropical' flows, and the assumed pasture utilization values for each pasture flow. The relations between 'temperate' and 'tropical' flows in each region are given in the section 'Relations between temperate and tropical phytomass flows' (p. 95). The assumed values on pasture utilization were, for permanent pasture, 0.50 for native temperate species, 0.45 for native tropical species, 0.55 for oversown temperate species, and 0.50 for oversown tropical species. For cropland pasture, the assumed value for both temperate and tropical species was 0.65.

Therefore, the estimates of pasture utilization in this study were based on only a few sources.[118] As a general rule, pasture utilization was assumed to be lower for the perma-

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[118] These estimates are mainly based on SNV [1997, p. 107] and Simpson et al. [1994, p. 458]. SNV states a utilization of 0.50 for permanent pasture and 0.65 for cropland pasture as representative values for Sweden today. Simpson et al report 0.60 for 'arid grassland' and 'temperate dry grasslands', and 0.80 for

*Notes continue on next page.*

nent pastures than for the cropland pastures, due to the higher degree of control of vegetation as well as of grazing activities in the latter case. Analogously, pasture utilization for the native permanent pastures was assumed to be inferior to that of the oversown permanent pastures, since the occurrence of palatable herbage generally is larger in oversown pastures. Table 3.18 shows the resulting average values of pasture utilization assumed, specified with respect to the three principal pasture types in the FPD model.

### *Feed energy density of pasture*

As mentioned above, the number of species in the grazing sector is relatively large, and therefore the variation in chemical composition within the sector is considerable. In addition, the nutritive content of the actually consumed herbage mass varies considerably depending of the growth state of the plant. For an individual species, the energy content at maturity may be only half of that at its vegetative stage (measured as net energy for maintenance, $NE_m$). Thus, there is a great variability in the pasture vegetation, which makes it difficult to make general assumptions on the nutritive value of pastures.

**Table 3.19** Assumed energy densities for pasture in this study.

| Pasture type | Unit | East Asia | East Europe | Latin America & Carib. | North Africa & W. Asia | North America & Oc. | South & Central Asia | Sub-Saharan Africa | West Europe |
|---|---|---|---|---|---|---|---|---|---|
| Cropland pasture | DE | 11.5 | 12.0 | 11.3 | 11.8 | 11.8 | 11.3 | 11.2 | 12.0 |
| | $NE_m$ | 5.8 | 6.2 | 5.6 | 6.0 | 6.1 | 5.6 | 5.6 | 6.2 |
| | $NE_g$ | 3.4 | 3.7 | 3.2 | 3.6 | 3.6 | 3.2 | 3.2 | 3.7 |
| Permanent pasture, | DE | 10.5 | 11.0 | 10.3 | 10.8 | 10.9 | 10.3 | 10.2 | 11.0 |
| oversown | $NE_m$ | 5.0 | 5.4 | 4.9 | 5.3 | 5.3 | 4.9 | 4.8 | 5.4 |
| | $NE_g$ | 2.7 | 3.0 | 2.5 | 2.9 | 3.0 | 2.5 | 2.5 | 3.0 |
| Permanent pasture, | DE | 8.9 | 9.3 | 8.7 | 9.1 | 9.2 | 8.7 | 8.7 | 9.3 |
| native | $NE_m$ | 3.8 | 4.1 | 3.7 | 4.0 | 4.0 | 3.7 | 3.6 | 4.1 |
| | $NE_g$ | 1.5 | 1.8 | 1.4 | 1.7 | 1.7 | 1.4 | 1.4 | 1.8 |

Values in digestible energy (DE) and net energy for maintenance ($NE_m$) and growth ($NE_g$) for beef cattle (MJ/kg DM). The values shown are averages for the defined relations between ‘temperate’ and ‘tropical’ flows, and the assumed DE values for each pasture flow. The relations between ‘temperate’ and ‘tropical’ flows in each region are given in the section ‘Relations between temperate and tropical phytomass flows’ (p. 95). The assumed DE values were, for permanent pasture, 9.3 for native temperate species, 8.5 for native tropical species, 11.0 for oversown temperate species, and 10.0 for oversown tropical species. For cropland pasture they were 12.0 for temperate, and 11.0 for tropical species. $NE_m$ and $NE_g$ values were calculated from the stated DE value (which is the actual input parameter) according to equations valid for beef cattle (given in Section 2.3.3, p. 36).

In addition, there are large variances in data availability as regards composition of pasture. Generally speaking, there are more data available for temperate species than for

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‘warm grasslands’ as representative values for China. Holmes [1987, p. 98] states 0.60 as mean value for ‘lowland grassland’ for the UK (late 1970s).

tropical ones, and there are certainly far more data available for domesticated species than for native species. For domesticated temperate species, such as alfalfa and clovers, composition data for separate species are normally available also at different stages of growth, as well as for different forms of treatment (such as, drying and ensiling).

These circumstances implied that the assumptions on energy content of the flows representing pasture — particularly as regards those for native permanent pastures — had to be based mainly on isolated values for individual species at different stages of growth. A few sources containing data with reference to a wider range of species and pasture types were also available.[119] In general, the DE content of the tropical-species flows (see Table 2.6, p. 47) was assumed to be roughly 10 percent lower than those of the temperate-species flows.[120] Also, the native permanent pastures were assumed to have somewhat lower DE content than the oversown permanent pastures. The oversown permanent pastures were, in turn, assumed to have lower DE density than the cropland pastures. Table 3.19 gives a list of the resulting average values of feed energy densities assumed in this study, specified with respect to the three principal pasture types in the FPD model.

### 3.1.5 Distribution, trade & storage

As we described in Section 2.6 (p. 53), the FPD model contains description of losses during storage and delivery, as well as trade between regions, expressed as net-import to region.

For flows included in the FAOSTAT Food Balance Sheets (FBS) which in the FPD model are represented by *products*, values on losses during storage and delivery were

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[119] For the predominantly tropical regions, some of the more important sources were the following: For the native savannas of Brazil (*cerrados*) and Colombia and Venezuela (*llanos*), Fisher et al. [1992, p. 48], reported a digestibility range of 24-43%, which corresponds to 4.2-7.7 MJ DE/kg DM if using a GE value of 18 MJ/kg DM. For introduced *Brachiaria*, digestibility was reported to have a range corresponding to 9.7-12.6 MJ DE/kg DM. In the humid inter-Andean valleys, Quiroz et al. [1997, p. 164], reported digestibility ranges for ‘native pastures’ corresponding to 8.1-11.7 MJ DE/kg DM, and 11-14 MJ DE/kg DM for ‘introduced pastures’. In other vegetation zones of the Andes, digestibility is generally lower, 7.2-10.8 for native pastures [Ibid.]. In a model of grazing systems in the humid tropics in Central America [Bouman & Nieuwenhuyse 1999], the model value of ‘natural’ pastures (unfertilized) was set equal to 8.8 MJ DE/kg DM. For Malaysia, Liang [1996, p. 134], stated a nutritive content (in ME) for ‘legume-guinea pasture’ corresponding to 7.3-9.5 MJ DE/kg DM. For grasses and legumes under plantations (oil palm, rubber), the reported value corresponds to 8.7 MJ DE/kg DM. For China, Simpson et al. [1994, p. 458], stated for both ‘warm grasslands’ and ‘temperate grasslands’ ruminant nutritive content (in ME) corresponding to 9.2 MJ DE/kg DM. For Sudan grass and Para grass in India, Upadhyay [1996] reported cattle DE of 8.4 MJ/kg DM. For the predominantly temperate regions, a large amount of data on major species (in oversown pastures and cropland pastures mainly) are available through the feed composition tables provided by NRC [NRC 1984, NRC 1989, NRC 1996]. For Europe, digestibility ranges reported by Lee [1988] were also relied on.

[120] In general, tropical grasses and legumes are less digestible than temperate grasses and legumes. Quoting Wilson & Minson [1980], Humphreys [1991, p. 90], reports that tropical grasses are on average 13% less digestible than temperate grasses, and that the digestibility of tropical legumes are about 4% lower than that of temperate pasture legumes.

taken directly from this source.[121] For products *not* covered in the FBS and *by-products*, some simple, generalized assumptions were made on losses: For all crop by-products,[122] and all food end-use residues,[123] dry matter losses were uniformly set to 10 percent. For conversion by-products[124] losses were assumed to be zero, with the exception of animal manure (feces, urine and used litter) for which dry matter loss was assumed to be 20 percent. For harvested grass-legume forage, as well as whole-cereals forage, distributional losses were included in the values for losses in the feed processing (see Section 3.1.2, p. 86) — thus, no losses were assumed in this part of the model.

In this study, values on net-import were included only for *products* with a stated trade value in the FBS. The FBS values on these flows were taken without any changes.[125] This approach implied that trade of converted *cereals commodities* (cereals flour etc) was not included. Instead, the stated trade values in the FBS for 'cereals ex. beer' were interpreted in this study as trade of *grains* only. Finally, trade of *by-products* was not included.

As was described above (p. 57), figures for former USSR were missing in the release of FAOSTAT which we used in this study. This implied that the data used for the region East Europe were far from accurate — a fact we were not aware of at the time of calculation. However, when preparing the data material before carrying out the calculations, we did suspect that some of the FAOSTAT data for this region were corrupt — this applied to the data on losses and trade. Therefore, as proxy for the losses in this region we used the FBS loss data for West Europe. The net-trade for East Europe was handled by allowing the net-import of this region to be an outcome of the net-import in all other regions, that is, this region's net-import balanced the sum of the net-import in all the other regions.

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[121] Flows in the FBS are given on as-is weight basis (that is, weights including water) and may differ in composition, for instance with respect to DM content, from the corresponding flows in the FPD model. Also, the *total amount* of loss may be generally higher in the FBS since the FBS also contains flows produced for other purposes than food. Due to these circumstances, as input data for losses we used *share* of supply, calculated from the FBS data (calculated from the FBS ratio 'waste'/'supply').

[122] Cereals straw and stover, etc, (Table 3.22, p. 129, gives a complete list of the crop by-products included in this study).

[123] Non-eaten food and human feces & urine.

[124] Cereals brans, etc, (Table 3.22, p. 129, gives a complete list of the conversion by-products included in this study).

[125] For the same reason as was the case with distribution & storage losses, the input data taken from the FBS were *share* of supply. We assumed that the model estimate in that way would give a better description of the extent of trade. There were two exceptions from this rule: (1) In the FPD model, *dairy cattle carcass* is formally a *by-product* from the cattle milk sub-system. However, in the model, trade of flows is an option only for *products* — consequently, trade of dairy cattle carcass was set equal to zero. This implied that the trade of *ruminant carcass* (the FBS flows 'bovine meat' and 'sheep/goat meat') had to be represented by the product *beef cattle carcass* alone. In order to more accurately depict the trade of ruminant carcass, the values on net-import of beef cattle carcass in the model were matched with the values in the FBS on the total *amount* — as opposed to *share of supply* — of the net-import of ruminant carcass. (2) In the FBS, barley grain dedicated for barley beer production is not shown, only barley beer is displayed. Analogous to the case with cattle carcass, the model values on net-import of barley grains were matched with the FBS values on net-import of the total *amount* instead of share of supply.

### 3.1.6 Assignment and use of by-products and residues

General description

A principal feature of the FPD model is its comprehensive description of all major by-products and residues in the food system (see Section 2.1.1, p. 13). This description includes all significant process steps in generation, handling and use, and is based on mass and energy balances over each of these processes. As a result of this physically consistent description throughout the system, the amount of by-products and residues used is directly comparable with the amount generated, and more importantly, with the amount *distributed*, that is, the amount available *after* flows tied-up internally in processes and various losses have been accounted for. This enables a more reliable analysis of the use of by-products and residues than would otherwise be the case.

The basis for estimating the *internal* use of by-products and residues, that is, use *within* the food system, has already been touched upon in the previous sections. As mentioned in Section 3.1.2 (p. 77), the geographic areas referred to in most data sources did not coincide with the regional structure in this study. The data employed in these sources were, therefore, either use as *share of total use*, or use as *share of total production* or *supply*. The latter kind of data was the most frequently available in the literature. In some cases, satisfactory accordance between these two types of data sources was not achieved. This is further described and commented upon in the discussion section — in particular, see the sections ‘Feed use’ (pp. 191 sq.), ’By-products and residues generation and importance’ (p. 221), and ’Comparisons with previous knowledge and studies’ (p. 237).

Besides the system-internal uses of by-products and residues, attention had also to be paid to possible uses in *other sectors*. Without having made a thorough literature analysis, it is obvious that the use of crop by-products, especially cereals straw and stover, for purposes of energy and materials is substantial in non-industrial countries in general.[126] In contrast, corresponding figures for industrial countries indicate that such uses are

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[126] Smil [1983, pp. 175-177] gives many examples from different countries on extensive use of crop by-products as fuel (not to be confused with burning of crop by-products in field). A relatively exceptional example on use for energy purposes is Egypt, where as much as three fourths of the total production of crop by-products were used for fuel in the late 1970s. Examples on use for materials purposes are South Korea where one-fifth of rice straw production was used as roofing material (no time period specified), and Taiwan where utilization of rice straw for paper making amounted to roughly 15% (of the produced amount of straw) in the late 1970s. Since all these figures are old they should not be taken as representative for those countries at present, but rather for countries at a corresponding stage of economic development. Smil [1993], cited in Smil [1999a], reports that China’s rural energy surveys show that roughly three-quarters of the country’s crop residues, including more than two-thirds of all straw, were burned in cooking stoves (late 1980s). More data on uses besides those taken into consideration in this study are given in the section ‘Food-system-internal uses and fates in relation to other systems’ (p. 224).

very limited.[127] Apart from the crop by-products, significant use outside the food system occur for, among others, sugarcane bagasse, and slaughter by-products.[128]

In the FPD model, limitations in availability of by-products and residues for internal use are represented by the ‘by-products and residues assigning variables’ (see Section 2.7, p. 53). These assignment variables express limitations for internal use of by-products and residues, with respect to technological and economical restrictions, as well as competing uses. The amount ‘assigned’ for a certain purpose stipulates the amount *maximally* available for this purpose. Thus, the amount ‘assigned’ is not to be confused with the amount actually *used* which may be lower than the assigned amount due to limitations *in the using process*.

Below follow more details regarding the modeling approaches and input data for each flow category and use. The overall picture of the outcome of the generation and use of by-products and residues is given in the results section below (Section 3.2.3, p. 174).

### Assignment to food use

Dairy cattle carcass as well as all vegetable oils generated as by-products (maize oil, sorghum oil, oil palm kernel oil) were assigned to end-use by 100 percent. The assignment of carcass fifth quarters (offals, etc) was entirely determined by the stated end-use of offals, since the amount that is end-used normally falls well below the amount of fifth quarters generated.

### Assignment to animal production for use as feed

Assumed values on total assignment as feed for the animal food production, that is, the total feed use for the whole animal food sector, are shown in Table 3.20. In the section ‘Feed use’ above, major data sources on the use as feed, including for by-products and residues, were specified (see footnote 96, p. 78). The assumed assignment values were based on those data, in combination with generalized assumptions, partly based on those data, regarding regional similarities and differences.

Generally speaking, use of crop by-products as feed was assumed to be much higher in the non-industrial regions than in the industrial regions, whereas use of conversion by-products was assumed to be lower in the non-industrial regions than in the industrial ones. Within each of the groups industrial and non-industrial regions respectively, assumptions on assignment were kept relatively close. In many cases, data referring to

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[127] Edwards [1991] reports for the UK (late 1980s) that use of straw for materials is less than 1%, and use for energy roughly 3% (both numbers as share of distributed amounts).

[128] Use of sugarcane bagasse as fuel within the cane sugar process is the prevalent practice [Kulkarni & Sardeshmukh 1995]. Smaller amounts, although significant, of the slaughtered body can, for example, be processed to high-grade tallow suitable for cosmetic industry, and high-protein meat meal for use in pet foods [Miller & Boer 1988, p. 173].

**Table 3.20** Assignment and use of by-products and residues as feed in this study.

| Category and flow | Status | East Asia | East Europe | Latin America & Carib. | North Africa & W. Asia | North America & Oc. | South & Central Asia | Sub-Saharan Africa | West Europe |
|---|---|---|---|---|---|---|---|---|---|
| **Crop by-products** | | | | | | | | | |
| Rice straw | Assignm. | 0.30 | 0 | 0.60 | 0.60 | 0 | 0.80 | 0.80 | 0 |
| | *Use* | *0.25* | | | | | *0.90* | | |
| Other cereals straw and stover[a] | Assignm. | 0.30 | 0.10 | 0.60 | 0.60 | 0.05 | 0.80 | 0.80 | 0.05 |
| | *Use* | | | | | | *0.90* | | |
| Cassava leaves | Assignm. | 0.05 | 0 | 0.20 | 0 | 0 | 0.40 | 0.60 | 0 |
| | *Use* | | | | | | | | |
| Potato tops | Assignm. | 0.80 | 0.60 | 0.60 | 0 | 0 | 0.80 | 0.80 | 0 |
| | *Use* | | | | | | *0.30* | *0.70* | |
| Sugar cane tops | Assignm. | 0.40 | 0 | 0.60 | 0.60 | 0 | 0.80 | 0.80 | 0 |
| | *Use* | | | | | | *0.90* | | |
| Sugar beet tops | Assignm. | 0.15 | 0.40 | 0 | 0.40 | 0.60 | 0.15 | 0 | 0.90 |
| | *Use* | | | | | | | | |
| Groundnut stalks | Assignm. | 0.40 | 0 | 0.60 | 0.60 | 0 | 0.80 | 0.80 | 0 |
| | *Use* | | | | | | *0.90* | | |
| Other oil crops straw and stalks[b] | Assignm. | 0.25 | 0 | 0.60 | 0.60 | 0 | 0.80 | 0.80 | 0 |
| | *Use* | | | | | | *0.90* | | |
| **Conversion by-products** | | | | | | | | | |
| Wheat mill run, rice bran, maize & sorghum hominy feed | Assignm. | 0.40 | 0.60 | 0.40 | 0.40 | 0.90 | 0.40 | 0.35 | 0.90 |
| Rice hulls | Assignm. | 0.30 | 0 | 0.40 | 0.40 | 0 | 0.40 | 0.35 | 0 |
| Sugar cane bagasse | Assignm. | 0.13 | 0 | 0.14 | 0.13 | 0 | 0.13 | 0.11 | 0 |
| Sugar molasses | Assignm. | 0.35 | 0.50 | 0.35 | 0.35 | 0.90 | 0.35 | 0.30 | 0.90 |
| Sugar beet pulp | Assignm. | 0.05 | 0.50 | 0.10 | 0.40 | 0.90 | 0.05 | 0.10 | 0.90 |
| Oil crops meals[c] | Assignm. | 0.80 | 0.80 | 0.80 | 0.80 | 0.90 | 0.80 | 0.70 | 0.90 |
| | *Use* | | | *0.60* | | | *0.25* | | |
| Brewer's grains | Assignm. | 0.30 | 0.50 | 0.30 | 0.30 | 0.90 | 0.30 | 0.25 | 0.90 |
| Carcass fifth quarters (meat and bone meal) | Assignm. | 0.10 | 0.20 | 0.10 | 0.10 | 0.50 | 0.10 | 0.10 | 0.50 |
| Cotton meal[d] | Assignm. | 0.30 | 0.50 | 0.30 | 0.30 | 0.90 | 0.30 | 0.25 | 0.90 |
| | *Use* | | | | | *0* | *0* | | |
| **End-use residues** | | | | | | | | | |
| Non-eaten food | Assignm. | - | - | - | - | 0 | - | - | 0 |
| | *Use* | *0.45* | *0.15* | *0.25* | *0* | | *0.04* | *0.20* | |

Values refer to the amount assigned and used respectively, expressed as share of the amount *distributed* (on DM basis). The value on use is displayed separately only if different from the value on assignment. Note that the values refer to the assignment and use as feed for the *whole animal food sector*, that is, the total of all five animal sub-systems included in this study. Details on use in each of the animal sub-systems are given in the results section (Section 3.2.2, pp. 135 sq.)

[a] Wheat straw, maize stover, sorghum stover, and barley straw.

[b] Soybean stalks & husks, sunflower stalks, and canola stalks & husks.

*Notes continue on next page.*

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[c] Soybean meal, groundnut meal, sunflower meal, and canola meal.
[d] System-external assignment, see Section 3.1.7 below.

individual countries were adopted as assignment value for all or most regions within each group. This applied, for instance, to most of the values on assignment of conversion by-products in the non-industrial regions — these assumption were essentially based on data valid for China.[129]

To facilitate comparison with the resulting *use* of by-products and residues, these values are also shown in Table 3.20 in those cases where use deviated from assignment. As can be seen in the table, for most crop by-products in the region South & Central Asia, the resulting use exceeded the amount ‘assigned’. This was due to the extraordinary conditions in that region. Comments on the resulting use, particularly as regards the region South & Central Asia, are given in the discussion section below (mainly in the sections ‘Feed use’, particularly pp. 199 sq. and p. 211, and the section ‘Food-system-internal uses and fates in relation to other systems’, p. 224).

For non-eaten food in the non-industrial regions, no assignment values were set due to lack of data. In these regions, use of non-eaten food as feed was adjusted with respect to its *share in feed mix* for pigs. In no region use was allowed to exceed 50 percent of the amount of non-eaten food distributed since logistical difficulties is likely to restrict a high degree of use. Further comments on this issue is given in the section ‘Feed use’ (pp. 204 sq.).

Assignment for use as litter and mulch

Assignment of cereals straw and stover for use as litter for bedding in animal production, and for mulching in crop production, were determined by their stated specific use, see Table 3.13 (p. 86) and p. 95, respectively. This approach was chosen since no alternative feedstocks for these purposes were considered in this study.

### 3.1.7 System-external related flows

Fish

Formally speaking, fish flows are not part of the FPD model. Use of *wild* fish as food does not induce terrestrial phytomass flows — however, *cultivated* fish normally does, but the contribution of the latter to the fish supply is relatively small. Data on fish production (catch) and use for various purposes are included in the FAOSTAT Food Balance Sheets (FBS).

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[129] [Simpson et al. 1994] (see footnote 96, p. 78).

Since fish gives small, but yet significant, contributions to the food supply, fish was taken into consideration in this study — both use as food and as feed was included. Values on use of fish as food in each region were settled in the same way as for other food commodities (see Section 3.1.1, p. 59). The amount of fish used as feed (in the form of fish meal) was estimated in the same way as other feed categories included in the FBS (see Section 3.1.2, p. 83).

Cotton and other fiber crops

Fiber-producing plants, such as cotton and flax, in many cases bear seeds which are suitable for further refining, for instance into oils. Among cropland-related fiber crops, cotton is entirely dominating — it accounts for more than 95 percent of the total production of cropland-related non-modified fibers.

Cotton oil and cotton meal (the latter by-product from the oil-extracting process) give significant contributions to the food and feed supply respectively, and therefore these flows were taken into consideration in this study. The purpose for including the flows was only to illustrate the order of magnitude of these flows in relation to the rest of the system. Therefore, a simple description was considered to be sufficient.

Using statistical data on total global production and estimates on end-use in industrial countries, rough regional values on end-use of cotton yarn and fabrics were estimated. For the regions North America & Oceania and West Europe the value 7.5 kg (as-is) per capita and year was chosen, and for all other regions 2.4 kg per capita and year.[130]

Descriptions of the processes for production of cotton yarn out of seed cotton, and production of cotton oil and cotton meal out of cotton seeds, were based on the same principles as the processes in the FPD model, that is, on mass and energy balances over each process part. Identical values for all regions on the process parameters were chosen.[131]

Since cotton oil is not a driving flow in the food use, use of cotton oil as *food* was treated in the same way as internal by-products assigned to food use. This means that assignment of cotton oil as food reduced the required distribution of vegetable oil *products* with an amount equal to the assigned amount. As in the case for other vegetable oil by-products, cotton oil was assigned to food use by 100 percent in all regions. Values on the assignment of cotton meal to animal *feed* use are shown in Table 3.20 above.

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[130] Total annual production of cropland-related non-modified fiber yarn and fabrics (cotton, flax, hemp, jute, etc) amounted to nearly 17 Tg (as-is weight) in the early 1990s [UN 1994]. Munro [1987, p. 381] reports that per capita end use in USA 1980-82 of cotton yarn and fabrics was about 5-6 kg (as-is) per year. Data for Sweden indicate an end-use totally for all textile types around 15-20 kg (as-is) per capita and year [SNV 1995, pp. 69-70]. The assumed regional values give a global total close to 17 Tg.

[131] The values on process characteristics and yields were mainly based on Munro [1987, pp. 343-348].

## 3.2 RESULTS

The purpose of this section is to present results from the model-based estimate of the biomass flows in today's food system. The data given here are only selections of representative results. The most detailed data are given on the global level. For principal results, such as for phytomass appropriation and feed use, also comparisons between regions are made. Comparisons *within* regions, however, are made only occasionally. In this section, mainly explaining comments are given in connection with each result; comments on accuracy, significance and relevance are given in the discussion section (Section 3.3, p. 179).

For an accurate interpretation of the results, insights into the construction of the FPD model, as well as the prerequisites regarding the input data, are necessary. For information on these matters, we direct the reader to Chapter 2 (p. 13) and Section 3.1 (p. 56) respectively. However, we want to make two reminders concerning some essential aspects:

Firstly, the modeled system comprises all terrestrial phytomass production, and its derivatives, induced by human food intake. Phytomass production refer to the *above-ground production*, except for underground crops for which the *whole plant* is included. Food intake refers to food intake *excluding* system-external inputs, such as cotton oil and fish, if not otherwise stated.

Secondly, all flows in the figures and tables below are *model* flows. In some cases, these model flows represents a considerably wider mix of flows than what their names suggest. This applies to, for instance, 'beef cattle carcass' and 'dairy cattle carcass' which represent all *ruminants* carcass.

The results are presented in three different sections. In the first one, we show results intended to illustrate the general characteristics of the biomass flows in the food system. The second one is focused on the animal sub-systems, which are the major determinants of the flows in the system, and also those which hold the largest differences between regions. The third section deals specifically with the by-products and residues of the system.

### 3.2.1 Overview of the whole system

From phytomass to food intake and other fates

This section is intended to give an overview and to present some aggregated measures of the characteristics of the biomass flows in the food system. The section also includes, for the reader interested in specific details, a table over the estimated biomass flow balance for the food system on a global level (Table 3.21, p. 126), and a table with specification of the generated amounts for all individual model flows and for all regions (Table 3.22, p. 129).

In Figure 3.3 below, a condensed picture of the estimated global flows of food-induced terrestrial phytomass in energy terms is given, showing the flows from phytomass production and forward. Figure 3.4 and Figure 3.5 are regional examples, Sub-Saharan Africa and West Europe, respectively, of the same kind but on a per-capita basis.

In these figures, system-external inputs for use as feed (fish meal and cotton meal) are not shown in the figures since they are negligible in comparison with the total feed use (globally these flows amount to no more than 0.2 EJ per year). For the same reason, neither are losses during storage & distribution for animal commodities and processed vegetable commodities shown (global total loss is roughly 0.06 EJ per year).[132]

The flow 'feed & feedstock' related to animal food production does not only include the *actual intake* of feed. For feedstuffs treated for purposes of nutrient enhancement and conservation (such as, hay and silage) it refers to the *processed* amount, and not to the amount feed ready-to-use. The difference, that is, the process losses, is accounted for in the flow 'heat' (total feed processing losses amount to 3.5 EJ per year globally). Also included in 'feed & feedstock' are crop by-products used as litter for animal bedding (amount to 4.5 EJ per year globally).[133]

The amount 'not recovered' of animal manure (feces, urine & used litter) is related to two categories of manure not recovered. Firstly, it includes feces and urine which are generated at grazing and that are not collected from the pasture. Secondly, it includes oxidational losses of feces, urine and used litter in animal confinements. Current model construction does not enable distinction between these two categories, but roughly two thirds is probably related to the first category.

The term 'not used in food system' signifies that no particular use, or other fate, was specified within the framework of this study's model description of the food system. The same applies also to the term 'not specified'. In the real food system, however, these flows are, at least in part, used within the system as fertilizers in crop production.

It should be noted already at this point that the division of manure into 'not recovered', 'storage losses' and 'not specified' has a lower significance relative to other parts of the estimate of the biomass flows in the food system. Relatively low significance between 'losses' and 'not specified' also holds for the division between the flows non-eaten food and human feces and urine. The relevance of the FPD model's current downstream sys-

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[132] Anecdotally, it may be noted that neither is shown the energy flow representing the growth of the human population; on a global basis it amounts to roughly 0.05 EJ per year.

[133] Other categories of flows which may require explanations are 'non-processed vegetable food commodities', which includes starchy root tubers, oil crops, pulses, vegetables, fruits, stimulants and tree nuts, as well as the 'system-external inputs' used as food, which includes cotton oil and fish.

tem boundaries for the by-products and residues, as well as the significance of the figures in this estimate, are further commented on in the section ‘By-products and residues generation and importance’ (p. 221).

The land area numbers shown in the figures are rough values on the land use corresponding to the phytomass production. ‘Flux’ refers to the phytomass production per unit area. The extent of land use related to the food system is further dealt with in Section 3.3.2 (p. 243).

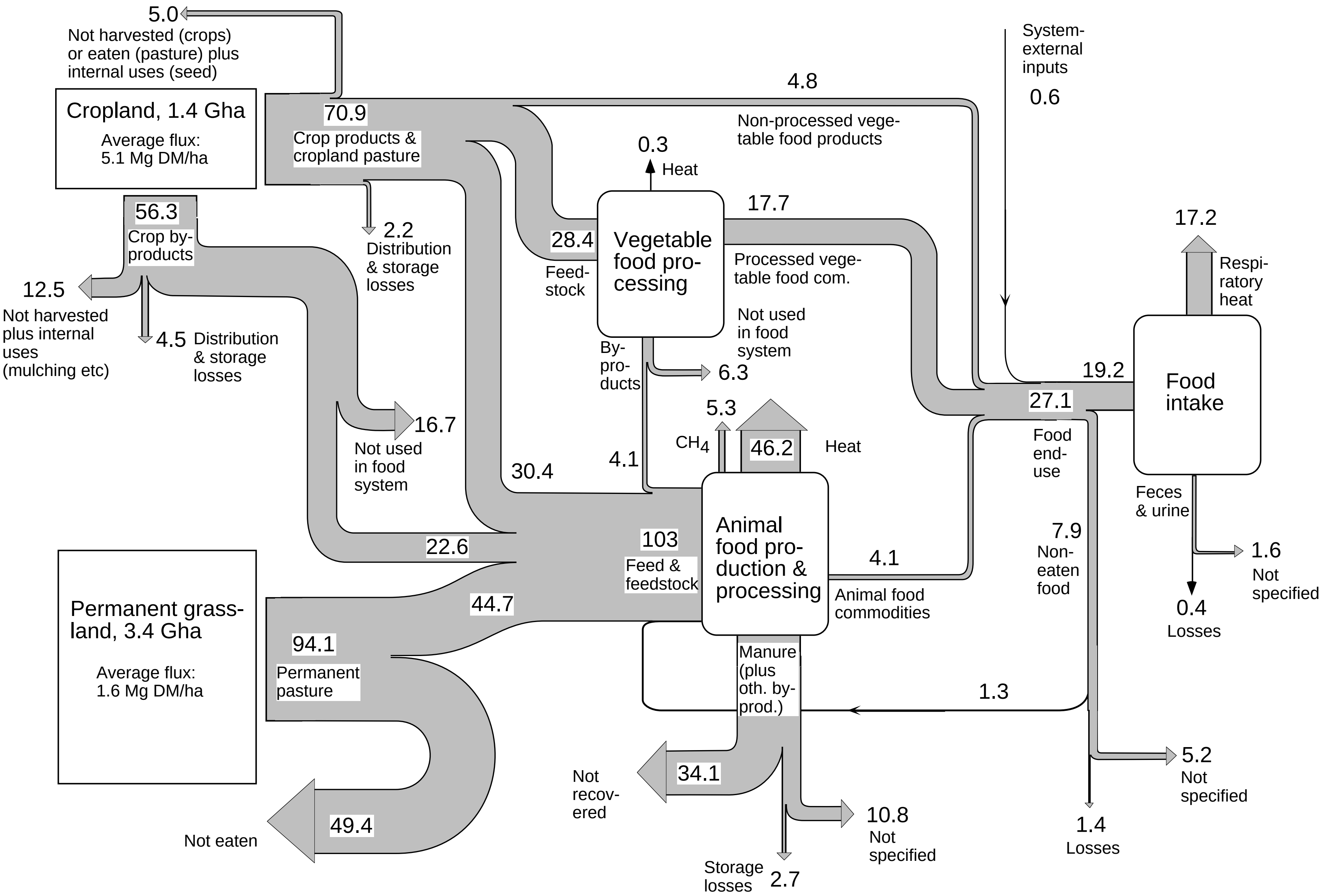

**Figure 3.3** Overview of the flows of terrestrial phytomass and its derivatives in the global food system. Values in EJ GE(HHV)/year. For explanations, see text.

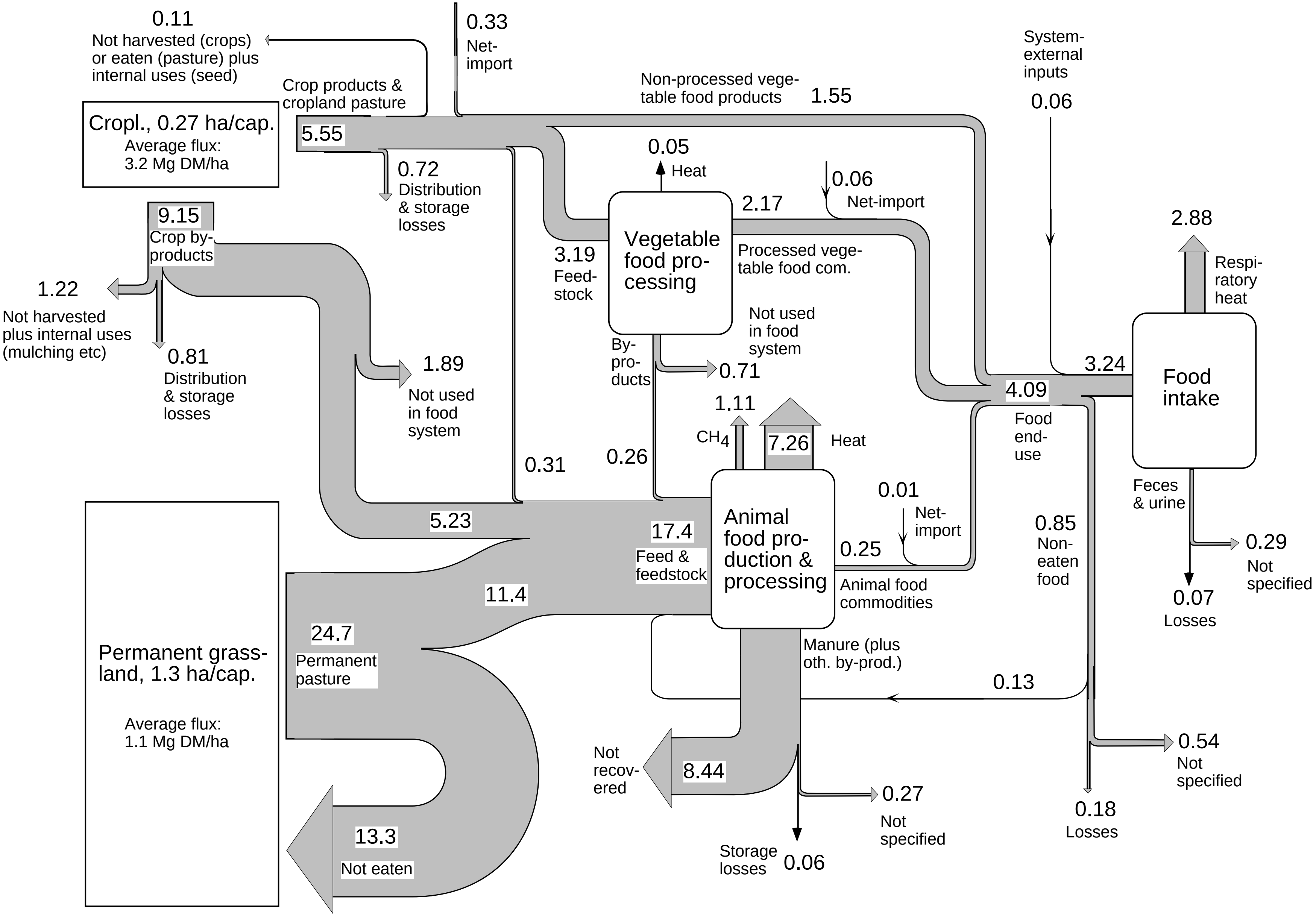

**Figure 3.4** Overview of the flows of phytomass and its derivatives in the food system. Values for Sub-Saharan Africa (GJ GE(HHV)/capita & year). For explanations, see text.

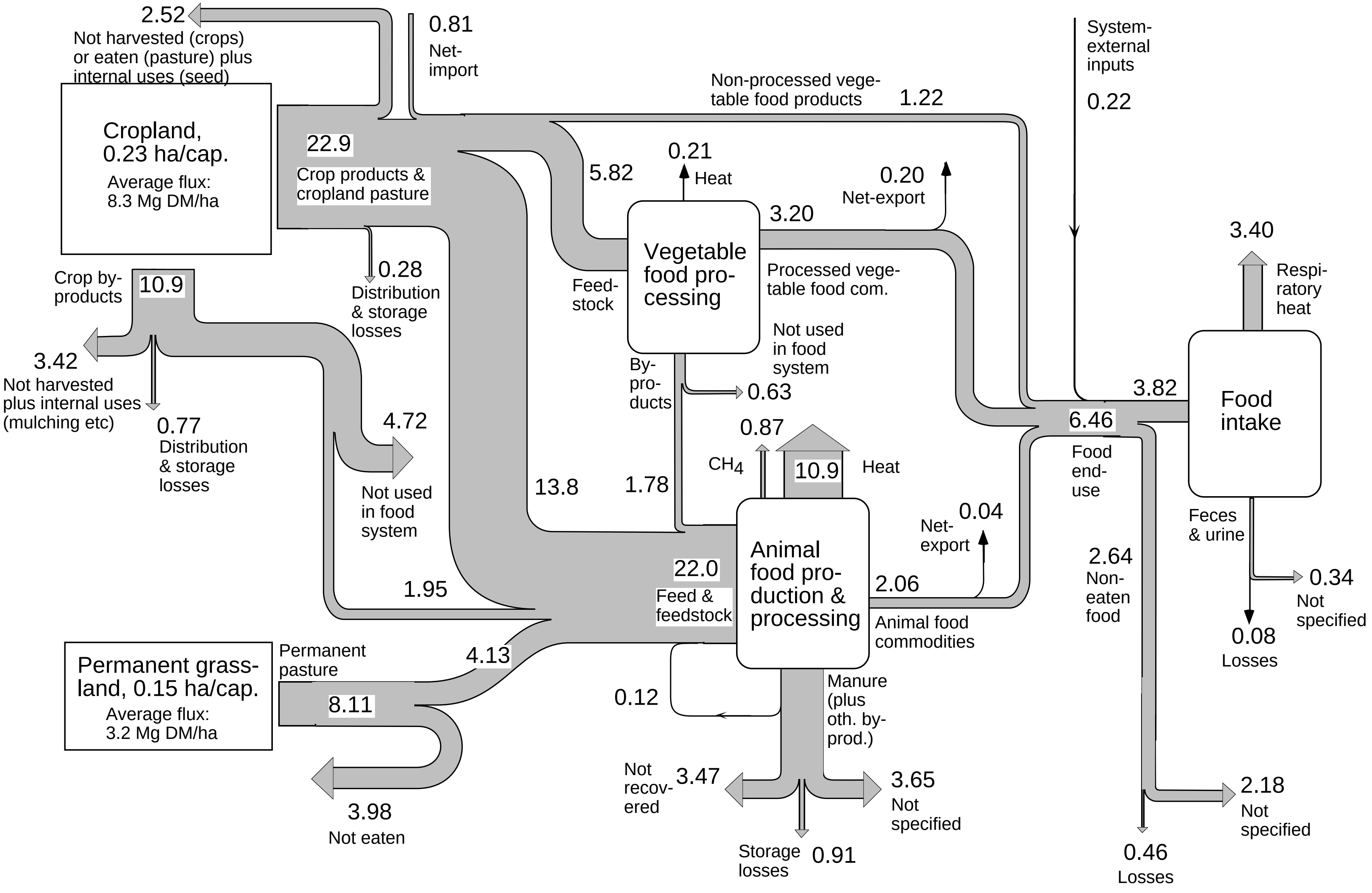

**Figure 3.5** Overview of the flows of phytomass and its derivatives in the food system. Values for West Europe (GJ GE(HHV)/capita & year). For explanations, see text.

*Extent and mix of phytomass appropriation*

In Figure 3.6 below, the global phytomass appropriation is shown by major phytomass categories. Figure 3.7 on next page shows the corresponding values on a regional basis. The category ‘other edible-type crops’ includes all edible-type crops other than cereals, and the category ‘other animal forage crops’ all animal forage crops other than whole-cereals (for specification of categories, see Table 2.6, p.47).

It should be noted that the concept ‘phytomass appropriation’ has a specific meaning here, as well as throughout the entire thesis. This concept is defined as the *total* phytomass production *induced by* the use of phytomass *products*, that is, crop products or eaten pasture (see Table 2.6). As ‘total’ phytomass production is counted here the above-ground production, except for roots and tubers, for which whole-plant production is included. Thus, the quantity refers to the *sum* of phytomass products use and all other (above-ground) parts of the plant matter production other than the product part used. The latter includes, essentially, phytomass products not harvested, crop by-products and pasture not eaten. Hence, referring to Figure 3.3 above, the sum of the two flows emanating from the cropland box gives the appropriation of phytomass on cropland. The flow emanating from the permanent-grassland box equals the phytomass appropriation on permanent grassland.

The global, yearly food-induced phytomass appropriation of 221 EJ corresponds to 13.0 Pg in dry matter (DM). Permanent pasture, which is the largest category, is 5.6 Pg DM,

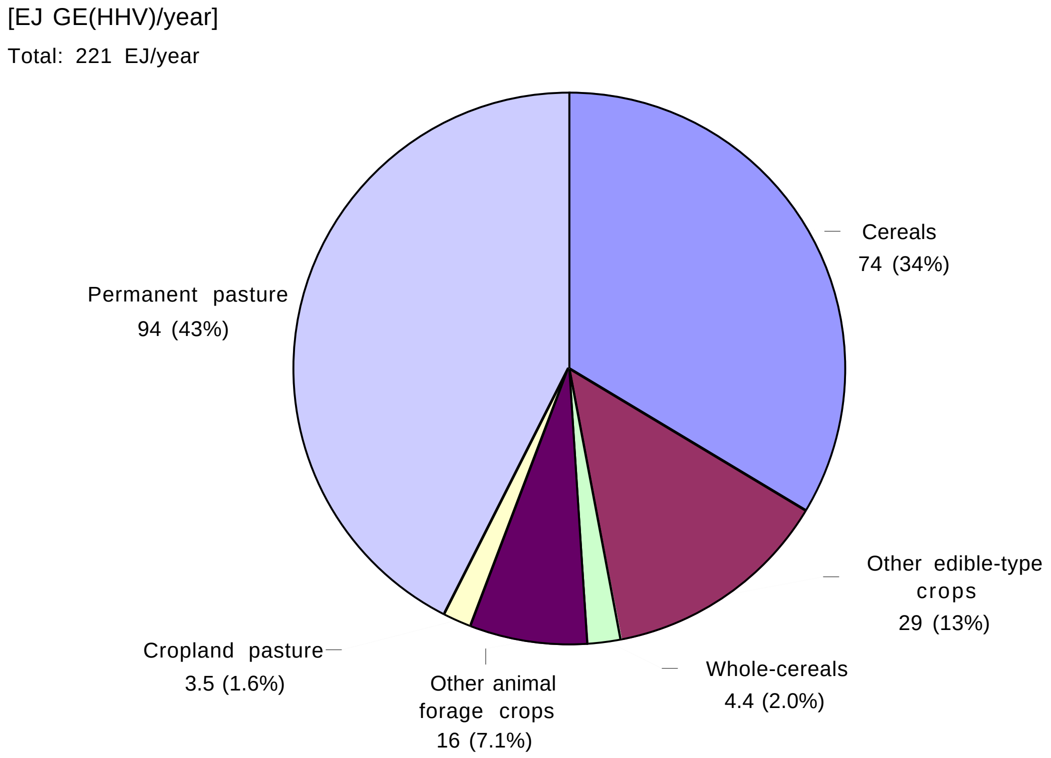

**Figure 3.6** Appropriation of terrestrial phytomass for food. World totals.

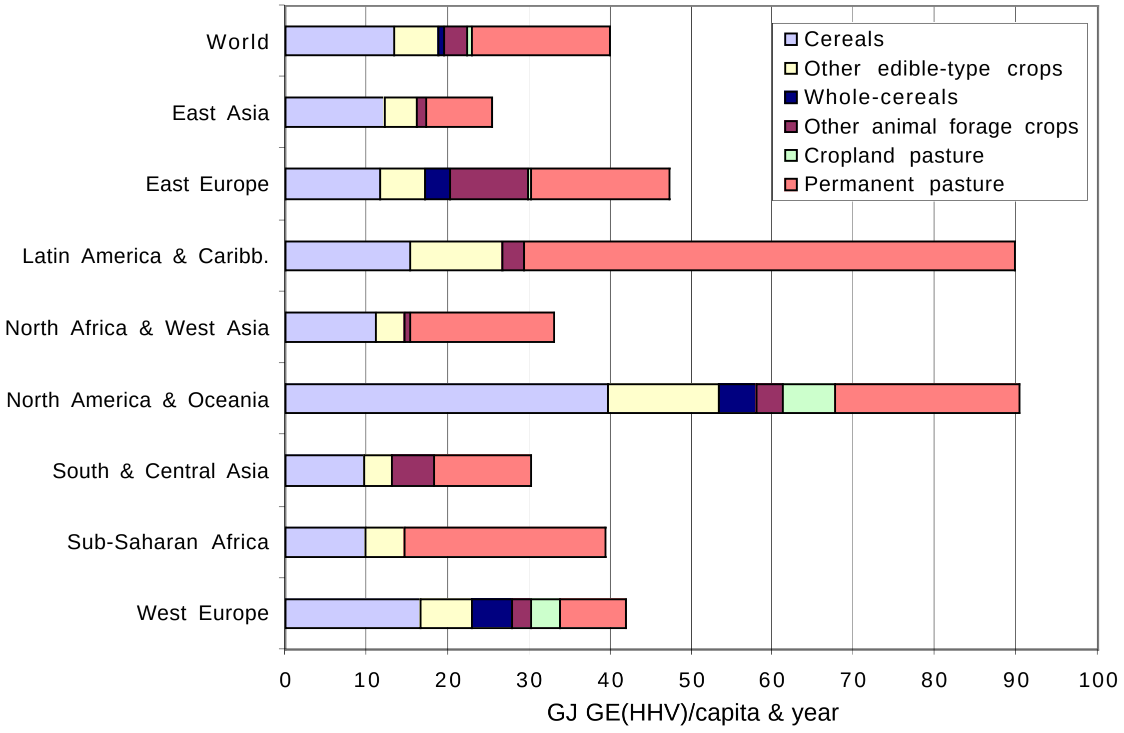

**Figure 3.7** Appropriation of terrestrial phytomass for food per capita. (The different components appear in the bars in the same order as in the list.)

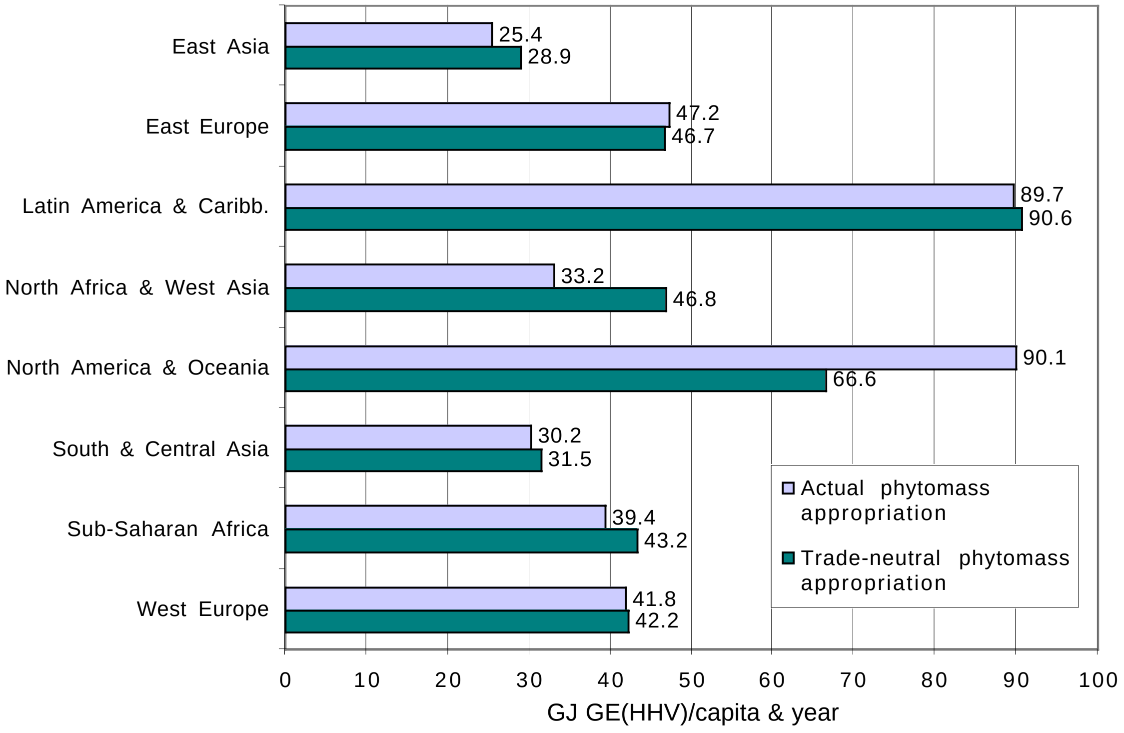

**Figure 3.8** Actual and trade-neutral appropriation of terrestrial phytomass per capita. See text for explanation of concepts.

cereals is 4.4 Pg DM, other edible-type crops make up 1.6 Pg DM, and whole-cereals, other animal forage crops and cropland pasture amount to 0.25, 0.90 and 0.20 Pg DM respectively.

Another essential concept for the interpretation of the results is the term ‘trade-neutral’. Net-import of crop products (for example grains), or converted products (for example meat), to a region implies that the phytomass appropriation within the region necessary to meet a certain food end-use, will be lower than if there was no net-import and the commodities were to be produced entirely within the region. Net-export of commodities from a region has the opposite effect, that is, the actual phytomass appropriation is higher than the phytomass appropriation required for meeting the region-domestic food end-use alone.

Figure 3.7 shows the required phytomass appropriation within each region, with the net effects of trade *included*. This phytomass appropriation we here designate as ‘actual’. ‘Trade-neutral’ phytomass appropriation for a region we define as the required phytomass appropriation if all food end-use was to be met entirely by production *within* the region alone, that is, *supplied by the region’s own production systems* in terms of standards as regards crop and animal productivity, efficiency, and so forth. Thus, this concept enables a ‘trade-neutral’ comparison between the regions of the phytomass appropriation required in each region depending on its diet, and productivity and efficiency standards.

In Figure 3.8 above a comparison is made of ‘actual’ and ‘trade-neutral’ phytomass appropriation. Evidently, for most regions trade is of minor importance for the total phytomass appropriation. Exceptions are the major net-exporting region North America & Oceania, and the clearly import-depending region North Africa & West Asia.

### *Aggregated efficiency measures*

How much of the appropriated phytomass ends up as food eaten? Where does the rest of the phytomass go?

Figure 3.9 below shows the relative distribution of the phytomass appropriation between different downstream end-points in the system, here referred to as ‘fates’.[134] Naturally, these ‘fates’ are to a large extent a consequence of the system-boundaries in the FPD model. Eventually, seen over a time period long enough, more or less all of the phytomass will be transformed into carbon dioxide and heat.

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[134] In Figure 3.9, the category ‘other conversion by-products’ includes animal food production by-products other than manure (mainly 'fifth quarters' — for definition, see Appendix 1) as well as by-products from vegetable food processing (see Table 3.21, p. 126, for further details).

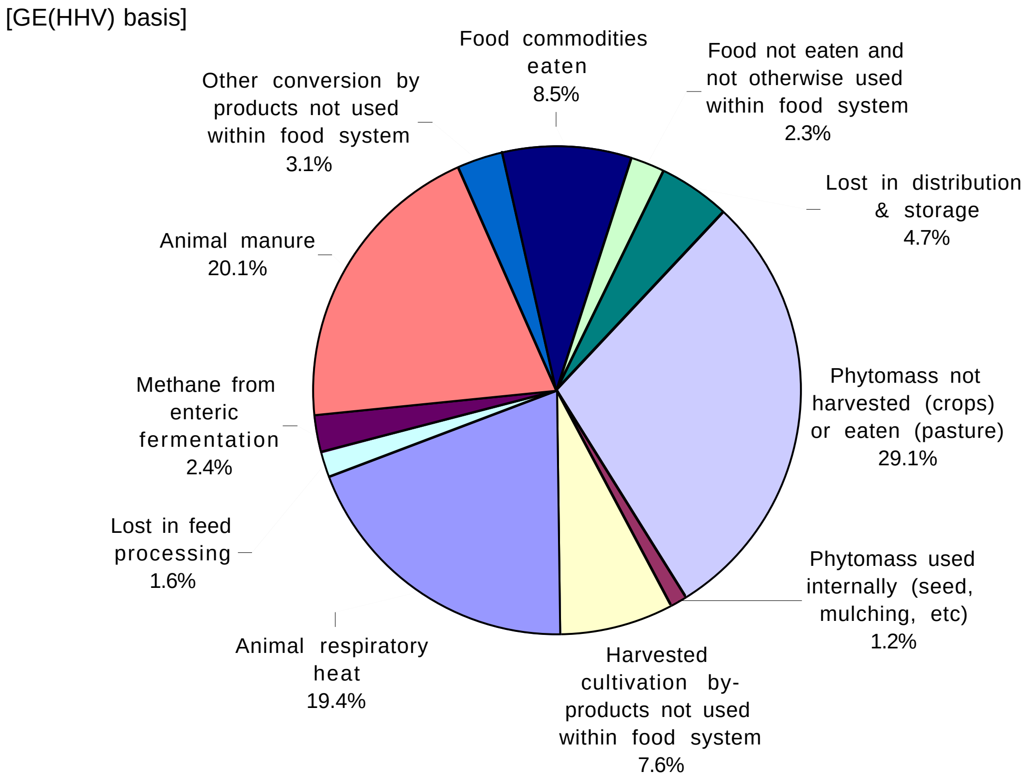

**Figure 3.9** Food intake and other fates of appropriated terrestrial phytomass in the food system. World totals. Values are expressed as share of the total amount of appropriated phytomass (221 EJ GE(HHV)/year).

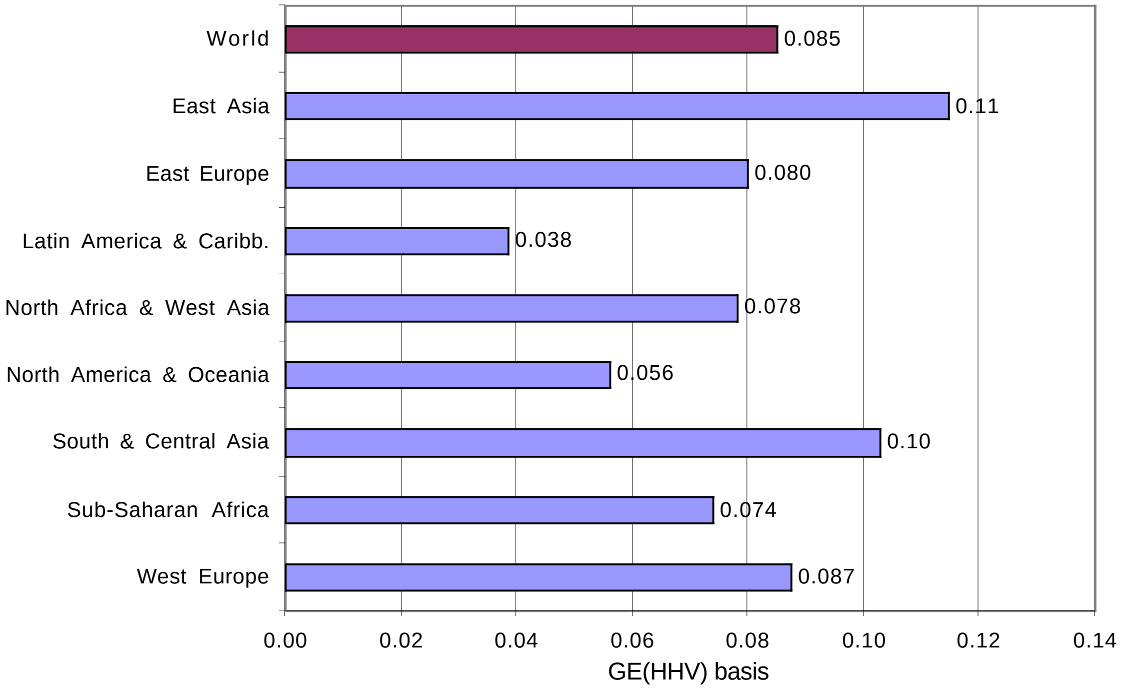

**Figure 3.10** Overall efficiency of the food system (see text for explanations). Average over all commodities. Trade-neutral values.

As can be seen from Figure 3.9, a substantial part of the appropriated phytomass consists of crop mass left behind at field and of herbage mass not grazed — this constitutes a local turnover of phytomass. We can also see that the amount of food eaten as share of the total amount of phytomass appropriated is no more than 8.5 percent (on GE basis). This ratio, food intake (excluding the system-external inputs) divided by phytomass appropriation, we define here as the 'overall efficiency' of the food system. This concept may be applied to the entire system, that is, for all food commodities together, or for a part of the system, for instance a certain commodity.

In Figure 3.10 above is shown the overall efficiency for the entire system on a regional basis. (Note that the values refer to trade-neutral phytomass appropriation in order to make them comparable.) As can be seen from the figure, differences between regions amounts to a factor of three at the most.

Where do the losses, or inefficiencies, occur? In Figure 3.11 we have split the overall efficiency into three aggregated efficiency measures. Each of them represents a principal part of the system. The product of the three gives the 'overall efficiency'.

'Feed & feedstock utilization efficiency' is defined as feed intake (for animal commodities) and feedstock use (for processed vegetable commodities) per corresponding phytomass appropriation. Hence, it reflects how much of the appropriated phytomass that actually becomes used in the principal part succeeding the phytomass production (that is, the phytomass *converting* processes). Among the factors that have the largest impact on this efficiency are, quite obviously, harvest index and pasture utilization. Also important is the extent of the use of by-products and residues as feed. Above that, it also reflects phytomass internal uses, losses of phytomass in distribution & storage, and feed processing losses.

'Conversion efficiency' is a more straightforward concept. It is defined as product generated per feed intake (animal commodities) and feedstock use (processed vegetable commodities). Thus, it reflects the efficiency of the actual conversion processes.
For animal food systems this concept is analogous to the concept '*feed-equivalent* conversion efficiencies', which was defined in Section 3.1.2 (see, for example, Table 3.10, p. 74).

'Commodities utilization efficiency' is defined as food eaten per food products generated. Important aspects that this concept takes into account are losses in distribution & storage of food products, and the losses in the food use process, that is, the amount of end-used food commodities which is not eaten.

For non-processed vegetable food products, which do not undergo conversion, the above-mentioned definitions only partly apply. 'Feed & feedstock utilization efficiency' is formally calculated as product generated per phytomass appropriated (equals the harvest index). The 'conversion efficiency' has formally the value one. 'Commodities utilization efficiency' is calculated in the same way as above.

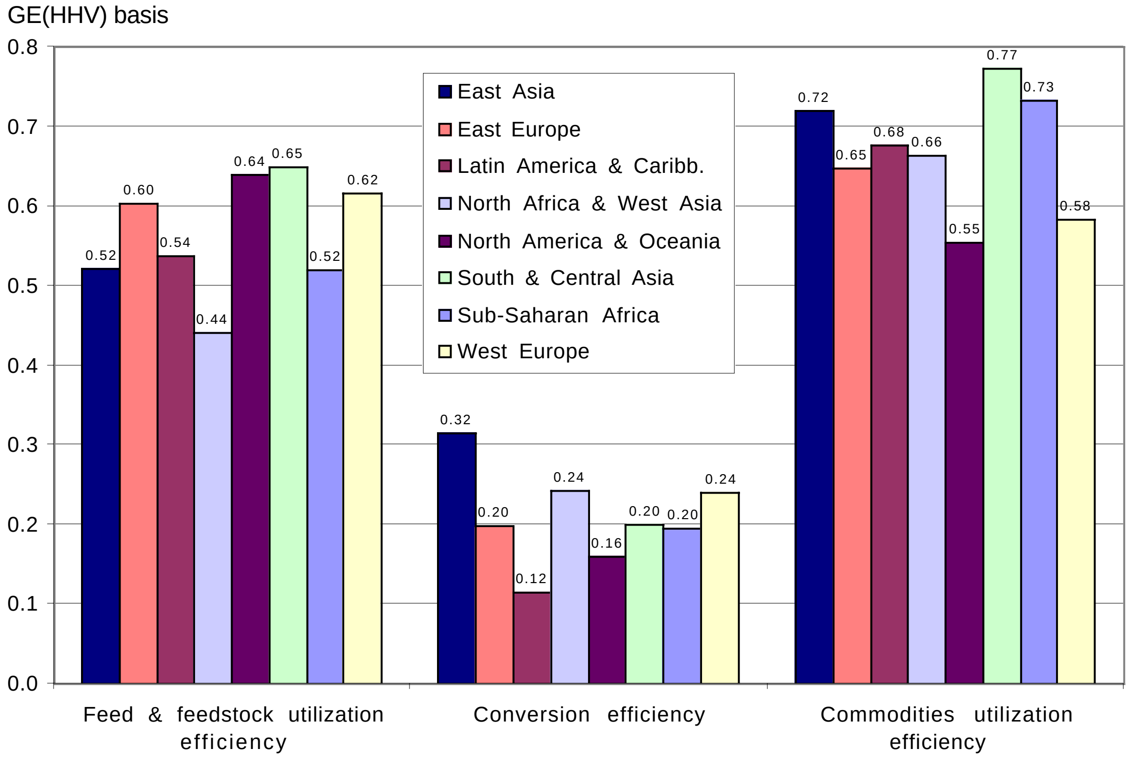

**Figure 3.11** Efficiencies for three principal parts of the food system (see text for explanations). Average over all commodities. Trade-neutral values. (The different components appear in the bars in the same order as in the list.)

From Figure 3.11 it is clear that the largest losses occur in the *conversion* step of the food system. Regional differences in conversion efficiency explain the greater part of the regional differences in overall efficiency (Figure 3.10). As will be seen further on, in all essentials the low conversion efficiency is a consequence of the relatively low conversion efficiency of the animal sub-systems. The regional differences in conversion efficiency are chiefly due to differences in animal food conversion efficiency as well as differences in share and mix of animal food in diet.

### Relation between commodities intake and phytomass appropriation

In this section, we intend to describe the relative contributions to phytomass appropriation by the separate parts of the food system — thus, the question here is: How does the intake of separate commodities relate to the phytomass appropriation?

#### *Comparisons of animal and vegetable food groups*

Figure 3.12 below illustrates the phytomass appropriation related to the two principal commodity groups in the system, animal food and vegetable food. The figure shows the global food intake, specified on these two groups, and the phytomass appropriation corresponding to each of the groups. In Figure 3.13 is shown phytomass appropriation on a regional basis specified for animal and vegetable food. Note that, due to the definition

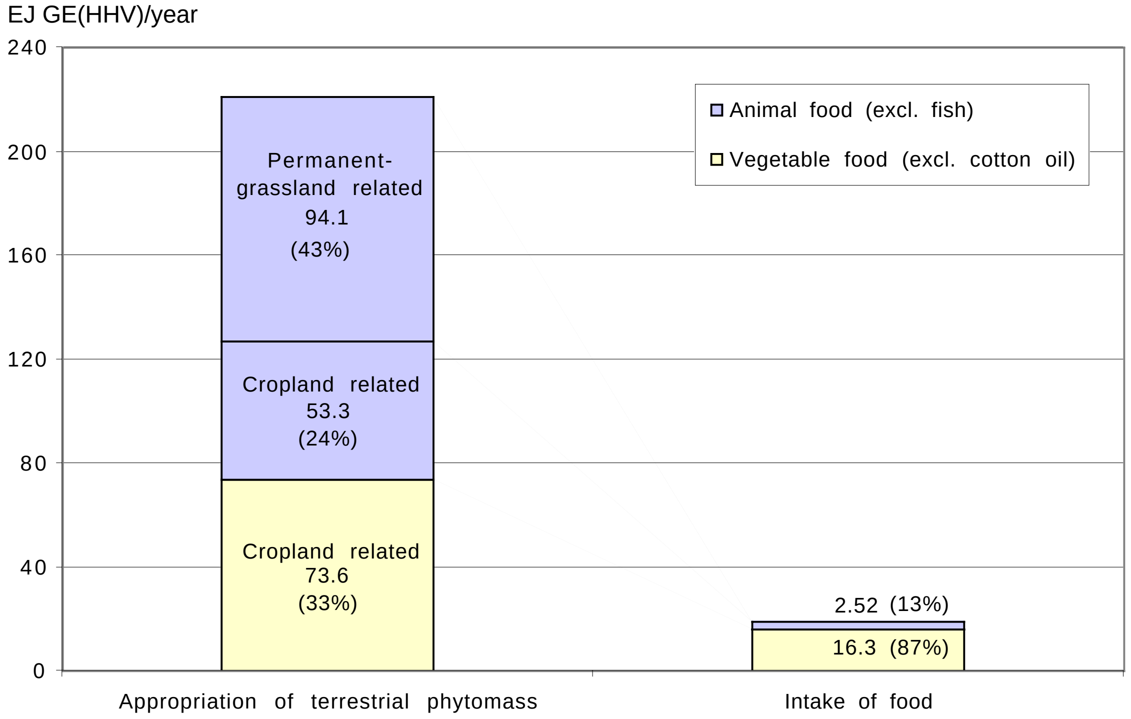

**Figure 3.12** Intake of vegetable and animal food, and corresponding appropriation of cropland and grassland phytomass for vegetable and animal food, respectively. World totals.

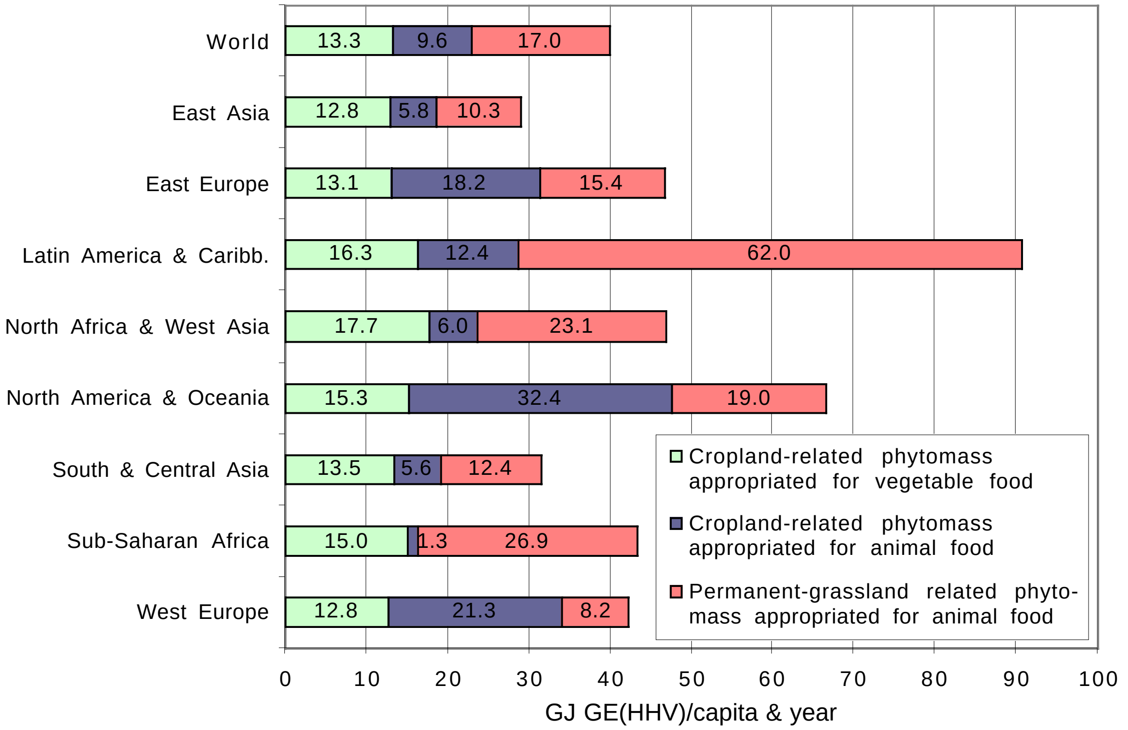

**Figure 3.13** Appropriation of cropland and grassland phytomass per capita for vegetable and animal food. Trade-neutral values.

of the concept, the phytomass appropriation for animal food includes no more than the phytomass appropriation induced by the feed use of phytomass *products*. Thus, it does not include, for example, the use of crop by-products originating from production of *vegetable* food commodities. How the use of this latter kind of by-flows may be illustrated is further dealt with in the section 'Marginal and net phytomass appropriation' (p. 135).

Since cropland and permanent grassland represent the two principal types of land use in the food system, phytomass appropriation is specified for these categories in Figure 3.12 and Figure 3.13. As permanent-grassland-related phytomass we count permanent pasture; as cropland-related all other phytomass.

As can be seen in Figure 3.12, animal food accounts for about 67 percent of the global phytomass appropriation, but it makes up only about 13 percent of the diet. It is evident from Figure 3.13 that animal food explains nearly all regional variation in total phytomass appropriation per capita. Phytomass appropriated for consumption of animal food varies from 56 percent of total in East Asia, to 82 percent of total in Latin America & Caribbean (trade-neutral values).

As Figure 3.12 suggests, the difference between animal and vegetable food in average efficiency is immense — this is further illustrated in Figure 3.14 below. Evidently, the regional differences in overall efficiency for animal food are also most substantial.

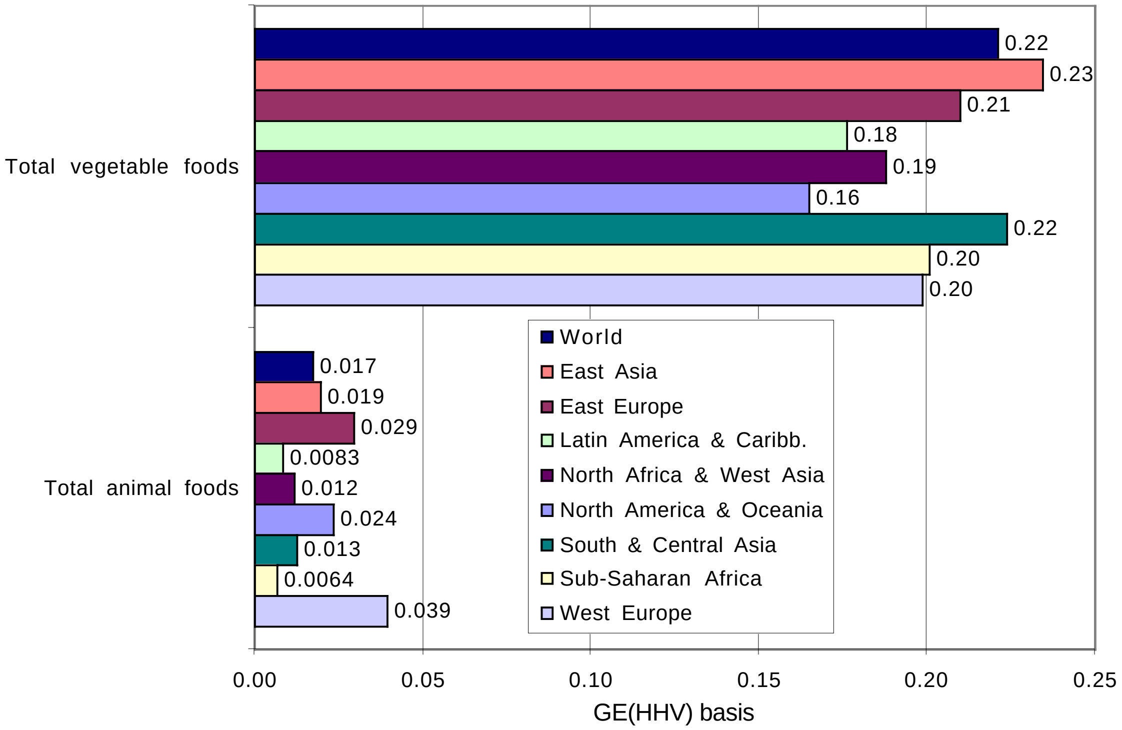

**Figure 3.14** Overall efficiency for all animal and all vegetable commodities. Trade-neutral values. (The different components appear in the bars in the same order as in the list.)

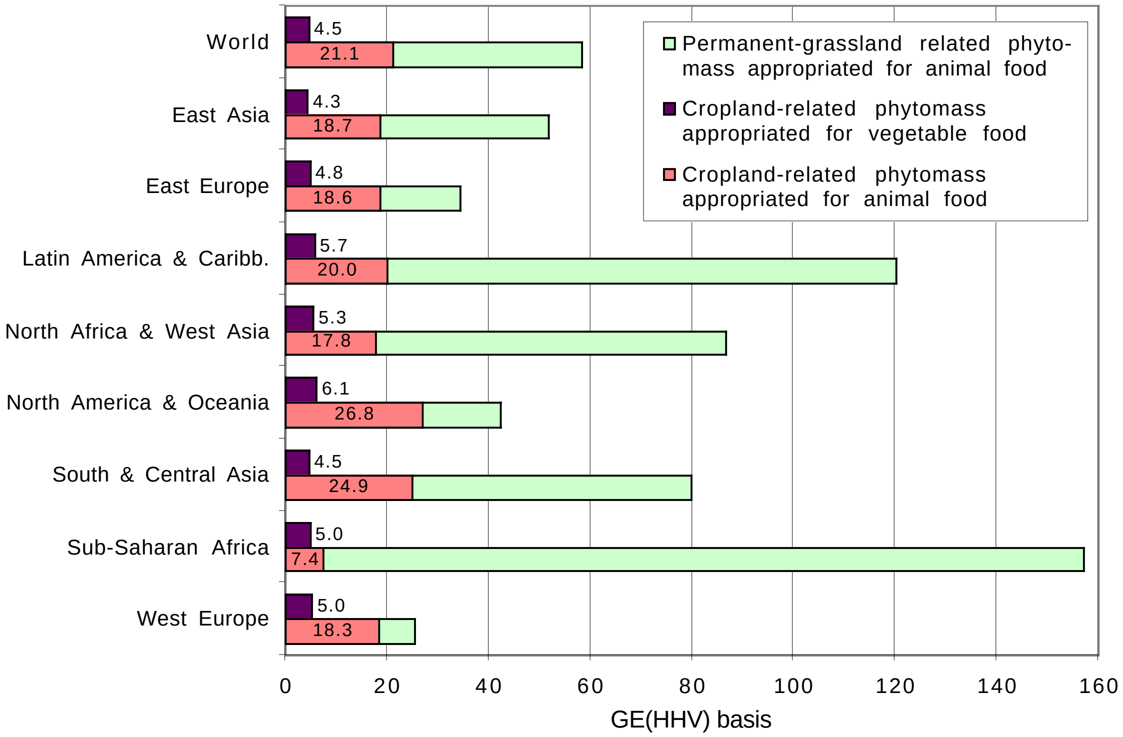

**Figure 3.15** Appropriation of cropland and grassland phytomass per intake of vegetable and animal food respectively (see text for explanations). Averages for all animal and all vegetable commodities respectively. Trade-neutral values.

In Figure 3.15, these differences are expressed in a complementing way, adding the relative appropriation of the principal groups of phytomass, cropland related and permanent-grassland related phytomass. Formally speaking, this figure shows the *inverted* values of the *overall efficiencies* in Figure 3.14, with specification of the two major phytomass groups. From this figure it may be noted that, on average, animal food appropriates more cropland-related phytomass per food intake than vegetable food. This holds for all regions.

*Comparisons of separate sub-systems*

Above we gave aggregated values of the phytomass appropriation for the animal and vegetable food groups. What does the picture look like at a more detailed level?

The Figures 3.16 and 3.17 give information analogous to the one in Figure 3.12, but with specification of separate sub-systems. To facilitate comparison of Figures 3.16 and 3.17, the relative shares of phytomass appropriation and food intake for each sub-system are shown in Figure 3.18 below. It should be observed that the food intake related to a sub-system here includes *both* the product and the by-product(s) generated in the sub-system. For instance, as food intake related to the chicken egg system is counted both the intake of eggs (product) and hen carcasses (by-product). Analogously, the phytomass appropriation related to a sub-system refers to the appropriation of the *entire*

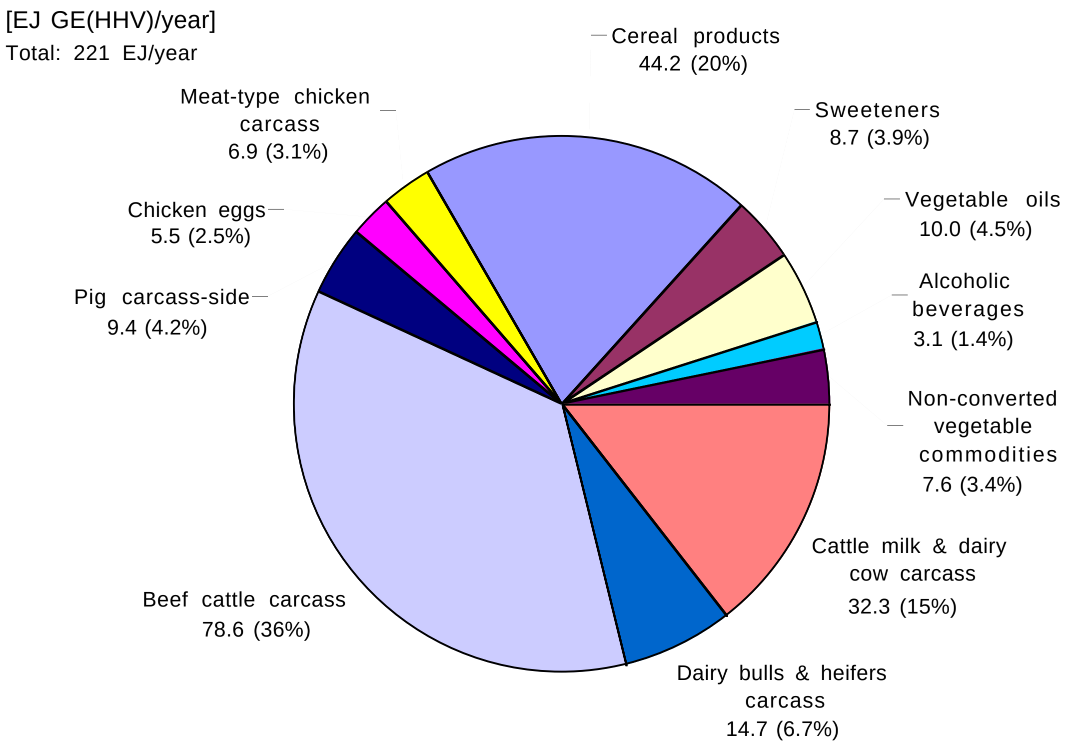

**Figure 3.16** Terrestrial phytomass appropriation related to separate sub-systems (see text for explanations). World totals.

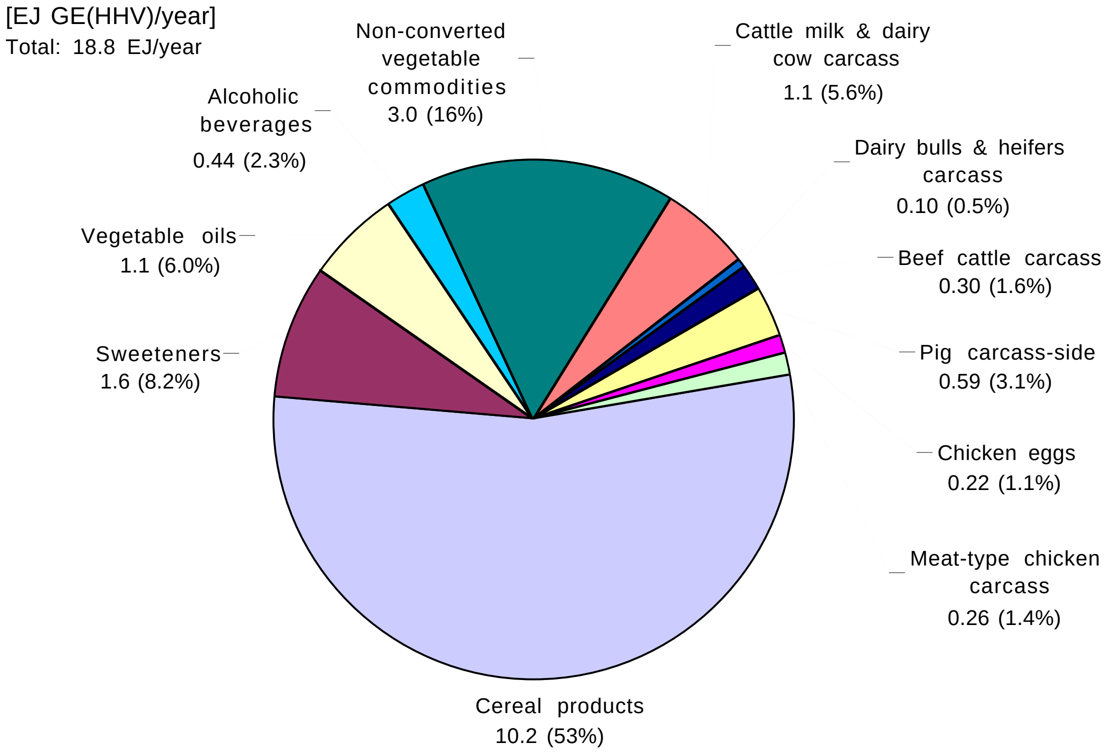

**Figure 3.17** Food intake related to separate sub-systems (see text for explanations). World totals.

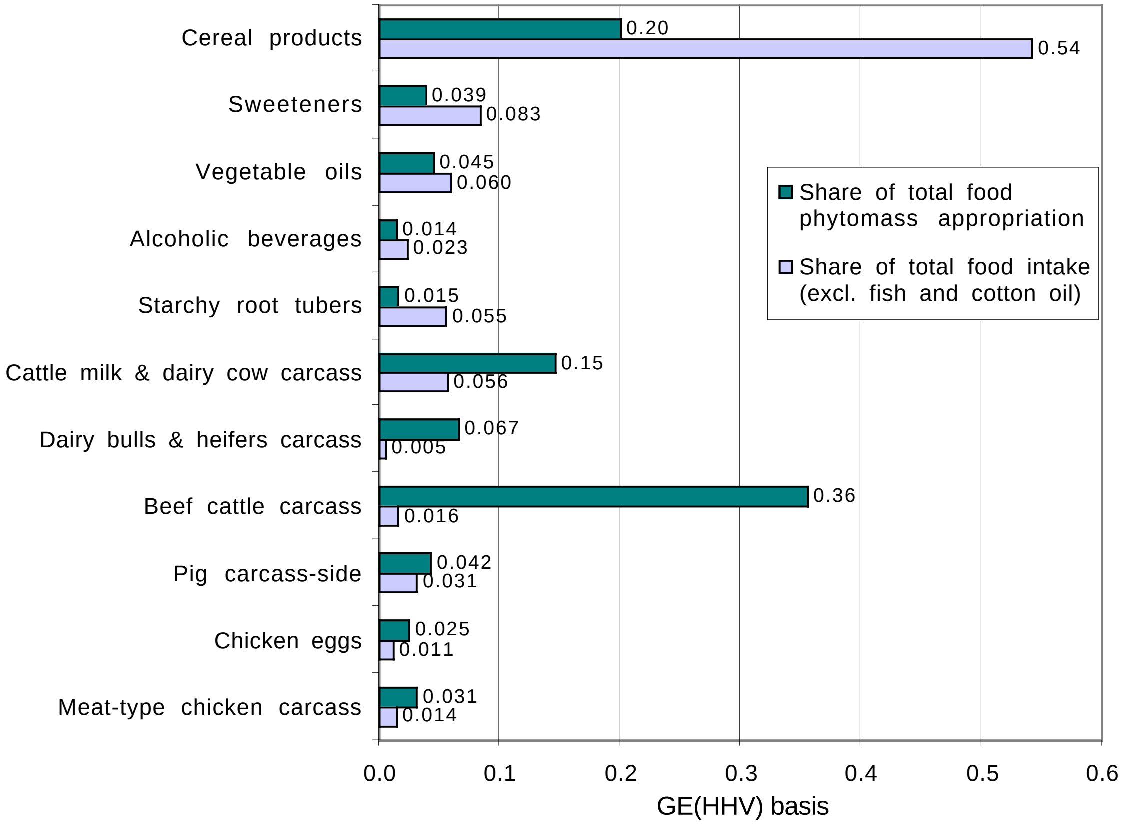

**Figure 3.18** Share of total food-driven terrestrial phytomass appropriation, and share of the total food intake for separate sub-systems. World averages.

sub-system, that is, the phytomass appropriation induced by the feed use for *all* animal categories in the sub-system included.

As can be seen from Figures 3.16 to 3.18, the ruminant carcass sub-systems (beef cattle carcass and dairy bulls & heifers carcass) dominates the phytomass appropriation of the food system, making up 42 percent of the total. In contrast, their contribution to the food intake is no more than about 2 percent of the total. More or less the opposite relation holds for starchy root tubers (main part of the category 'non-converted vegetable commodities') and cereals products.

Figures 3.16 to 3.18 obviously indicate that there is an immense span in efficiency between the different sub-systems. This is illustrated in Figure 3.19 below, which shows the global averages of the *overall* efficiency for each individual sub-system. In Figure 3.20 is given a comparison of the corresponding values between a non-industrial region (Sub-Saharan Africa) and an industrial region (West Europe). We can see that the global pattern of differences in overall efficiency (Figure 3.19) also apply for these regions. In general, the same pattern holds for all the other regions.

In which steps do the largest losses occur for each of the sub-systems? In Figures 3.21, 3.22 and 3.23 we have split the overall efficiency into three aggregated efficiency concepts in the same way as in Figure 3.11 (p. 116). (For definitions of the concepts, see

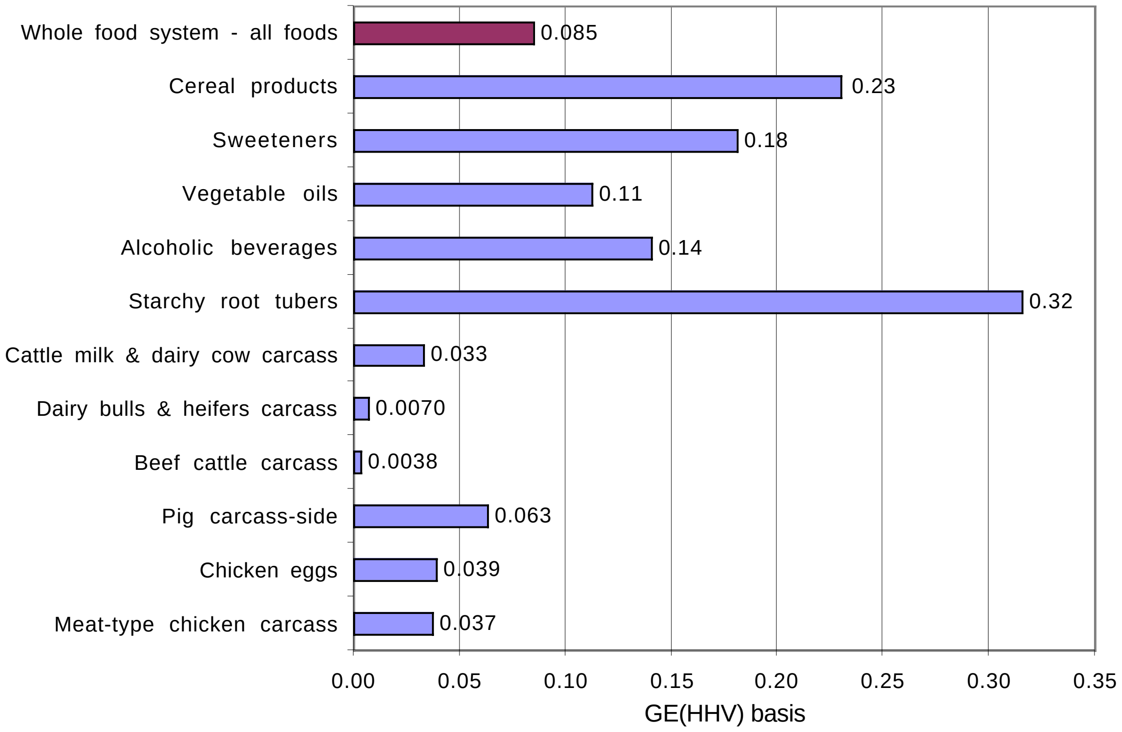

**Figure 3.19** Overall efficiency for separate sub-systems. World averages.

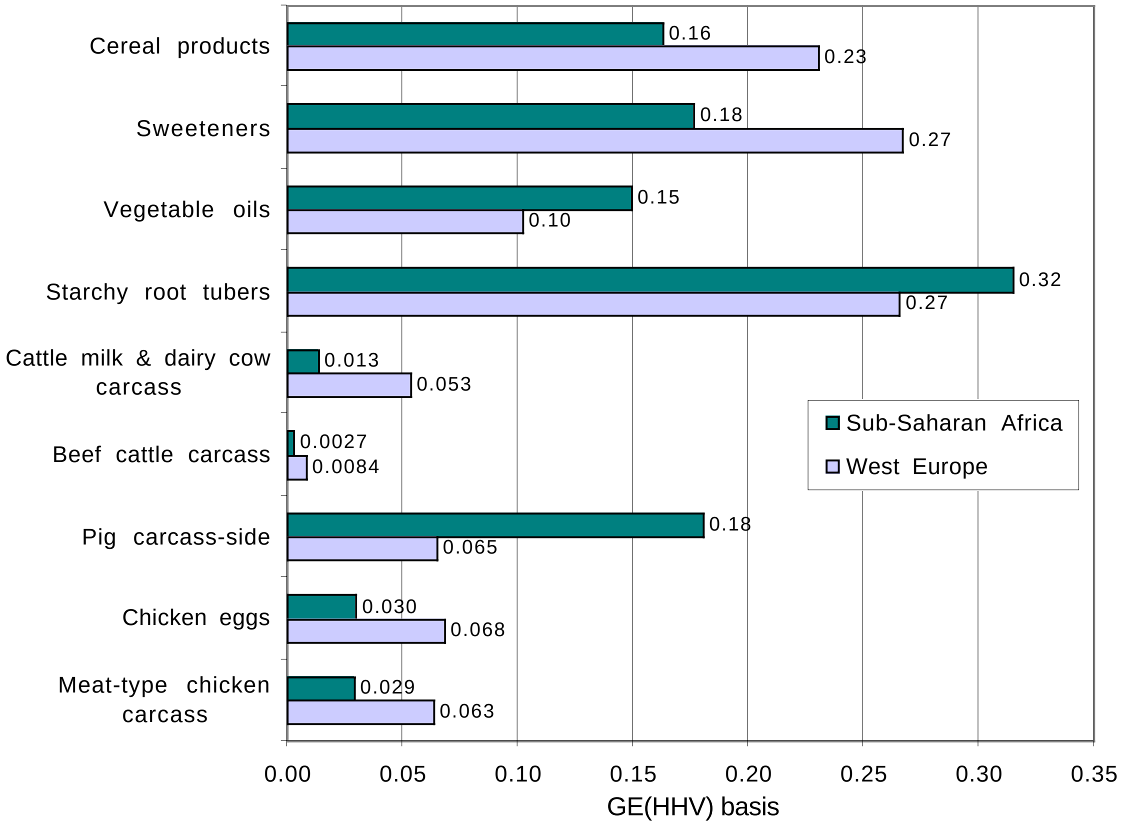

**Figure 3.20** Two regional examples of overall efficiency for separate sub-systems. Trade-neutral values.

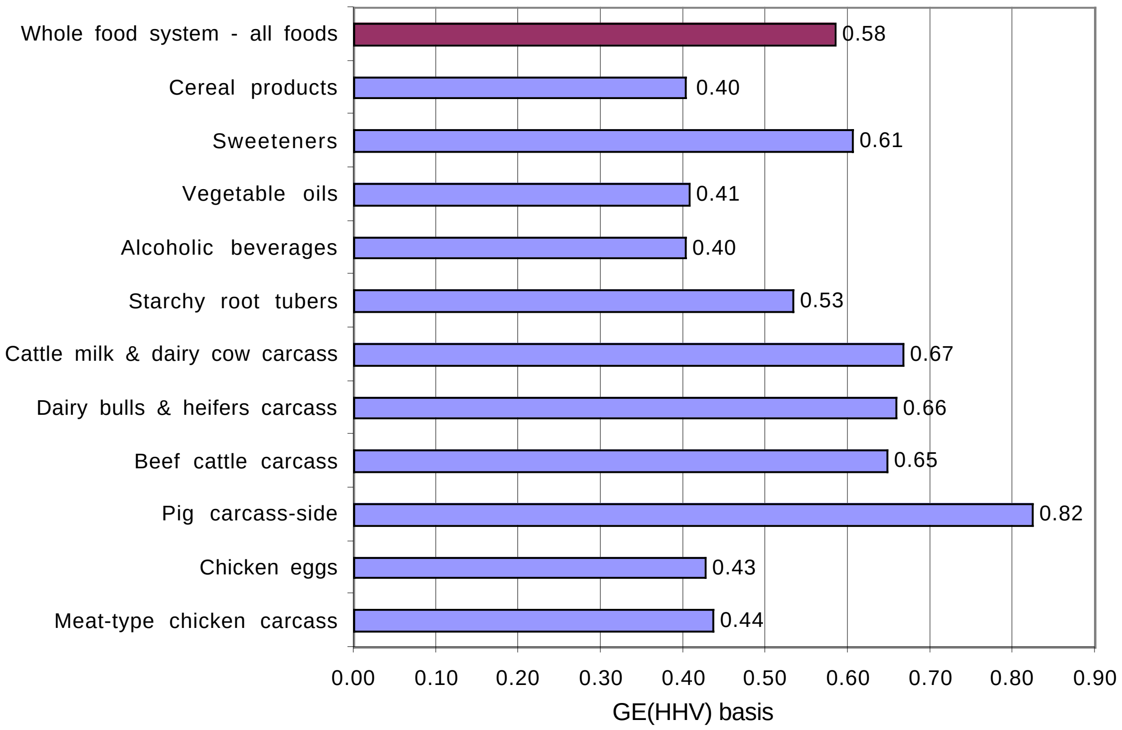

**Figure 3.21** Feed & feedstock utilization efficiency for separate sub-systems. World averages.

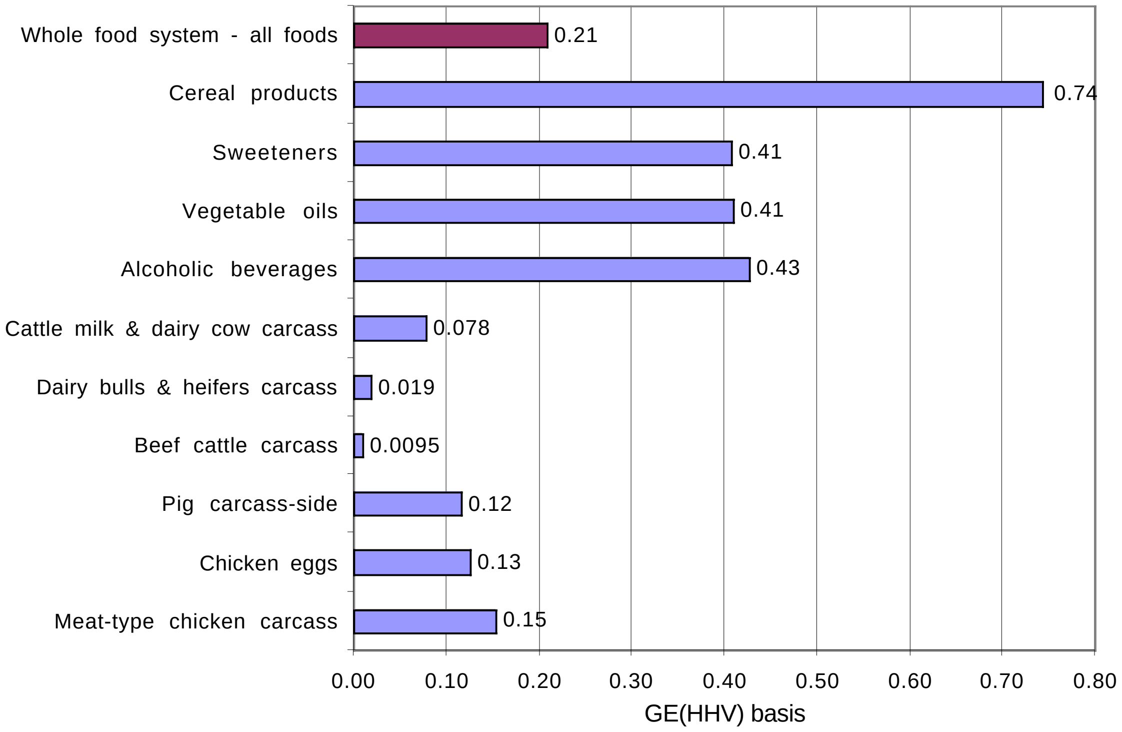

**Figure 3.22** Conversion efficiency for separate sub-systems. World averages.

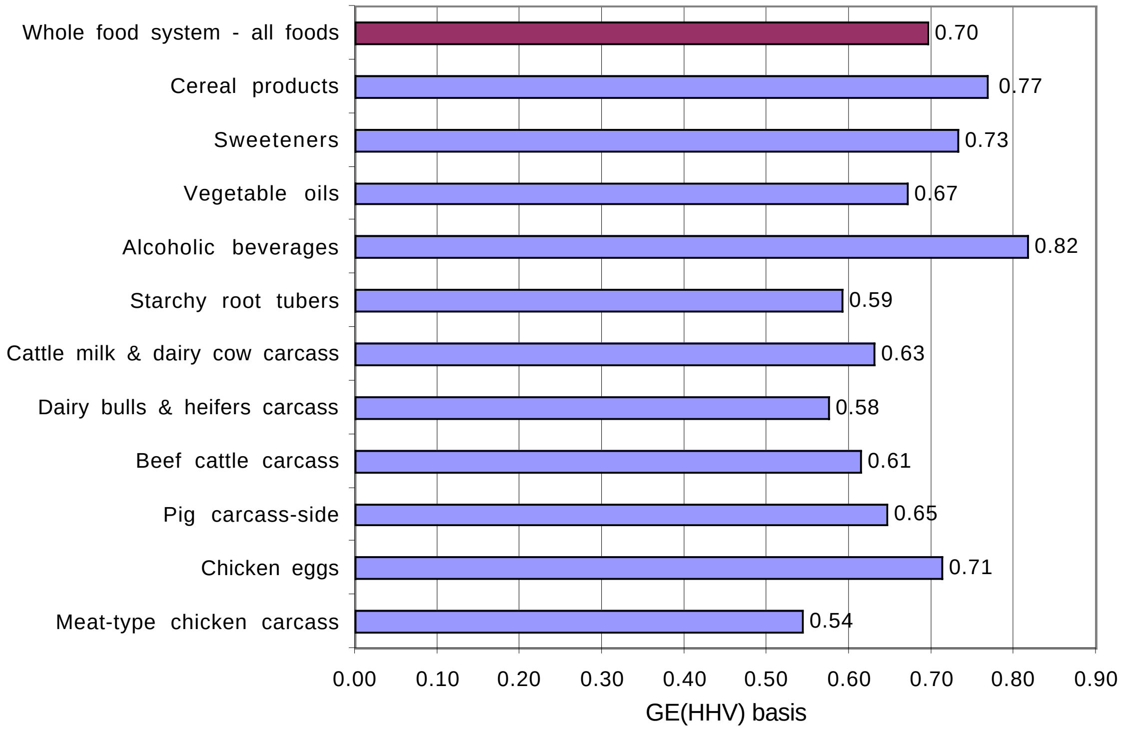

**Figure 3.23** Commodities utilization efficiency for separate sub-systems. World averages.

explanations in connection with that figure.) As one might expect, very large differences exist in the *conversion* step (Figure 3.22), with beef cattle carcass lying at the lower extreme end with 0.9 percent conversion efficiency and cereals products at the higher end (74 percent). More surprisingly, there are relatively large differences between separate sub-systems also for the feed & feedstock utilization efficiency, those of the animal sub-systems generally being higher than those of the vegetable food sub-systems. A main reasons for this is the extensive use of crop by-products in the animal food production. The notably high value for the pig sub-system is an exceptional case — this, and other details on the efficiency of separate animal sub-systems for animal food are dealt with in the next section.

**Table 3.21** Concise biomass flow balance of the food system. World totals.

| | SUPPLY | | | | | DISTRIBUTION | | | | USE | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flow | *Generated*[a] | Not recovered[b] | | Used internally in generating sub-system[c] | | Lost in distribution & storage[d] | | *Distributed*[e] | | Used as mulch in crop production | | Used as feedstock for vegetable products | | Used as feed & feedstock for animal products[f] | | Used as litter for animal bedding | | Used as food | | Actually eaten | | *No use within food system specified* | |
| | Total | Total | Share of gen. | Total | Share of gen. | Total | Share of gen. | Total | Share of gen. | Total | Share of distr. | Total | Share of distr. | Total | Share of distr. | Total | Share of distr. | Total | Share of distr. | Total | Share of distr. | Total | Share of distr. |
| ***SUM ALL FLOWS***[g] | 18 400 | 6100 | 33% | 97 | 0.5% | 620 | 3.4% | 11 600 | 63% | 57 | 0.5% | 1 520 | 13% | 5 790 | 50% | 270 | 2.4% | 1 380 | 12% | 970 | 8.4% | 2 580 | 22% |
| **SYSTEM** | | | | | | | | | | | | | | | | | | | | | | | |
| ***A. Total all phytomass*** | 13 000 | 3 840 | 30% | 97 | 0.7% | 400 | 3.1% | 8 630 | 67% | 57 | 0.7% | 1 520 | 18% | 5 480 | 64% | 270 | 3.2% | 260 | 3.1% | 160 | 1.9% | 1 030 | 12% |
| **A1. Edible-type crops products** | 2 540 | 14 | 0.5% | 70 | 2.8% | 120 | 4.6% | 2 340 | 92% | | | 1 520 | 65% | 550 | 23% | | | 260 | 11% | 160 | 6.9% | 4.8 | 0.2% |
| Cereals grains | 1 650 | 0 | 0% | 53 | 3.2% | 76 | 4.6% | 1 520 | 92% | | | 1 050 | 69% | 480 | 31% | | | 0 | 0% | 0 | 0% | 0 | 0% |
| Starchy root tubers | 160 | 0 | 0% | 3.3 | 2.1% | 16 | 10% | 140 | 88% | | | 0 | 0% | 50 | 36% | | | 88 | 64% | 60 | 44% | 0 | 0% |
| Sugar crops stems & roots | 320 | 0 | 0% | 4.9 | 1.5% | 2.4 | 0.8% | 310 | 98% | | | 310 | 100% | 0 | 0% | | | 0 | 0% | 0 | 0% | 0 | 0% |
| Oil crops products | 250 | 14 | 5.6% | 9.1 | 3.7% | 7.1 | 2.9% | 220 | 88% | | | 170 | 78% | 21 | 9.6% | | | 22 | 10% | 17 | 7.6% | 4.8 | 2.2% |
| Other edible-type cultivation-products | 170 | - | - | - | - | 14.2 | 8.4% | 150 | 92% | | | 0 | 0% | 0 | 0% | | | 150 | 100% | 84 | 54% | 0 | 0% |
| **A2. Animal forage crops** | 1 150 | 110 | 9.5% | 10 | 0.9% | - | - | 1 030 | 89% | | | | | 1 030 | 100% | | | | | | | 0 | 0% |
| Grass-legume | 790 | 79 | 10% | 7.9 | 1.0% | | | 700 | 89% | | | | | 700 | 100% | | | | | | | 0 | 0% |
| Whole-cereals | 250 | 25 | 10% | 2.5 | 1.0% | | | 220 | 89% | | | | | 220 | 100% | | | | | | | 0 | 0% |
| Other animal forage crops | 110 | 6 | 5.0% | 0 | 0% | 5.0 | 4.5% | 100 | 90% | | | | | 100 | 100% | | | | | | | 0 | 0% |
| **A3. Pasture** | 5 820 | 3 020 | 52% | | | | | 2 790 | 48% | | | | | 2 790 | 100% | | | | | | | 0 | 0% |
| Cropland pasture | 200 | 70 | 35% | | | | | 130 | 65% | | | | | 130 | 100% | | | | | | | 0 | 0% |
| Permanent pasture | 5 620 | 2 950 | 53% | | | | | 2 660 | 47% | | | | | 2 660 | 100% | | | | | | | 0 | 0% |
| **A4. Edible-type crops by-products** | 3 460 | 690 | 20% | 16 | 0.5% | 280 | 8.0% | 2 470 | 72% | 57 | 2.3% | | | 1 120 | 46% | 270 | 11% | | | | | 1 020 | 39% |
| Cereals straw & stover | 2 700 | 530 | 20% | 13 | 0.5% | 220 | 8.0% | 1 940 | 72% | 57 | 3.0% | | | 890 | 47% | 270 | 14% | | | | | 710 | 34% |
| Starchy roots tops | 140 | 0 | 0% | 0 | 0% | 14 | 10% | 130 | 90% | | | | | 43 | 35% | | | | | | | 87 | 65% |
| Sugar crops tops & leaves | 200 | 20 | 10% | 0 | 0% | 18 | 9.0% | 160 | 81% | | | | | 95 | 59% | | | | | | | 70 | 41% |
| Oil crops by-products | 410 | 140 | 34% | 2.5 | 0.6% | 27 | 6.7% | 240 | 59% | | | | | 88 | 37% | | | | | | | 150 | 63% |
| ***B. Total all conversion-products & by-products*** | 4 840 | 2 200 | 58% | | | 180 | 3.6% | 2 460 | 51% | | | | | 230 | 9.2% | | | 1 090 | 44% | 800 | 32% | 1 150 | 47% |
| **B1. Vegetable products** | 930 | 0 | 0% | | | 0.3 | 0.0% | 930 | 100% | | | | | | | | | 930 | 100% | 710 | 76% | 0 | 0% |
| Cereals products | 730 | 0 | 0% | | | 0.0 | 0.0% | 730 | 100% | | | | | | | | | 730 | 100% | 560 | 77% | 0 | 0% |
| Sweeteners | 120 | 0 | 0% | | | 0.2 | 0.1% | 120 | 100% | | | | | | | | | 120 | 100% | 90 | 73% | 0 | 0% |

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Vegetable oils | 43 | 0 | 0% | 0.1 | 0.2% | 42 | 100% |  |  | 42 | 100% | 28 | 66% | 0 | 0% |
| Other vegetable products | 36 | 0 | 0% | 0.1 | 0.2% | 35 | 100% |  |  | 35 | 100% | 29 | 82% | 0 | 0% |
| **B2. Animal products** | 140 | 0 | 0% | 2.0 | 1.5% | 140 | 98% |  |  | 140 | 100% | 82 | 58% | 0 | 0% |
| Carcass | 67 | 0 | 0% | 0.1 | 0.2% | 67 | 100% |  |  | 67 | 100% | 36 | 53% | 0 | 0% |
| Cattle milk | 62 | 0 | 0% | 1.5 | 2.4% | 61 | 98% |  |  | 61 | 100% | 39 | 64% | 0 | 0% |
| Egg | 14 | 0 | 0% | 0.6 | 4.2% | 13 | 96% |  |  | 13 | 100% | 6.9 | 53% | 0 | 0% |
| **B3. Vegetable conv.-by-products** | 570 | 0 | 0% | 0 | 0% | 570 | 100% | 220 | 38% | 2.2 | 0.5% | 1.5 | 0.3% | 350 | 61% |
| Cereals milling by-products | 250 | 0 | 0% | 0 | 0% | 250 | 100% | 100 | 42% | 1.5 | 0.6% | 1.1 | 0.4% | 140 | 57% |
| Sugar crops conversion by-products | 180 | 0 | 0% | 0 | 0% | 180 | 100% | 39 | 22% | 0 | 0% | 0 | 0% | 140 | 78% |
| Oilseed conversion by-products | 130 | 0 | 0% | 0 | 0% | 130 | 100% | 68 | 54% | 0.6 | 0.5% | 0.4 | 0.4% | 58 | 45% |
| Other vegetable by-products | 20 | 0 | 0% | 0 | 0% | 20 | 100% | 8.7 | 44% | 0 | 0% | 0 | 0% | 11 | 56% |
| **B4. Animal conversion-by-products** | 3 190 | 2 200 | 69% | 170 | 5.4% | 820 | 26% | 5.8 | 0.7% | 15 | 1.8% | 8.4 | 1.0% | 790 | 97% |
| Carcass | 12 | 0 | 0% | 0 | 0.2% | 12 | 100% |  |  | 12 | 100% | 6.0 | 51% | 0 | 0% |
| Carcass by-products | 29 | 0 | 0% | 2.7 | 9.4% | 26 | 91% | 5.8 | 22% | 2.9 | 11% | 2.4 | 9.1% | 18 | 67% |
| Manure (feces, urine & used litter) | 3 050 | 2 200 | 72% | 170 | 5.6% | 680 | 22% |  |  |  |  |  |  | 680 | 100% |
| Methane | 96 |  |  |  |  | 96 | 100% |  |  |  |  |  |  | 96 | 100% |
| ***C. Total all end-use residues*** | 560 | 56 | 10% | 51 | 9.0% | 450 | 81% | 64 | 14% |  |  |  |  | 390 | 86% |
| Non-eaten food | 410 | 41 | 10% | 37 | 9.0% | 330 | 81% | 64 | 20% |  |  |  |  | 270 | 80% |
| Human feces & urine | 150 | 15 | 10% | 14 | 9.0% | 120 | 81% |  |  |  |  |  |  | 120 | 100% |
| **SYSTEM-EXTERNAL INPUTS** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Fish | 26 | 0 | 0% | 1.3 | 5.0% | 25 | 95% | 6.6 | 26% | 19 | 74% | 9.4 | 38% | 0 | 0% |
| Cotton oil | 5.1 | 0 | 0% | 0 | 0% | 5.1 | 100% |  |  | 5.1 | 100% | 3.4 | 66% | 0 | 0% |
| Cotton meal | 16 | 0 | 0% | 0 | 0% | 16 | 100% | 5.0 | 31% |  |  |  |  | 11 | 69% |

Amounts in dry weight (Tg DM/year), and shares of generated and distributed amounts in percent (DM basis). Amount-numbers are rounded to 2 significant digits, except for values exceeding 1000 (3 significant digits), and for values less than 1 (1 significant digit). For more detailed specification of flows belonging to each category, see Table 3.22 below.

[a] Refers to all generating processes within system, that is, phytomass production, conversion of phytomass to vegetable and animal products, and food use.

[b] 'Not recovered' refers to generated flows not made available for further use within or outside the system. For crops, it refers to phytomass not removed from field; for pasture to herbage not eaten; for manure it mainly refers to non-collected feces & urine generated at grazing on pastures, or stubble and alike.

[c] Major internal uses are use as seeds for crop production and use of crop by-products for coil conservation (mulching).

*Notes continue on next page.*

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[d] Distribution and storage losses do not include losses in the production of hay and silage from grass-legume crops and whole-cereals; such losses are accounted for in the description of the animal food sub-systems (compare note f below).

[e] ‘Distributed’ refers to amount available for actual use within the system after all losses and sub-system-internal uses have been accounted for. For some flows, such as pastures and methane, this concept has only a formal meaning.

[f] Feedstock refers to flows processed for purposes of nutrient enhancement and/or conservation. Thus, *actual intake* of feed dry matter is lower (see Table 3.23, p. 144).

[g] Refers to sum of all flows displayed in table, that is, both system flows and system-external inputs.

**Table 3.22** Biomass-related products, by-products and residues generated in the food system globally (total values) and regionally (per-capita values).

| Flow | World | | | East Asia | | | East Europe | | | Latin America & Caribbean | | | North Africa & West Asia | | | North America & Oceania | | | South & Central Asia | | | Sub-Saharan Africa | | | West Europe | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | AW (Tg) | DW (Tg) | GE (EJ) | AW (kg) | DW (kg) | GE (GJ) | AW (kg) | DW (kg) | GE (GJ) | AW (kg) | DW (kg) | GE (GJ) | AW (kg) | DW (kg) | GE (GJ) | AW (kg) | DW (kg) | GE (GJ) | AW (kg) | DW (kg) | GE (GJ) | AW (kg) | DW (kg) | GE (GJ) | AW (kg) | DW (kg) | GE (GJ) |
| ***A. Total all phytomass*** | 38 028 | 12 967 | 221.26 | 3 906 | 1 498 | 25.43 | 8 895 | 2 736 | 47.28 | 17 841 | 5 315 | 89.79 | 5 771 | 1 941 | 33.16 | 12 960 | 5 160 | 90.32 | 5 280 | 1 785 | 30.24 | 7 455 | 2 345 | 39.39 | 6 598 | 2 400 | 41.84 |
| *Total all cropland-related phytomass (A1+A2+A4)* | 15 555 | 7 349 | 127.21 | 1 988 | 1 018 | 17.40 | 4 878 | 1 731 | 30.16 | 3 314 | 1 683 | 29.30 | 1 540 | 882.8 | 15.30 | 7 629 | 3 827 | 67.61 | 2 378 | 1 059 | 18.17 | 1 511 | 858.6 | 14.70 | 4 699 | 1 925 | 33.73 |
| Edible-type crops products and by-products (A1+A4) | 9 854 | 5 998 | 103.62 | 1 548 | 943.0 | 16.11 | 1 807 | 990.1 | 17.20 | 2 719 | 1 534 | 26.69 | 1 395 | 846.6 | 14.66 | 4 348 | 3 007 | 53.26 | 1 229 | 771.9 | 13.14 | 1 510 | 858.6 | 14.70 | 2 232 | 1 308 | 22.94 |
| Animal forage crops (A2) | 4 905 | 1 152 | 20.10 | 440.2 | 75.3 | 1.29 | 2 988 | 720.6 | 12.59 | 595.6 | 148.9 | 2.60 | 144.9 | 36.2 | 0.63 | 1 808 | 451.9 | 7.91 | 1 149 | 287.2 | 5.03 | 0.2 | 0.0 | 0.00 | 1 649 | 412.0 | 7.21 |
| Cropland pasture (A3) | 796.6 | 199.2 | 3.49 | 0.0 | 0.0 | 0.00 | 83.2 | 20.8 | 0.36 | 0.2 | 0.0 | 0.00 | 0.1 | 0.0 | 0.00 | 1 473 | 368.1 | 6.44 | 0.1 | 0.0 | 0.00 | 0.1 | 0.0 | 0.00 | 818.4 | 204.6 | 3.58 |
| *Total all permanent-grassland-related phytomass (A3)* | 22 473 | 5 618 | 94.05 | 1 919 | 479.6 | 8.03 | 4 017 | 1 004 | 17.12 | 14 527 | 3 632 | 60.49 | 4 231 | 1 058 | 17.87 | 5 331 | 1 333 | 22.71 | 2 902 | 725.5 | 12.07 | 5 944 | 1 486 | 24.69 | 1 899 | 474.7 | 8.11 |
| **A1. Edible-type crops products** | 4 794 | 2 541 | 47.35 | 723.0 | 396.4 | 7.33 | 867.0 | 419.0 | 7.83 | 1 312 | 598.5 | 11.26 | 728.0 | 348.7 | 6.45 | 2 202 | 1 405 | 26.78 | 611.0 | 320.6 | 5.90 | 638.8 | 300.3 | 5.55 | 1 240 | 647.8 | 12.07 |
| Cereals grains | 1 883 | 1 651 | 30.32 | 320.3 | 280.1 | 5.10 | 290.6 | 255.7 | 4.73 | 296.9 | 260.9 | 4.85 | 264.5 | 232.6 | 4.28 | 1 154 | 1 015 | 18.87 | 242.2 | 211.8 | 3.85 | 166.4 | 146.2 | 2.72 | 511.5 | 450.1 | 8.28 |
| Wheat grains | 569.7 | 501.3 | 9.22 | 58.9 | 51.9 | 0.95 | 159.0 | 139.9 | 2.57 | 47.4 | 41.7 | 0.77 | 157.7 | 138.8 | 2.55 | 362.6 | 319.1 | 5.87 | 88.9 | 78.2 | 1.44 | 11.2 | 9.9 | 0.18 | 255.6 | 224.9 | 4.14 |
| Rice grains | 537.9 | 467.9 | 8.38 | 174.7 | 152.0 | 2.72 | 0.3 | 0.3 | 0.00 | 38.6 | 33.6 | 0.60 | 17.3 | 15.1 | 0.27 | 18.8 | 16.3 | 0.29 | 127.4 | 110.9 | 1.98 | 22.3 | 19.4 | 0.35 | 5.6 | 4.8 | 0.09 |
| Maize grains | 526.6 | 463.4 | 8.71 | 70.1 | 61.7 | 1.16 | 81.9 | 72.1 | 1.36 | 172.3 | 151.6 | 2.85 | 33.1 | 29.1 | 0.55 | 593.3 | 522.1 | 9.82 | 10.6 | 9.3 | 0.18 | 89.5 | 78.7 | 1.48 | 75.8 | 66.7 | 1.25 |
| Sorghum grains | 77.6 | 68.3 | 1.28 | 3.7 | 3.3 | 0.06 | 2.2 | 2.0 | 0.04 | 23.9 | 21.1 | 0.39 | 19.5 | 17.1 | 0.32 | 66.9 | 58.8 | 1.10 | 11.2 | 9.8 | 0.18 | 29.8 | 26.3 | 0.49 | 2.4 | 2.2 | 0.04 |
| Barley grains | 170.8 | 150.3 | 2.74 | 12.9 | 11.4 | 0.21 | 47.2 | 41.5 | 0.76 | 14.7 | 12.9 | 0.24 | 37.0 | 32.5 | 0.59 | 112.0 | 98.5 | 1.79 | 4.1 | 3.6 | 0.06 | 13.5 | 11.9 | 0.22 | 172.1 | 151.5 | 2.76 |
| Starchy root tubers | 547.4 | 157.9 | 2.73 | 120.5 | 36.5 | 0.63 | 176.0 | 41.3 | 0.72 | 88.5 | 26.8 | 0.46 | 36.9 | 7.9 | 0.14 | 65.7 | 14.1 | 0.24 | 25.0 | 6.0 | 0.10 | 217.9 | 74.0 | 1.28 | 100.1 | 22.3 | 0.39 |
| Cassava tubers | 207.6 | 72.7 | 1.26 | 39.4 | 13.8 | 0.24 | 0.3 | 0.1 | 0.00 | 54.9 | 19.2 | 0.33 | 0.0 | 0.0 | 0.00 | 0.0 | 0.0 | 0.00 | 4.1 | 1.4 | 0.02 | 192.4 | 67.3 | 1.16 | 0.0 | 0.0 | 0.00 |
| White potato tubers | 181.4 | 38.7 | 0.67 | 14.0 | 3.0 | 0.05 | 129.2 | 27.6 | 0.48 | 29.0 | 6.2 | 0.11 | 36.3 | 7.8 | 0.13 | 64.2 | 13.7 | 0.24 | 19.5 | 4.2 | 0.07 | 10.8 | 2.3 | 0.04 | 88.8 | 19.0 | 0.33 |
| Sweet potato tubers | 158.4 | 46.5 | 0.80 | 67.2 | 19.7 | 0.34 | 46.5 | 13.7 | 0.24 | 4.7 | 1.4 | 0.02 | 0.5 | 0.1 | 0.00 | 1.5 | 0.4 | 0.01 | 1.4 | 0.4 | 0.01 | 14.7 | 4.3 | 0.07 | 11.3 | 3.3 | 0.06 |
| Sugar crops stems & roots | 1 205 | 316.4 | 5.38 | 111.4 | 29.8 | 0.51 | 224.0 | 53.8 | 0.91 | 576.7 | 155.6 | 2.64 | 137.1 | 34.8 | 0.59 | 571.0 | 148.8 | 2.53 | 201.4 | 54.2 | 0.92 | 80.3 | 21.7 | 0.37 | 318.5 | 76.4 | 1.30 |
| Sugar cane stems | 904.7 | 244.3 | 4.15 | 102.7 | 27.7 | 0.47 | 0.2 | 0.1 | 0.00 | 572.0 | 154.4 | 2.63 | 63.4 | 17.1 | 0.29 | 392.3 | 105.9 | 1.80 | 197.2 | 53.2 | 0.91 | 80.3 | 21.7 | 0.37 | 0.0 | 0.0 | 0.00 |
| Sugar beet roots | 300.3 | 72.1 | 1.23 | 8.7 | 2.1 | 0.04 | 223.8 | 53.7 | 0.91 | 4.7 | 1.1 | 0.02 | 73.7 | 17.7 | 0.30 | 178.6 | 42.9 | 0.73 | 4.2 | 1.0 | 0.02 | 0.0 | 0.0 | 0.00 | 318.4 | 76.4 | 1.30 |

*Table continues on next page.*

**Table 3.22** (continued)

| Flow | World | | | East Asia | | | East Europe | | | Latin America & Caribbean | | | North Africa & West Asia | | | North America & Ocarina | | | South & Central Asia | | | Sub-Saharan Africa | | | West Europe | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | AW (Tg) | DW (Tg) | GE (EJ) | AW (kg) | DW (kg) | GE (GJ) | AW (kg) | DW (kg) | GE (GJ) | AW (kg) | DW (kg) | GE (GJ) | AW (kg) | DW (kg) | GE (GJ) | AW (kg) | DW (kg) | GE (GJ) | AW (kg) | DW (kg) | GE (GJ) | AW (kg) | DW (kg) | GE (GJ) | AW (kg) | DW (kg) | GE (GJ) |
| Oil crops products | 283.5 | 246.9 | 5.95 | 36.9 | 28.8 | 0.72 | 54.7 | 50.2 | 1.16 | 110.1 | 99.0 | 2.31 | 27.4 | 25.4 | 0.59 | 206.9 | 188.7 | 4.45 | 24.5 | 22.6 | 0.56 | 27.3 | 20.0 | 0.51 | 63.4 | 58.4 | 1.41 |
| Soybean seeds | 146.7 | 133.5 | 3.12 | 13.0 | 11.8 | 0.28 | 16.4 | 14.9 | 0.35 | 82.4 | 75.0 | 1.75 | 3.1 | 2.8 | 0.07 | 188.5 | 171.5 | 4.01 | 7.2 | 6.6 | 0.15 | 1.6 | 1.4 | 0.03 | 20.8 | 18.9 | 0.44 |
| Groundnut pods | 35.6 | 33.4 | 0.85 | 6.3 | 6.0 | 0.15 | 0.1 | 0.1 | 0.00 | 4.5 | 4.3 | 0.11 | 5.6 | 5.2 | 0.13 | 7.3 | 6.8 | 0.17 | 9.2 | 8.7 | 0.22 | 10.1 | 9.5 | 0.24 | 0.0 | 0.0 | 0.00 |
| Sunflower achenes | 44.7 | 41.5 | 0.93 | 1.5 | 1.4 | 0.03 | 33.9 | 31.5 | 0.71 | 18.8 | 17.5 | 0.39 | 17.4 | 16.2 | 0.36 | 3.8 | 3.5 | 0.08 | 2.5 | 2.4 | 0.05 | 2.5 | 2.4 | 0.05 | 26.6 | 24.8 | 0.55 |
| Canola seeds | 23.2 | 21.4 | 0.59 | 3.4 | 3.1 | 0.09 | 3.4 | 3.1 | 0.09 | 0.0 | 0.0 | 0.00 | 1.3 | 1.2 | 0.03 | 7.4 | 6.8 | 0.19 | 5.3 | 4.9 | 0.14 | 0.1 | 0.1 | 0.00 | 15.9 | 14.7 | 0.41 |
| Oil palm fruit bunches | 33.3 | 17.0 | 0.45 | 12.7 | 6.5 | 0.17 | 0.9 | 0.5 | 0.01 | 4.3 | 2.2 | 0.06 | 0.0 | 0.0 | 0.00 | 0.0 | 0.0 | 0.00 | 0.2 | 0.1 | 0.00 | 13.0 | 6.6 | 0.18 | 0.0 | 0.0 | 0.00 |
| Other edible-type cultivation-products | 875.9 | 168.9 | 2.97 | 133.9 | 21.2 | 0.37 | 121.6 | 18.0 | 0.31 | 239.5 | 56.2 | 0.99 | 262.1 | 47.9 | 0.84 | 204.7 | 38.4 | 0.68 | 117.9 | 25.9 | 0.46 | 146.9 | 38.4 | 0.68 | 246.5 | 40.7 | 0.71 |
| Tree nuts | 5.0 | 4.5 | 0.10 | 0.4 | 0.3 | 0.01 | 0.7 | 0.7 | 0.01 | 0.9 | 0.8 | 0.02 | 3.3 | 3.0 | 0.07 | 2.7 | 2.4 | 0.05 | 0.5 | 0.4 | 0.01 | 0.6 | 0.5 | 0.01 | 2.0 | 1.8 | 0.04 |
| Pulses | 36.3 | 32.6 | 0.62 | 3.4 | 3.0 | 0.06 | 0.8 | 0.7 | 0.01 | 11.7 | 10.5 | 0.20 | 7.8 | 7.0 | 0.13 | 7.2 | 6.5 | 0.12 | 10.2 | 9.2 | 0.17 | 9.5 | 8.5 | 0.16 | 2.7 | 2.4 | 0.05 |
| Vegetables | 452.3 | 45.2 | 0.77 | 92.4 | 9.2 | 0.16 | 87.0 | 8.7 | 0.15 | 55.8 | 5.6 | 0.09 | 127.9 | 12.8 | 0.22 | 107.6 | 10.8 | 0.18 | 60.6 | 6.1 | 0.10 | 36.9 | 3.7 | 0.06 | 134.5 | 13.5 | 0.23 |
| Fruits | 367.9 | 73.6 | 1.25 | 36.3 | 7.3 | 0.12 | 31.2 | 6.2 | 0.11 | 163.9 | 32.8 | 0.56 | 122.4 | 24.5 | 0.42 | 85.3 | 17.1 | 0.29 | 45.3 | 9.1 | 0.15 | 91.8 | 18.4 | 0.31 | 105.2 | 21.0 | 0.36 |
| Stimulants | 14.4 | 13.0 | 0.23 | 1.5 | 1.3 | 0.02 | 1.9 | 1.7 | 0.03 | 7.3 | 6.6 | 0.12 | 0.7 | 0.6 | 0.01 | 1.9 | 1.7 | 0.03 | 1.3 | 1.1 | 0.02 | 8.1 | 7.3 | 0.13 | 2.1 | 1.9 | 0.03 |
| **A2. Animal forage crops** | 4 905 | 1 152 | 20.10 | 440.2 | 75.3 | 1.29 | 2 988 | 720.6 | 12.59 | 595.6 | 148.9 | 2.60 | 144.9 | 36.2 | 0.63 | 1 808 | 451.9 | 7.91 | 1 149 | 287.2 | 5.03 | 0.2 | 0.0 | 0.00 | 1 649 | 412.0 | 7.21 |
| Grass-legume | 3 153 | 788.2 | 13.79 | 93.1 | 23.3 | 0.41 | 2 043 | 510.8 | 8.94 | 595.1 | 148.8 | 2.60 | 144.9 | 36.2 | 0.63 | 722.9 | 180.7 | 3.16 | 1 149 | 287.3 | 5.03 | 0.1 | 0.0 | 0.00 | 494.4 | 123.6 | 2.16 |
| Grass-legume, temp. spp. | 1 775 | 443.7 | 7.76 | 46.5 | 11.6 | 0.20 | 2 043 | 510.7 | 8.94 | 178.5 | 44.6 | 0.78 | 115.9 | 29.0 | 0.51 | 650.6 | 162.6 | 2.85 | 344.8 | 86.2 | 1.51 | 0.0 | 0.0 | 0.00 | 494.2 | 123.6 | 2.16 |
| Grass-legume, trop. spp. | 1 378 | 344.5 | 6.03 | 46.5 | 11.6 | 0.20 | 0.4 | 0.1 | 0.00 | 416.6 | 104.1 | 1.82 | 29.0 | 7.2 | 0.13 | 72.3 | 18.1 | 0.32 | 804.3 | 201.1 | 3.52 | 0.1 | 0.0 | 0.00 | 0.1 | 0.0 | 0.00 |
| Whole-cereals | 1 010 | 252.5 | 4.42 | 0.0 | 0.0 | 0.00 | 680.6 | 170.2 | 2.98 | 0.0 | 0.0 | 0.00 | 0.0 | 0.0 | 0.00 | 1 084 | 271.1 | 4.74 | 0.0 | 0.0 | 0.00 | 0.0 | 0.0 | 0.00 | 1 153 | 288.3 | 5.04 |
| Whole-maize | 1 010 | 252.5 | 4.42 | 0.0 | 0.0 | 0.00 | 680.6 | 170.2 | 2.98 | 0.0 | 0.0 | 0.00 | 0.0 | 0.0 | 0.00 | 1 084 | 271.1 | 4.74 | 0.0 | 0.0 | 0.00 | 0.0 | 0.0 | 0.00 | 1 153 | 288.3 | 5.04 |
| Other animal forage crops | 741.8 | 111.3 | 1.89 | 347.1 | 52.1 | 0.89 | 264.2 | 39.6 | 0.67 | 0.4 | 0.1 | 0.00 | 0.0 | 0.0 | 0.00 | 0.9 | 0.1 | 0.00 | 0.0 | 0.0 | 0.00 | 0.1 | 0.0 | 0.00 | 1.2 | 0.2 | 0.00 |
| Forage-vegetables | 741.8 | 111.3 | 1.89 | 347.1 | 52.1 | 0.89 | 264.2 | 39.6 | 0.67 | 0.4 | 0.1 | 0.00 | 0.0 | 0.0 | 0.00 | 0.9 | 0.1 | 0.00 | 0.0 | 0.0 | 0.00 | 0.1 | 0.0 | 0.00 | 1.2 | 0.2 | 0.00 |
| **A3. Pasture** | 23 269 | 5 817 | 97.54 | 1 919 | 479.6 | 8.03 | 4 100 | 1 025 | 17.48 | 14 527 | 3 632 | 60.49 | 4 231 | 1 058 | 17.87 | 6 804 | 1 701 | 29.15 | 2 902 | 725.5 | 12.07 | 5 944 | 1 486 | 24.69 | 2 717 | 679.3 | 11.70 |
| Cropland pasture | 796.6 | 199.2 | 3.49 | 0.0 | 0.0 | 0.00 | 83.2 | 20.8 | 0.36 | 0.2 | 0.0 | 0.00 | 0.1 | 0.0 | 0.00 | 1 473 | 368.1 | 6.44 | 0.1 | 0.0 | 0.00 | 0.1 | 0.0 | 0.00 | 818.4 | 204.6 | 3.58 |
| Grass-legume, temp. spp. | 750.1 | 187.5 | 3.28 | 0.0 | 0.0 | 0.00 | 83.2 | 20.8 | 0.36 | 0.1 | 0.0 | 0.00 | 0.1 | 0.0 | 0.00 | 1 325 | 331.3 | 5.80 | 0.0 | 0.0 | 0.00 | 0.0 | 0.0 | 0.00 | 818.4 | 204.6 | 3.58 |
| Grass-legume, trop. spp. | 46.5 | 11.6 | 0.20 | 0.0 | 0.0 | 0.00 | 0.0 | 0.0 | 0.00 | 0.1 | 0.0 | 0.00 | 0.0 | 0.0 | 0.00 | 147 | 36.8 | 0.64 | 0.1 | 0.0 | 0.00 | 0.1 | 0.0 | 0.00 | 0.1 | 0.0 | 0.00 |
| Permanent pasture | 22 473 | 5 618 | 94.05 | 1 919 | 479.6 | 8.03 | 4 017 | 1 004 | 17.12 | 14 527 | 3 632 | 60.49 | 4 231 | 1 058 | 17.87 | 5 331 | 1 333 | 22.71 | 2 902 | 725.5 | 12.07 | 5 944 | 1 486 | 24.69 | 1 899 | 474.7 | 8.11 |
| Native grass-legume, temperate spp. | 9 493 | 2 373 | 40.34 | 908.8 | 227.2 | 3.86 | 3 648 | 912.0 | 15.50 | 4 058 | 1 015 | 17.25 | 3 311 | 827.8 | 14.07 | 3 867 | 966.8 | 16.44 | 807.7 | 201.9 | 3.43 | 1 372 | 342.9 | 5.83 | 1 547 | 386.8 | 6.58 |
| Native grass-legume, tropical spp. | 538.4 | 134.6 | 2.36 | 0.0 | 0.0 | 0.00 | 368.5 | 92.1 | 1.61 | 1.2 | 0.3 | 0.01 | 0.2 | 0.0 | 0.00 | 878.9 | 219.7 | 3.85 | 0.1 | 0.0 | 0.00 | 0.2 | 0.0 | 0.00 | 351.7 | 87.9 | 1.54 |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oversown grass-legume, temperate spp. | 12 189 | 3 047 | 50.28 | 1 010 | 252.4 | 4.16 | 0.5 | 0.1 | 0.00 | 9 995 | 2 499 | 41.23 | 919.8 | 229.9 | 3.79 | 477.5 | 119.4 | 1.97 | 2 094 | 523.5 | 8.64 | 4 572 | 1 143 | 18.86 | 0.1 | 0.0 | 0.00 |
| Oversown grass-legume, tropical spp. | 253.3 | 63.3 | 1.08 | 0.2 | 0.0 | 0.00 | 0.0 | 0.0 | 0.00 | 472.1 | 118.0 | 2.01 | 0.0 | 0.0 | 0.00 | 107.4 | 26.9 | 0.46 | 0.0 | 0.0 | 0.00 | 0.4 | 0.1 | 0.00 | 0.0 | 0.0 | 0.00 |
| **A4. Edible-type crops by-products** | 5 059 | 3 456 | 56.26 | 824.7 | 546.7 | 8.78 | 939.6 | 571.1 | 9.38 | 1 407 | 935.7 | 15.43 | 667.3 | 497.9 | 8.21 | 2 146 | 1 602 | 26.48 | 617.6 | 451.4 | 7.24 | 871.6 | 558.3 | 9.15 | 991.7 | 660.6 | 10.86 |
| Cereals straw & stover | 3 080 | 2 699 | 43.93 | 503.4 | 441.6 | 7.08 | 467.2 | 412.2 | 6.87 | 746.1 | 641.0 | 10.54 | 469.2 | 414.1 | 6.87 | 1 444 | 1 257 | 20.83 | 414.7 | 369.3 | 5.87 | 507.9 | 435.9 | 7.16 | 561.9 | 500.7 | 8.37 |
| Wheat straw | 782.3 | 704.0 | 11.76 | 86.4 | 77.8 | 1.30 | 233.1 | 209.8 | 3.50 | 69.6 | 62.6 | 1.05 | 231.3 | 208.2 | 3.48 | 433.3 | 390.0 | 6.51 | 144.9 | 130.4 | 2.18 | 25.6 | 23.0 | 0.38 | 249.9 | 224.9 | 3.76 |
| Rice straw | 614.1 | 552.7 | 8.29 | 168.9 | 152.0 | 2.28 | 0.3 | 0.3 | 0.00 | 45.6 | 41.1 | 0.62 | 20.4 | 18.4 | 0.28 | 22.2 | 20.0 | 0.30 | 184.8 | 166.3 | 2.49 | 32.4 | 29.1 | 0.44 | 6.6 | 5.9 | 0.09 |
| Maize stover | 1 235 | 1 049 | 17.32 | 217.6 | 185.0 | 3.05 | 157.5 | 133.9 | 2.21 | 535.0 | 454.7 | 7.50 | 102.8 | 87.4 | 1.44 | 750.8 | 638.1 | 10.53 | 37.7 | 32.1 | 0.53 | 319.1 | 271.2 | 4.47 | 95.9 | 81.5 | 1.34 |
| Sorghum stover | 221.1 | 187.9 | 3.10 | 11.5 | 9.8 | 0.16 | 6.9 | 5.9 | 0.10 | 74.3 | 63.2 | 1.04 | 60.4 | 51.4 | 0.85 | 103.8 | 88.3 | 1.46 | 39.9 | 33.9 | 0.56 | 106.4 | 90.4 | 1.49 | 3.8 | 3.2 | 0.05 |
| Barley straw | 228.0 | 205.2 | 3.47 | 19.0 | 17.1 | 0.29 | 69.2 | 62.3 | 1.05 | 21.6 | 19.4 | 0.33 | 54.2 | 48.8 | 0.82 | 133.8 | 120.4 | 2.04 | 7.4 | 6.6 | 0.11 | 24.5 | 22.1 | 0.37 | 205.7 | 185.2 | 3.13 |
| Starchy roots tops | 741.4 | 144.7 | 2.36 | 191.5 | 34.0 | 0.55 | 229.3 | 41.3 | 0.67 | 102.9 | 23.3 | 0.38 | 39.8 | 7.9 | 0.13 | 71.4 | 14.1 | 0.23 | 28.2 | 5.7 | 0.09 | 260.7 | 61.7 | 1.02 | 116.9 | 22.3 | 0.37 |
| Cassava tops incl. leaves | 237.8 | 59.5 | 0.98 | 45.1 | 11.3 | 0.19 | 0.3 | 0.1 | 0.00 | 62.9 | 15.7 | 0.26 | 0.0 | 0.0 | 0.00 | 0.0 | 0.0 | 0.00 | 4.7 | 1.2 | 0.02 | 220.4 | 55.1 | 0.91 | 0.0 | 0.0 | 0.00 |
| White potato tops | 193.6 | 38.7 | 0.64 | 14.9 | 3.0 | 0.05 | 137.9 | 27.6 | 0.45 | 30.9 | 6.2 | 0.10 | 38.8 | 7.8 | 0.13 | 68.5 | 13.7 | 0.23 | 20.8 | 4.2 | 0.07 | 11.5 | 2.3 | 0.04 | 94.8 | 19.0 | 0.31 |
| Sweet potato tops | 310.0 | 46.5 | 0.74 | 131.4 | 19.7 | 0.32 | 91.1 | 13.7 | 0.22 | 9.1 | 1.4 | 0.02 | 1.0 | 0.1 | 0.00 | 2.9 | 0.4 | 0.01 | 2.7 | 0.4 | 0.01 | 28.8 | 4.3 | 0.07 | 22.1 | 3.3 | 0.05 |
| Sugar crops tops & leaves | 782.8 | 203.1 | 3.29 | 72.9 | 19.9 | 0.33 | 144.8 | 29.0 | 0.38 | 371.5 | 103.7 | 1.76 | 99.7 | 23.2 | 0.35 | 367.6 | 93.7 | 1.50 | 130.1 | 36.2 | 0.61 | 51.6 | 14.5 | 0.25 | 205.8 | 41.2 | 0.54 |
| Sugar cane tops & leaves | 581.6 | 162.8 | 2.77 | 66.0 | 18.5 | 0.31 | 0.1 | 0.0 | 0.00 | 367.7 | 103.0 | 1.75 | 40.8 | 11.4 | 0.19 | 252.2 | 70.6 | 1.20 | 126.8 | 35.5 | 0.60 | 51.6 | 14.5 | 0.25 | 0.0 | 0.0 | 0.00 |
| Sugar beet tops | 201.2 | 40.2 | 0.52 | 6.9 | 1.4 | 0.02 | 144.6 | 28.9 | 0.38 | 3.7 | 0.7 | 0.01 | 59.0 | 11.8 | 0.15 | 115.4 | 23.1 | 0.30 | 3.3 | 0.7 | 0.01 | 0.0 | 0.0 | 0.00 | 205.8 | 41.2 | 0.53 |
| Oil crops by-products | 455.0 | 409.5 | 6.68 | 56.9 | 51.2 | 0.82 | 98.4 | 88.6 | 1.46 | 186.4 | 167.8 | 2.76 | 58.5 | 52.7 | 0.87 | 263.5 | 237.1 | 3.91 | 44.6 | 40.1 | 0.66 | 51.4 | 46.2 | 0.73 | 107.1 | 96.4 | 1.59 |
| Soybean stalks & husks | 196.8 | 177.2 | 2.92 | 16.1 | 14.5 | 0.24 | 24.9 | 22.4 | 0.37 | 125.0 | 112.5 | 1.86 | 4.7 | 4.2 | 0.07 | 232.9 | 209.6 | 3.46 | 10.9 | 9.8 | 0.16 | 2.4 | 2.2 | 0.04 | 25.7 | 23.2 | 0.38 |
| Groundnut stalks | 51.6 | 46.5 | 0.77 | 8.1 | 7.3 | 0.12 | 0.2 | 0.2 | 0.00 | 7.1 | 6.4 | 0.11 | 8.7 | 7.8 | 0.13 | 9.3 | 8.3 | 0.14 | 14.4 | 13.0 | 0.21 | 15.8 | 14.2 | 0.23 | 0.0 | 0.0 | 0.00 |
| Sunflower stalks & thr. heads | 96.4 | 86.7 | 1.43 | 3.6 | 3.2 | 0.05 | 65.0 | 58.5 | 0.96 | 45.4 | 40.9 | 0.67 | 42.1 | 37.8 | 0.62 | 7.3 | 6.5 | 0.11 | 6.1 | 5.5 | 0.09 | 6.1 | 5.5 | 0.09 | 51.1 | 46.0 | 0.76 |
| Canola stalks & husks | 50.8 | 45.8 | 0.75 | 8.0 | 7.2 | 0.12 | 6.5 | 5.8 | 0.10 | 0.1 | 0.1 | 0.00 | 3.1 | 2.8 | 0.05 | 14.0 | 12.6 | 0.21 | 12.7 | 11.4 | 0.19 | 0.3 | 0.2 | 0.00 | 30.3 | 27.2 | 0.45 |
| Oil palm leaves & trunks | 59.3 | 53.4 | 0.80 | 21.2 | 19.1 | 0.29 | 1.9 | 1.7 | 0.03 | 8.8 | 7.9 | 0.12 | 0.0 | 0.0 | 0.00 | 0.0 | 0.0 | 0.00 | 0.4 | 0.4 | 0.01 | 26.8 | 24.1 | 0.36 | 0.0 | 0.0 | 0.00 |
| ***B. Total all conv.-prod. & by-prod.*** | 25 763 | 4 837 | 85.25 | 2 346 | 589.0 | 10.45 | 6 130 | 1 162 | 20.47 | 10 998 | 1 804 | 31.40 | 4 092 | 791.2 | 13.93 | 8 960 | 1 489 | 26.29 | 4 255 | 776.4 | 13.61 | 4 699 | 759.9 | 13.26 | 5 027 | 917.1 | 16.70 |
| **B1. Vegetable products** | 1 399 | 930.4 | 17.59 | 260.8 | 180.8 | 3.38 | 313.0 | 167.1 | 3.13 | 260.7 | 172.8 | 3.40 | 221.0 | 185.6 | 3.47 | 341.9 | 167.8 | 3.35 | 195.0 | 168.5 | 3.13 | 182.0 | 114.0 | 2.14 | 400.9 | 160.2 | 3.20 |
| Cereals products | 839.0 | 729.8 | 13.24 | 181.6 | 158.6 | 2.87 | 136.8 | 117.8 | 2.15 | 112.8 | 98.0 | 1.78 | 190.4 | 164.4 | 3.00 | 85.3 | 73.6 | 1.34 | 166.6 | 145.0 | 2.63 | 111.7 | 97.2 | 1.76 | 89.5 | 77.1 | 1.41 |
| Wheat straight flour | 355.5 | 305.7 | 5.59 | 50.8 | 43.6 | 0.80 | 128.6 | 110.6 | 2.02 | 41.6 | 35.7 | 0.65 | 142.4 | 122.4 | 2.24 | 68.0 | 58.5 | 1.07 | 69.1 | 59.4 | 1.09 | 17.4 | 15.0 | 0.27 | 80.0 | 68.8 | 1.26 |
| White rice | 346.8 | 305.2 | 5.49 | 110.1 | 96.9 | 1.74 | 3.5 | 3.1 | 0.05 | 27.7 | 24.4 | 0.44 | 16.5 | 14.5 | 0.26 | 7.6 | 6.7 | 0.12 | 82.1 | 72.3 | 1.30 | 17.6 | 15.5 | 0.28 | 4.7 | 4.1 | 0.07 |
| Maize grits, meal & flour | 108.6 | 94.5 | 1.71 | 19.5 | 16.9 | 0.31 | 4.5 | 3.9 | 0.07 | 43.5 | 37.8 | 0.68 | 19.5 | 17.0 | 0.31 | 9.7 | 8.4 | 0.15 | 7.2 | 6.2 | 0.11 | 56.4 | 49.0 | 0.89 | 4.6 | 4.0 | 0.07 |
| Sorghum grits, meal & flour | 28.0 | 24.4 | 0.44 | 1.3 | 1.1 | 0.02 | 0.3 | 0.2 | 0.00 | 0.0 | 0.0 | 0.00 | 11.9 | 10.4 | 0.19 | 0.1 | 0.1 | 0.00 | 8.2 | 7.1 | 0.13 | 20.4 | 17.7 | 0.32 | 0.1 | 0.1 | 0.00 |

*Table continues on next page.*

**Table 3.22** (continued)

| Flow | World | | | East Asia | | | East Europe | | | Latin America & Caribbean | | | North Africa & West Asia | | | North America & Oceania | | | South & Central Asia | | | Sub-Saharan Africa | | | West Europe | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | AW (Tg) | DW (Tg) | GE (EJ) | AW (kg) | DW (kg) | GE (GJ) | AW (kg) | DW (kg) | GE (GJ) | AW (kg) | DW (kg) | GE (GJ) | AW (kg) | DW (kg) | GE (GJ) | AW (kg) | DW (kg) | GE (GJ) | AW (kg) | DW (kg) | GE (GJ) | AW (kg) | DW (kg) | GE (GJ) | AW (kg) | DW (kg) | GE (GJ) |
| Sweeteners | 122.5 | 122.5 | 2.14 | 10.4 | 10.4 | 0.18 | 30.0 | 30.0 | 0.53 | 52.6 | 52.6 | 0.92 | 15.7 | 15.7 | 0.27 | 60.0 | 60.0 | 1.05 | 18.6 | 18.6 | 0.33 | 7.1 | 7.1 | 0.13 | 42.7 | 42.7 | 0.75 |
| Cane white sugar | 82.3 | 82.3 | 1.44 | 9.2 | 9.2 | 0.16 | 0.0 | 0.0 | 0.00 | 51.9 | 51.9 | 0.91 | 5.8 | 5.8 | 0.10 | 36.0 | 36.0 | 0.63 | 18.1 | 18.1 | 0.32 | 7.1 | 7.1 | 0.13 | 0.0 | 0.0 | 0.00 |
| Beet white sugar | 40.3 | 40.3 | 0.70 | 1.1 | 1.1 | 0.02 | 30.0 | 30.0 | 0.53 | 0.6 | 0.6 | 0.01 | 9.9 | 9.9 | 0.17 | 24.0 | 24.0 | 0.42 | 0.6 | 0.6 | 0.01 | 0.0 | 0.0 | 0.00 | 42.7 | 42.7 | 0.75 |
| Vegetable oils | 42.6 | 42.6 | 1.67 | 6.1 | 6.1 | 0.24 | 6.7 | 6.7 | 0.26 | 15.0 | 15.0 | 0.59 | 4.7 | 4.7 | 0.18 | 18.1 | 18.1 | 0.71 | 4.3 | 4.3 | 0.17 | 4.4 | 4.4 | 0.17 | 17.8 | 17.8 | 0.70 |
| Soybean oil | 15.5 | 15.5 | 0.61 | 1.2 | 1.2 | 0.05 | 0.6 | 0.6 | 0.02 | 10.3 | 10.3 | 0.41 | 0.6 | 0.6 | 0.02 | 15.8 | 15.8 | 0.62 | 0.6 | 0.6 | 0.02 | 0.2 | 0.2 | 0.01 | 6.1 | 6.1 | 0.24 |
| Groundnut oil | 4.4 | 4.4 | 0.17 | 0.6 | 0.6 | 0.02 | 0.0 | 0.0 | 0.00 | 0.5 | 0.5 | 0.02 | 0.4 | 0.4 | 0.02 | 0.4 | 0.4 | 0.01 | 1.6 | 1.6 | 0.06 | 1.0 | 1.0 | 0.04 | 0.1 | 0.1 | 0.00 |
| Sunflower oil | 8.0 | 8.0 | 0.31 | 0.3 | 0.3 | 0.01 | 5.5 | 5.5 | 0.22 | 3.2 | 3.2 | 0.13 | 3.1 | 3.1 | 0.12 | 0.5 | 0.5 | 0.02 | 0.5 | 0.5 | 0.02 | 0.4 | 0.4 | 0.02 | 5.6 | 5.6 | 0.22 |
| Canola oil | 7.6 | 7.6 | 0.30 | 1.3 | 1.3 | 0.05 | 0.4 | 0.4 | 0.02 | 0.1 | 0.1 | 0.00 | 0.5 | 0.5 | 0.02 | 1.4 | 1.4 | 0.06 | 1.5 | 1.5 | 0.06 | 0.1 | 0.1 | 0.00 | 5.9 | 5.9 | 0.23 |
| Palm oil | 7.1 | 7.1 | 0.28 | 2.7 | 2.7 | 0.11 | 0.2 | 0.2 | 0.01 | 0.9 | 0.9 | 0.04 | 0.0 | 0.0 | 0.00 | 0.0 | 0.0 | 0.00 | 0.0 | 0.0 | 0.00 | 2.7 | 2.7 | 0.11 | 0.0 | 0.0 | 0.00 |
| Other vegetable products | 394.9 | 35.5 | 0.54 | 62.7 | 5.6 | 0.09 | 139.4 | 12.6 | 0.19 | 80.4 | 7.2 | 0.11 | 10.3 | 0.9 | 0.01 | 178.5 | 16.1 | 0.24 | 5.5 | 0.5 | 0.01 | 58.8 | 5.3 | 0.08 | 250.9 | 22.6 | 0.34 |
| Barley beer | 394.9 | 35.5 | 0.54 | 62.7 | 5.6 | 0.09 | 139.4 | 12.6 | 0.19 | 80.4 | 7.2 | 0.11 | 10.3 | 0.9 | 0.01 | 178.5 | 16.1 | 0.24 | 5.5 | 0.5 | 0.01 | 58.8 | 5.3 | 0.08 | 250.9 | 22.6 | 0.34 |
| **B2. Animal products** | 710.9 | 143.3 | 3.72 | 46.6 | 15.8 | 0.42 | 347.0 | 57.5 | 1.49 | 153.2 | 32.6 | 0.84 | 97.7 | 16.4 | 0.41 | 409.9 | 87.5 | 2.27 | 78.8 | 11.3 | 0.29 | 34.2 | 7.4 | 0.19 | 399.3 | 71.9 | 1.87 |
| Carcass | 157.4 | 67.4 | 1.87 | 25.4 | 11.2 | 0.32 | 39.8 | 17.5 | 0.50 | 40.4 | 17.2 | 0.46 | 12.0 | 5.0 | 0.13 | 120.0 | 49.4 | 1.33 | 4.3 | 1.9 | 0.05 | 9.2 | 4.0 | 0.11 | 67.6 | 28.5 | 0.80 |
| Beef cattle carcass | 43.4 | 18.2 | 0.48 | 2.8 | 1.2 | 0.03 | 7.1 | 2.9 | 0.08 | 18.2 | 7.9 | 0.21 | 4.7 | 2.0 | 0.05 | 46.7 | 19.0 | 0.50 | 2.8 | 1.2 | 0.03 | 5.3 | 2.3 | 0.06 | 12.1 | 4.9 | 0.13 |
| Pig carcass-side | 68.7 | 30.9 | 0.91 | 17.4 | 7.9 | 0.23 | 26.3 | 11.9 | 0.35 | 6.3 | 2.9 | 0.09 | 0.0 | 0.0 | 0.00 | 29.2 | 12.9 | 0.38 | 0.4 | 0.2 | 0.01 | 1.4 | 0.6 | 0.02 | 36.6 | 16.1 | 0.47 |
| Meat-type chicken carcass | 45.4 | 18.2 | 0.47 | 5.2 | 2.1 | 0.06 | 6.4 | 2.6 | 0.07 | 15.9 | 6.5 | 0.17 | 7.2 | 2.9 | 0.08 | 44.0 | 17.5 | 0.45 | 1.1 | 0.4 | 0.01 | 2.6 | 1.1 | 0.03 | 18.9 | 7.5 | 0.19 |
| Other animal products | 553.5 | 75.9 | 1.85 | 21.2 | 4.6 | 0.10 | 307.2 | 40.0 | 0.99 | 112.8 | 15.4 | 0.38 | 85.7 | 11.4 | 0.28 | 289.9 | 38.2 | 0.94 | 74.4 | 9.5 | 0.24 | 25.0 | 3.4 | 0.08 | 331.7 | 43.3 | 1.07 |
| Cattle milk | 511.6 | 62.4 | 1.58 | 11.0 | 1.3 | 0.03 | 294.4 | 35.9 | 0.91 | 104.7 | 12.8 | 0.32 | 80.8 | 9.9 | 0.25 | 276.0 | 33.7 | 0.85 | 72.5 | 8.8 | 0.22 | 23.1 | 2.8 | 0.07 | 317.5 | 38.7 | 0.98 |
| Chicken egg | 41.9 | 13.5 | 0.27 | 10.1 | 3.3 | 0.07 | 12.7 | 4.1 | 0.08 | 8.1 | 2.6 | 0.05 | 4.9 | 1.6 | 0.03 | 13.9 | 4.5 | 0.09 | 1.9 | 0.6 | 0.01 | 1.9 | 0.6 | 0.01 | 14.2 | 4.6 | 0.09 |
| **B3. Vegetable conv.-by-products** | 852.4 | 573.9 | 10.50 | 128.5 | 90.3 | 1.64 | 126.5 | 87.7 | 1.61 | 309.3 | 188.6 | 3.44 | 105.3 | 82.7 | 1.53 | 308.3 | 192.7 | 3.56 | 134.8 | 94.0 | 1.69 | 82.6 | 52.5 | 1.01 | 193.6 | 129.5 | 2.41 |
| Cereals milling by-products | 273.0 | 247.1 | 4.58 | 62.3 | 56.7 | 1.03 | 37.6 | 33.5 | 0.63 | 33.3 | 30.1 | 0.58 | 53.3 | 47.8 | 0.91 | 31.5 | 28.2 | 0.53 | 54.9 | 49.8 | 0.91 | 31.3 | 28.3 | 0.57 | 32.5 | 29.0 | 0.54 |
| Wheat mill run | 101.2 | 90.1 | 1.69 | 13.8 | 12.3 | 0.23 | 35.1 | 31.2 | 0.59 | 11.3 | 10.1 | 0.19 | 38.8 | 34.5 | 0.65 | 24.3 | 21.6 | 0.40 | 18.8 | 16.8 | 0.31 | 4.7 | 4.2 | 0.08 | 28.6 | 25.5 | 0.48 |
| Rice hulls | 93.5 | 86.0 | 1.45 | 29.7 | 27.3 | 0.46 | 0.9 | 0.9 | 0.01 | 7.5 | 6.9 | 0.12 | 4.5 | 4.1 | 0.07 | 2.0 | 1.9 | 0.03 | 22.1 | 20.4 | 0.34 | 4.7 | 4.4 | 0.07 | 1.3 | 1.2 | 0.02 |
| Rice bran | 42.5 | 38.7 | 0.75 | 13.5 | 12.3 | 0.24 | 0.4 | 0.4 | 0.01 | 3.4 | 3.1 | 0.06 | 2.0 | 1.8 | 0.04 | 0.9 | 0.8 | 0.02 | 10.1 | 9.2 | 0.18 | 2.2 | 2.0 | 0.04 | 0.6 | 0.5 | 0.01 |
| Maize hominy oil | 1.2 | 1.2 | 0.05 | 0.2 | 0.2 | 0.01 | 0.0 | 0.0 | 0.00 | 0.5 | 0.5 | 0.02 | 0.2 | 0.2 | 0.01 | 0.1 | 0.1 | 0.00 | 0.1 | 0.1 | 0.00 | 0.6 | 0.6 | 0.02 | 0.1 | 0.1 | 0.00 |
| Maize hominy feed | 27.4 | 24.7 | 0.51 | 4.8 | 4.3 | 0.09 | 1.1 | 1.0 | 0.02 | 10.6 | 9.6 | 0.20 | 4.8 | 4.3 | 0.09 | 4.1 | 3.7 | 0.07 | 1.8 | 1.6 | 0.03 | 13.8 | 12.4 | 0.26 | 1.9 | 1.7 | 0.03 |
| Sorghum oil | 0.3 | 0.3 | 0.01 | 0.0 | 0.0 | 0.00 | 0.0 | 0.0 | 0.00 | 0.0 | 0.0 | 0.00 | 0.1 | 0.1 | 0.01 | 0.0 | 0.0 | 0.00 | 0.1 | 0.1 | 0.00 | 0.2 | 0.2 | 0.01 | 0.0 | 0.0 | 0.00 |
| Sorghum hominy feed | 6.9 | 6.2 | 0.13 | 0.3 | 0.3 | 0.01 | 0.1 | 0.1 | 0.00 | 0.0 | 0.0 | 0.00 | 2.9 | 2.6 | 0.05 | 0.0 | 0.0 | 0.00 | 2.0 | 1.8 | 0.04 | 5.0 | 4.5 | 0.09 | 0.0 | 0.0 | 0.00 |
| Sugar crops conversion by-products | 345.4 | 180.0 | 3.11 | 35.2 | 17.7 | 0.31 | 31.6 | 22.0 | 0.39 | 192.0 | 95.5 | 1.64 | 31.7 | 17.8 | 0.31 | 157.9 | 83.5 | 1.44 | 67.2 | 33.5 | 0.58 | 26.3 | 13.1 | 0.23 | 44.8 | 31.3 | 0.55 |
| Sugar cane bagasse | 256.1 | 128.1 | 2.18 | 28.8 | 14.4 | 0.24 | 0.1 | 0.0 | 0.00 | 161.7 | 80.8 | 1.37 | 18.0 | 9.0 | 0.15 | 112.1 | 56.1 | 0.95 | 56.3 | 28.1 | 0.48 | 22.2 | 11.1 | 0.19 | 0.0 | 0.0 | 0.00 |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sugar cane molasses | 21.4 | 16.1 | 0.26 | 2.4 | 1.8 | 0.03 | 0.0 | 0.0 | 0.00 | 13.5 | 10.1 | 0.16 | 1.5 | 1.1 | 0.02 | 9.4 | 7.0 | 0.11 | 4.7 | 3.5 | 0.06 | 1.9 | 1.4 | 0.02 | 0.0 | 0.0 | 0.00 |
| Sugar beet pulp | 16.8 | 15.1 | 0.26 | 0.5 | 0.4 | 0.01 | 12.5 | 11.3 | 0.20 | 0.3 | 0.2 | 0.00 | 4.1 | 3.7 | 0.06 | 10.0 | 9.0 | 0.16 | 0.2 | 0.2 | 0.00 | 0.0 | 0.0 | 0.00 | 17.8 | 16.0 | 0.28 |
| Sugar beet molasses | 12.9 | 9.7 | 0.16 | 0.4 | 0.3 | 0.00 | 9.7 | 7.2 | 0.12 | 0.2 | 0.2 | 0.00 | 3.2 | 2.4 | 0.04 | 7.7 | 5.8 | 0.09 | 0.2 | 0.1 | 0.00 | 0.0 | 0.0 | 0.00 | 13.7 | 10.3 | 0.17 |
| Other[a] | 38.1 | 11.1 | 0.25 | 3.2 | 0.9 | 0.02 | 9.3 | 3.5 | 0.07 | 16.4 | 4.1 | 0.10 | 4.9 | 1.6 | 0.03 | 18.7 | 5.6 | 0.13 | 5.8 | 1.5 | 0.04 | 2.2 | 0.6 | 0.01 | 13.3 | 5.0 | 0.10 |
| Oilseed conversion by-products | 149.3 | 126.7 | 2.42 | 17.5 | 12.7 | 0.24 | 27.4 | 25.0 | 0.46 | 66.8 | 58.9 | 1.14 | 18.1 | 16.6 | 0.31 | 80.7 | 71.9 | 1.41 | 11.4 | 10.3 | 0.20 | 12.4 | 8.1 | 0.15 | 62.5 | 56.5 | 1.07 |
| Soybean meal | 74.4 | 66.2 | 1.30 | 5.7 | 5.1 | 0.10 | 2.7 | 2.4 | 0.05 | 49.4 | 44.0 | 0.86 | 3.0 | 2.7 | 0.05 | 75.5 | 67.2 | 1.32 | 3.0 | 2.6 | 0.05 | 0.7 | 0.7 | 0.01 | 29.3 | 26.0 | 0.51 |
| Groundnut husks | 5.1 | 4.8 | 0.08 | 0.7 | 0.7 | 0.01 | 0.0 | 0.0 | 0.00 | 0.5 | 0.5 | 0.01 | 0.5 | 0.5 | 0.01 | 0.4 | 0.4 | 0.01 | 1.9 | 1.8 | 0.03 | 1.2 | 1.1 | 0.02 | 0.1 | 0.1 | 0.00 |
| Groundnut meal | 5.8 | 5.3 | 0.11 | 0.8 | 0.7 | 0.02 | 0.0 | 0.0 | 0.00 | 0.6 | 0.6 | 0.01 | 0.6 | 0.5 | 0.01 | 0.5 | 0.5 | 0.01 | 2.2 | 2.0 | 0.04 | 1.3 | 1.2 | 0.03 | 0.2 | 0.2 | 0.00 |
| Sunflower husks | 21.1 | 19.6 | 0.33 | 0.7 | 0.6 | 0.01 | 14.7 | 13.6 | 0.23 | 8.5 | 7.9 | 0.13 | 8.2 | 7.6 | 0.13 | 1.3 | 1.2 | 0.02 | 1.2 | 1.1 | 0.02 | 1.1 | 1.1 | 0.02 | 15.0 | 13.9 | 0.24 |
| Sunflower meal | 12.7 | 11.7 | 0.23 | 0.4 | 0.4 | 0.01 | 8.8 | 8.1 | 0.16 | 5.1 | 4.7 | 0.09 | 4.9 | 4.5 | 0.09 | 0.8 | 0.7 | 0.01 | 0.7 | 0.7 | 0.01 | 0.7 | 0.6 | 0.01 | 9.0 | 8.3 | 0.17 |
| Canola meal | 11.4 | 10.1 | 0.19 | 2.0 | 1.8 | 0.03 | 0.7 | 0.6 | 0.01 | 0.1 | 0.1 | 0.00 | 0.8 | 0.7 | 0.01 | 2.2 | 1.9 | 0.04 | 2.3 | 2.1 | 0.04 | 0.1 | 0.1 | 0.00 | 8.9 | 7.9 | 0.15 |
| Oil palm kernel oil | 0.6 | 0.6 | 0.03 | 0.2 | 0.2 | 0.01 | 0.0 | 0.0 | 0.00 | 0.1 | 0.1 | 0.00 | 0.0 | 0.0 | 0.00 | 0.0 | 0.0 | 0.00 | 0.0 | 0.0 | 0.00 | 0.2 | 0.2 | 0.01 | 0.0 | 0.0 | 0.00 |
| Oil palm kernel meal | 0.7 | 0.6 | 0.01 | 0.3 | 0.2 | 0.00 | 0.0 | 0.0 | 0.00 | 0.1 | 0.1 | 0.00 | 0.0 | 0.0 | 0.00 | 0.0 | 0.0 | 0.00 | 0.0 | 0.0 | 0.00 | 0.3 | 0.2 | 0.00 | 0.0 | 0.0 | 0.00 |
| Other[b] | 17.5 | 7.6 | 0.13 | 6.7 | 2.9 | 0.05 | 0.5 | 0.2 | 0.00 | 2.3 | 1.0 | 0.02 | 0.0 | 0.0 | 0.00 | 0.0 | 0.0 | 0.00 | 0.1 | 0.0 | 0.00 | 6.7 | 2.9 | 0.05 | 0.0 | 0.0 | 0.00 |
| Other vegetable by-products | 84.7 | 20.1 | 0.39 | 13.4 | 3.2 | 0.06 | 29.9 | 7.1 | 0.14 | 17.2 | 4.1 | 0.08 | 2.2 | 0.5 | 0.01 | 38.3 | 9.1 | 0.18 | 1.2 | 0.3 | 0.01 | 12.6 | 3.0 | 0.06 | 53.8 | 12.8 | 0.25 |
| Brewer’s grains | 80.2 | 16.0 | 0.32 | 12.7 | 2.5 | 0.05 | 28.3 | 5.7 | 0.11 | 16.3 | 3.3 | 0.07 | 2.1 | 0.4 | 0.01 | 36.2 | 7.2 | 0.14 | 1.1 | 0.2 | 0.00 | 11.9 | 2.4 | 0.05 | 50.9 | 10.2 | 0.20 |
| Other[c] | 4.5 | 4.1 | 0.07 | 0.7 | 0.6 | 0.01 | 1.6 | 1.4 | 0.02 | 0.9 | 0.8 | 0.01 | 0.1 | 0.1 | 0.00 | 2.0 | 1.8 | 0.03 | 0.1 | 0.1 | 0.00 | 0.7 | 0.6 | 0.01 | 2.9 | 2.6 | 0.04 |
| **B4. Animal conversion-by-products** | 22 801 | 3 190 | 53.44 | 1 910 | 302.1 | 5.01 | 5 344 | 849.6 | 14.24 | 10 274 | 1 410 | 23.72 | 3 668 | 506.4 | 8.52 | 7 900 | 1 041 | 17.11 | 3 847 | 502.6 | 8.50 | 4 400 | 586.0 | 9.92 | 4 033 | 555.5 | 9.22 |
| Carcass | 28.4 | 11.9 | 0.32 | 1.1 | 0.5 | 0.01 | 17.9 | 7.5 | 0.20 | 8.2 | 3.5 | 0.09 | 5.2 | 2.3 | 0.06 | 11.6 | 4.8 | 0.13 | 2.7 | 1.2 | 0.03 | 2.8 | 1.2 | 0.03 | 15.4 | 6.3 | 0.17 |
| Dairy cow carcass | 9.7 | 4.1 | 0.11 | 0.2 | 0.1 | 0.00 | 6.3 | 2.6 | 0.07 | 1.3 | 0.6 | 0.02 | 1.1 | 0.5 | 0.01 | 5.8 | 2.4 | 0.06 | 0.9 | 0.4 | 0.01 | 0.7 | 0.3 | 0.01 | 7.5 | 3.1 | 0.08 |
| Dairy bulls & heifers carcass | 16.0 | 6.8 | 0.18 | 0.3 | 0.1 | 0.00 | 10.8 | 4.5 | 0.12 | 6.4 | 2.8 | 0.07 | 3.8 | 1.7 | 0.04 | 5.1 | 2.1 | 0.05 | 1.7 | 0.7 | 0.02 | 2.0 | 0.9 | 0.02 | 7.1 | 2.9 | 0.08 |
| Leghorn-type chicken carcass | 2.7 | 1.1 | 0.03 | 0.7 | 0.3 | 0.01 | 0.8 | 0.3 | 0.01 | 0.5 | 0.2 | 0.01 | 0.3 | 0.1 | 0.00 | 0.7 | 0.3 | 0.01 | 0.1 | 0.1 | 0.00 | 0.1 | 0.1 | 0.00 | 0.8 | 0.3 | 0.01 |
| Carcass by-products | 131.3 | 28.9 | 0.76 | 18.2 | 3.7 | 0.09 | 41.7 | 8.8 | 0.23 | 42.7 | 10.1 | 0.27 | 14.8 | 3.6 | 0.10 | 76.4 | 17.4 | 0.46 | 7.4 | 1.8 | 0.05 | 12.0 | 2.8 | 0.08 | 48.3 | 10.3 | 0.27 |
| Dairy cattle fifth quarter | 19.7 | 5.3 | 0.15 | 0.5 | 0.1 | 0.00 | 11.5 | 3.1 | 0.09 | 7.3 | 2.0 | 0.06 | 4.6 | 1.3 | 0.03 | 6.5 | 1.8 | 0.05 | 2.5 | 0.7 | 0.02 | 2.6 | 0.7 | 0.02 | 8.7 | 2.4 | 0.07 |
| Beef cattle fifth quarter | 33.3 | 9.0 | 0.25 | 2.6 | 0.7 | 0.02 | 4.7 | 1.3 | 0.04 | 17.2 | 4.6 | 0.13 | 4.5 | 1.2 | 0.03 | 26.8 | 7.2 | 0.20 | 2.7 | 0.7 | 0.02 | 5.1 | 1.4 | 0.04 | 6.9 | 1.9 | 0.05 |
| Pig fifth quarter | 40.1 | 7.2 | 0.18 | 10.6 | 1.9 | 0.05 | 16.1 | 2.9 | 0.07 | 4.6 | 0.8 | 0.02 | 0.0 | 0.0 | 0.00 | 14.9 | 2.8 | 0.07 | 0.3 | 0.1 | 0.00 | 1.0 | 0.2 | 0.00 | 18.6 | 3.4 | 0.09 |
| Leghorn-type chicken fifth quarter | 1.4 | 0.4 | 0.01 | 0.4 | 0.1 | 0.00 | 0.4 | 0.1 | 0.00 | 0.3 | 0.1 | 0.00 | 0.2 | 0.0 | 0.00 | 0.4 | 0.1 | 0.00 | 0.1 | 0.0 | 0.00 | 0.1 | 0.0 | 0.00 | 0.4 | 0.1 | 0.00 |
| Meat-type chicken fifth quarter | 19.6 | 5.3 | 0.14 | 2.5 | 0.7 | 0.02 | 3.0 | 0.8 | 0.02 | 7.5 | 2.0 | 0.05 | 3.4 | 0.9 | 0.02 | 16.3 | 4.4 | 0.12 | 0.6 | 0.2 | 0.00 | 1.5 | 0.4 | 0.01 | 7.0 | 1.9 | 0.05 |
| Other[d] | 17.2 | 1.7 | 0.03 | 1.7 | 0.2 | 0.00 | 6.0 | 0.6 | 0.01 | 5.9 | 0.6 | 0.01 | 2.1 | 0.2 | 0.00 | 11.6 | 1.2 | 0.02 | 1.2 | 0.1 | 0.00 | 1.8 | 0.2 | 0.00 | 6.6 | 0.7 | 0.01 |

*Table continues on next page.*

**Table 3.22** (continued)

| Flow | World | | | East Asia | | | East Europe | | | Latin America & Caribbean | | | North Africa & West Asia | | | North America & Oceania | | | South & Central Asia | | | Sub-Saharan Africa | | | West Europe | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | AW (Tg) | DW (Tg) | GE (EJ) | AW (kg) | DW (kg) | GE (GJ) | AW (kg) | DW (kg) | GE (GJ) | AW (kg) | DW (kg) | GE (GJ) | AW (kg) | DW (kg) | GE (GJ) | AW (kg) | DW (kg) | GE (GJ) | AW (kg) | DW (kg) | GE (GJ) | AW (kg) | DW (kg) | GE (GJ) | AW (kg) | DW (kg) | GE (GJ) |
| Manure (feces, urine & used litter) | 22 545 | 3 053 | 47.02 | 1 883 | 290.4 | 4.49 | 5 263 | 812.3 | 12.65 | 10 179 | 1 352 | 20.89 | 3 632 | 484.5 | 7.47 | 7 782 | 988.5 | 14.85 | 3 819 | 482.2 | 7.45 | 4 365 | 562.0 | 8.71 | 3 954 | 523.2 | 7.91 |
| Dairy cattle manure | 8 133 | 1 039 | 16.00 | 238.1 | 30.8 | 0.47 | 3 534 | 522.3 | 8.16 | 2 989 | 372.8 | 5.74 | 1 829 | 234.9 | 3.63 | 1 460 | 188.4 | 2.88 | 1 896 | 230.3 | 3.54 | 1 472 | 179.4 | 2.76 | 1 944 | 241.2 | 3.68 |
| Beef cattle manure | 12 943 | 1 682 | 26.06 | 1 271 | 170.0 | 2.65 | 1 279 | 200.3 | 3.14 | 6 881 | 903.6 | 14.04 | 1 724 | 227.3 | 3.53 | 5 790 | 684.8 | 10.32 | 1 895 | 244.7 | 3.81 | 2 824 | 366.1 | 5.70 | 1 467 | 184.3 | 2.81 |
| Pig manure | 1 050 | 210.3 | 3.25 | 304.7 | 69.9 | 1.09 | 364.1 | 64.3 | 0.99 | 177.5 | 36.7 | 0.57 | 0.4 | 0.1 | 0.00 | 252.9 | 33.2 | 0.49 | 14.4 | 3.2 | 0.05 | 49.8 | 11.2 | 0.18 | 390.5 | 52.8 | 0.78 |
| Leghorn-type chicken manure | 177.6 | 52.1 | 0.74 | 41.5 | 12.2 | 0.17 | 52.9 | 15.5 | 0.22 | 36.5 | 10.7 | 0.15 | 28.4 | 8.3 | 0.12 | 56.1 | 16.5 | 0.23 | 8.6 | 2.5 | 0.04 | 7.6 | 2.2 | 0.03 | 61.0 | 17.9 | 0.25 |
| Meat-type chicken manure | 241.8 | 69.2 | 0.97 | 27.6 | 7.6 | 0.10 | 34.1 | 10.0 | 0.14 | 94.6 | 27.8 | 0.39 | 50.6 | 13.9 | 0.19 | 223.2 | 65.5 | 0.93 | 5.9 | 1.5 | 0.02 | 12.3 | 3.1 | 0.04 | 91.9 | 27.0 | 0.38 |
| Methane (enteric) | 96.1 | 96.1 | 5.35 | 7.5 | 7.5 | 0.42 | 21.0 | 21.0 | 1.17 | 44.4 | 44.4 | 2.47 | 16.0 | 16.0 | 0.89 | 30.2 | 30.2 | 1.68 | 17.5 | 17.5 | 0.97 | 19.9 | 19.9 | 1.11 | 15.7 | 15.7 | 0.87 |
| Dairy cattle | 35.6 | 35.6 | 1.98 | 1.0 | 1.0 | 0.06 | 15.3 | 15.3 | 0.85 | 12.7 | 12.7 | 0.71 | 8.0 | 8.0 | 0.45 | 6.8 | 6.8 | 0.38 | 8.3 | 8.3 | 0.46 | 6.3 | 6.3 | 0.35 | 9.3 | 9.3 | 0.52 |
| Beef cattle | 59.3 | 59.3 | 3.30 | 6.1 | 6.1 | 0.34 | 5.3 | 5.3 | 0.29 | 31.5 | 31.5 | 1.75 | 8.0 | 8.0 | 0.44 | 23.1 | 23.1 | 1.29 | 9.2 | 9.2 | 0.51 | 13.5 | 13.5 | 0.75 | 6.0 | 6.0 | 0.34 |
| Pig | 1.2 | 1.2 | 0.07 | 0.4 | 0.4 | 0.02 | 0.4 | 0.4 | 0.02 | 0.2 | 0.2 | 0.01 | 0.0 | 0.0 | 0.00 | 0.3 | 0.3 | 0.01 | 0.0 | 0.0 | 0.00 | 0.1 | 0.1 | 0.00 | 0.3 | 0.3 | 0.02 |
| ***C. Total all end-use residues*** | 3 915 | 561.0 | 9.94 | 667.5 | 94.7 | 1.59 | 895.8 | 134.7 | 2.51 | 731.3 | 108.1 | 1.99 | 825.0 | 121.5 | 2.16 | 1 015 | 175.6 | 3.45 | 569.1 | 71.9 | 1.22 | 612.6 | 73.5 | 1.19 | 961.5 | 159.0 | 3.11 |
| Non-eaten food | 1 359 | 407.6 | 7.94 | 227.8 | 68.3 | 1.25 | 337.1 | 101.1 | 2.07 | 267.6 | 80.3 | 1.63 | 299.8 | 89.9 | 1.75 | 478.1 | 143.4 | 3.03 | 157.3 | 47.2 | 0.90 | 153.3 | 46.0 | 0.83 | 422.1 | 126.6 | 2.69 |
| Human feces & urine | 2 557 | 153.4 | 1.99 | 439.8 | 26.4 | 0.34 | 558.7 | 33.5 | 0.44 | 463.7 | 27.8 | 0.36 | 525.2 | 31.5 | 0.41 | 536.7 | 32.2 | 0.42 | 411.9 | 24.7 | 0.32 | 459.3 | 27.6 | 0.36 | 539.4 | 32.4 | 0.42 |

World numbers are annual total values in Tg actual weight (AW), Tg dry weight (DW) and EJ gross energy HHV (GE). Region numbers are annual per-capita values in kg actual weight, kg dry weight, and GJ gross energy (HHV). Weight numbers are given with one decimal, and energy numbers with two decimals. The as-is weights are given with the purpose to facilitate comparisons with the corresponding values in FAOSTAT and in other statistical databases. These as-is weight values refer to weight at time of *supply*, that is, after applicable drying processes, or other process steps affecting water content, have been carried out. For instance, drying is normal pre-storage treatment for grains as well as most oil crops and pulses. At time of harvest, water content for such crop products is significantly higher.

[a] Includes other by-products from the processing of sugar cane (cane filter cake) and sugar beet (broken beet roots and beet scums).

[b] Includes other by-products from the processing of oil palm fruit bunches (bunch refuse, press cake fiber and nut shells).

[c] Includes other by-products from beer production (malt sprouts & hulls, brewer’s yeast and spent hops).

[d] Includes cattle and pig ingesta (intestinal contents).

### 3.2.2 Animal food

In the preceding section we gave some general results of the biomass turnover of the animal sector as a whole. In this section we give more details on separate animal sub-systems, as well as the extent and mix of phytomass appropriation of the animal sector. We also present some results on the generation of methane and other by-products.

Phytomass appropriation and feed use mixes

This section is intended to present results on feed energy requirements, use and mix of feed dry matter, as well as on 'marginal' and 'net' values, of the phytomass appropriation of the animal sub-systems. For those interested in specific feed use details, the section includes tables of the estimated total feed energy requirements as well as feed use in each region (Table 3.25, p. 152, and Table 3.24, p. 148, respectively), and a table of the estimated global feed use for each animal sub-system (Table 3.23, p. 144).

*Marginal and net phytomass appropriation*

In Section 3.2.1 above we introduced the concept of 'phytomass appropriation' (see p. 111). As mentioned, this quantity refers to the *total* phytomass production *induced by* the use of *phytomass products* in a particular sub-system (that is, either use of crop products or intake of pasture). This means that a use of crop by-products, or other by-products and residues, by a sub-system does *not* affect the value of the phytomass appropriation. Defined in this way, this concept serves as a 'marginal' quantity: the sub-system which uses a phytomass product is recognized as *the inducer* of a required *additional,* or marginal, phytomass production. Hence, use of a *phytomass by-product* (that is, crop by-product) by the sub-system does not induce any additional required phytomass production.[135]

This concept of marginal phytomass production is useful for attributing the phytomass production of the *total* food system to the *different parts* of the system, that is, to the separate animal and vegetable food sub-systems. However, if we want to compare these sub-systems in terms of *actual use* of the induced phytomass production, this concept is not adequate. For this reason, we also introduce the concept '*net* phytomass appropriation', which refers to the 'marginal phytomass appropriation' plus the *net-use* of crop by-products.

This 'net-use of crop by-products', in turn, is calculated as the amount of crop by-products used, for *all* purposes, by a particular sub-system, minus the *amount of crop by-products in the marginal phytomass appropriation* induced by the sub-system. Since

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[135] Of course, the division of the phytomass flows in this study into driving flow (product) and non-driving flow (by-product) is somewhat inadequate. In the real system, demand for by-products may influence the economics and other conditions determining the crop production in such a way that the level of production increases. However, here we disregard such feedbacks in the system.

use for all purposes is included, this definition implies that both use of crop by-products for feed and for animal bedding is accounted for in the quantity ‘net phytomass appropriation’.

For the whole animal sector (that is, total for all animal sub-systems) globally, the *marginal* phytomass appropriation is 147 EJ GE per year, while the *net* appropriation is 150 EJ GE per year. Thus, globally, the animal sector *in total* use a larger amount of crop by-products than the amount of crop by-products induced by its use of phytomass products. Thus, to some extent (3 EJ per year) the global animal sector relies on use of crop by-products whose production is induced by the vegetable food sector.

On a regional basis, however, there are cases where the animal sector either is a net-user or a net-supplier of crop by-products (Figure 3.24). In most non-industrial regions, the net phytomass appropriation is higher than the marginal phytomass appropriation. This is mainly an effect of extensive use of crop by-products as feed. In contrast, in North America & Oceania and West Europe, use of crop by-products as feed is negligible. This means that, in these regions, the animal food sector as a whole provides a surplus of crop by-products.

In the section ‘Comparisons between the animal sub-systems’ (p. 158) numbers are given on marginal and net phytomass appropriation for each of the animal sub-systems. Note that throughout the entire thesis, ‘phytomass appropriation’ refers to the *marginal* phytomass appropriation, if not otherwise stated.

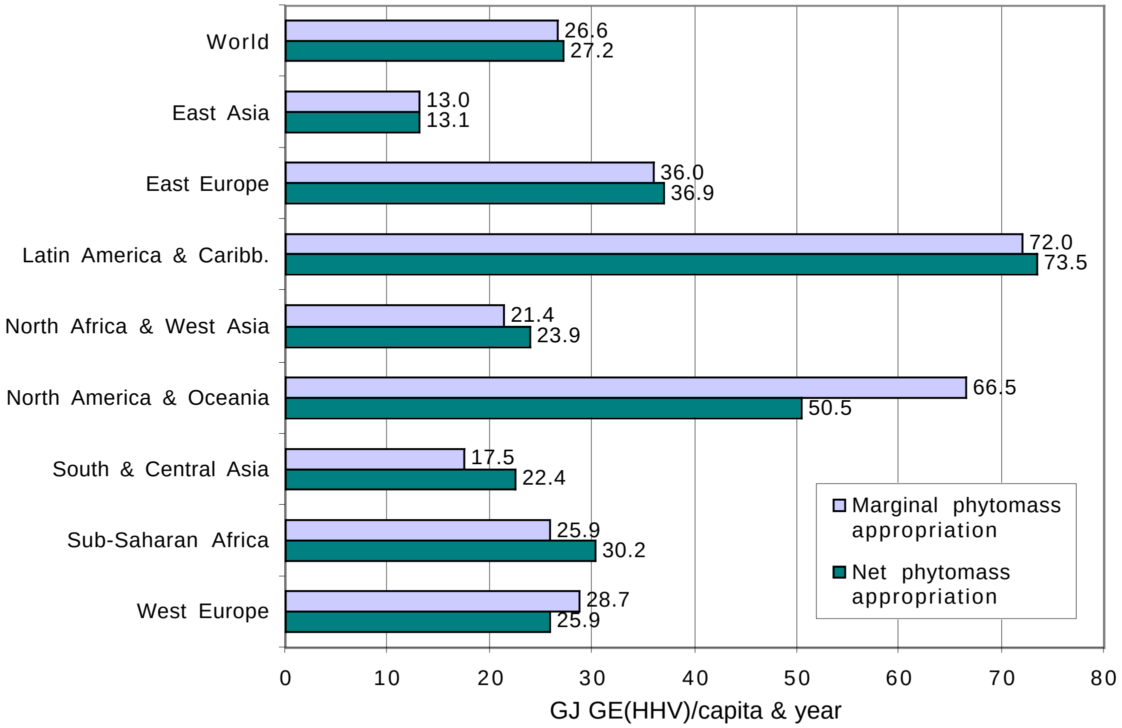

**Figure 3.24** Marginal and net phytomass appropriation for the total animal food sector (sum for all animal sub-systems). Actual values. See text for explanation of concepts.

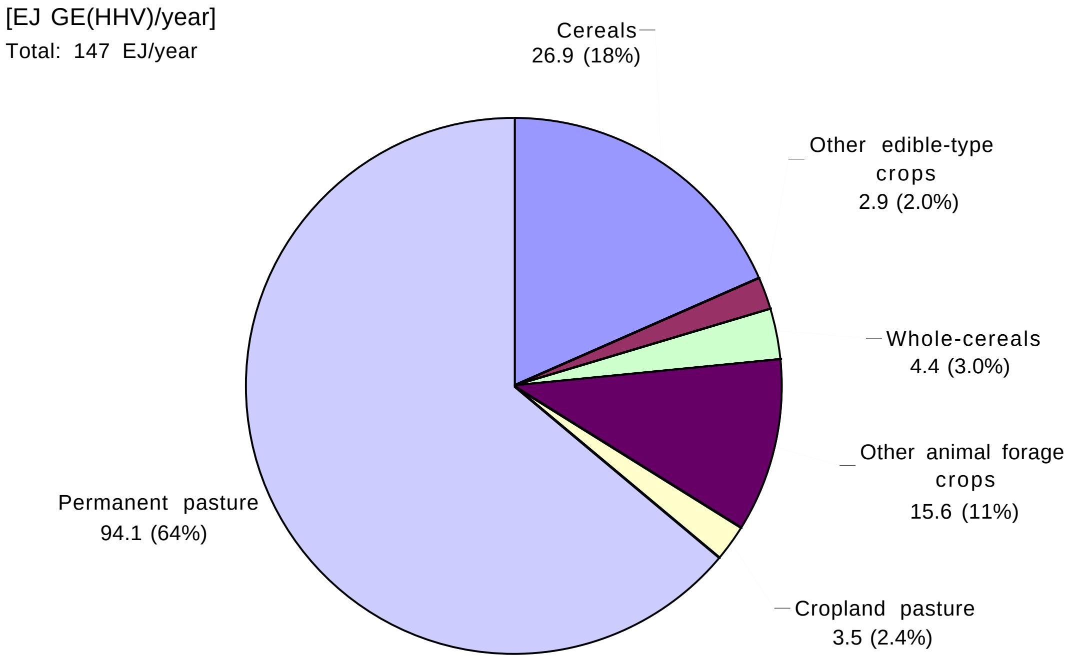

**Figure 3.25** Phytomass appropriation for the total animal food sector (sum for all animal sub-systems). World totals.

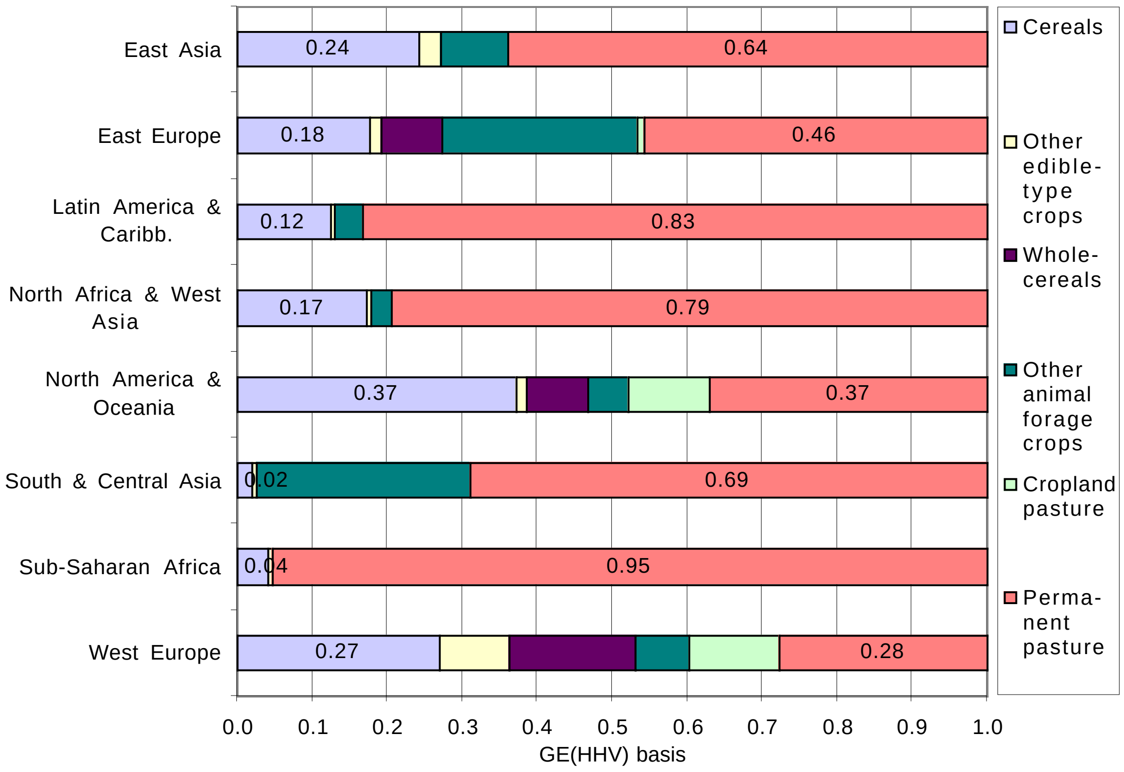

**Figure 3.26** Phytomass appropriation mix for the total animal food sector (average for all animal sub-systems). Trade-neutral values. Numbers refer to shares of cereals and permanent pasture respectively. (The different components appear in the bars in the same order as in the list.)

Figure 3.25 presents the extent and mix of the global phytomass appropriation for the entire animal food sector. In Figure 3.26 is shown the phytomass appropriation mix for the animal food sector on a regional basis. Clearly, on a global level, permanent pasture together with cereals constitute the major phytomass basis for the animal food production, amounting to more than 80 percent of the total appropriation.

### *Feed matter use*

The preceding section focused on the extent and mix of the phytomass appropriation by the animal sector. What does the picture look like at the point of the actual *feed intake*?

Figure 3.27 shows the global feed use for the entire animal food sector. In dry weight terms, the global sum of 95 EJ GE per year corresponds to roughly 5.6 Pg DM (see Table 3.23, p. 144, for further details on feed use in dry weight terms). Evidently, permanent pasture is dominating also at the feed use level, making up nearly half of the total feed use. By-products and residues constitute a substantial contribution to the feed supply: the sum of all by-products and residues amounts to 25 percent of the feed intake, cereals straw and stover being the major part. More or less identical relations hold on a dry matter basis.

In Figure 3.28 below we give the feed mix for the *entire animal sector* in each region. The share of permanent pasture ranges from some 20 percent in West Europe to 70

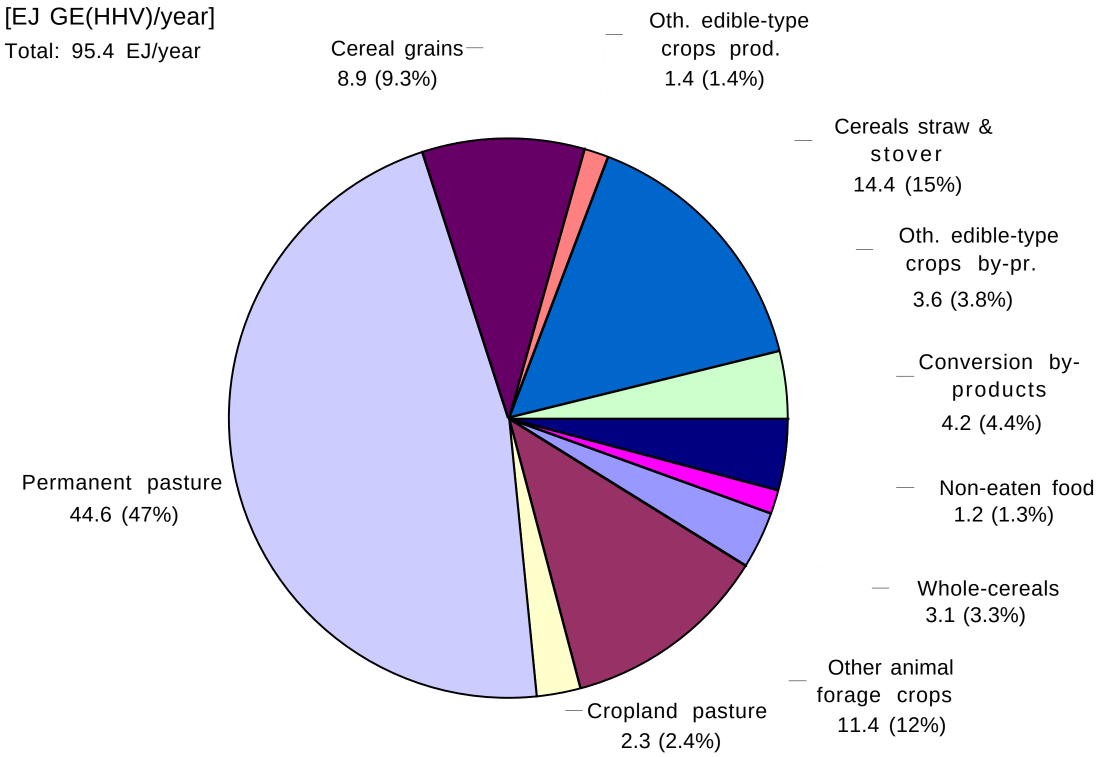

**Figure 3.27** Feed use (actual intake) for the total animal food sector (sum for all animal subsystems). World totals.

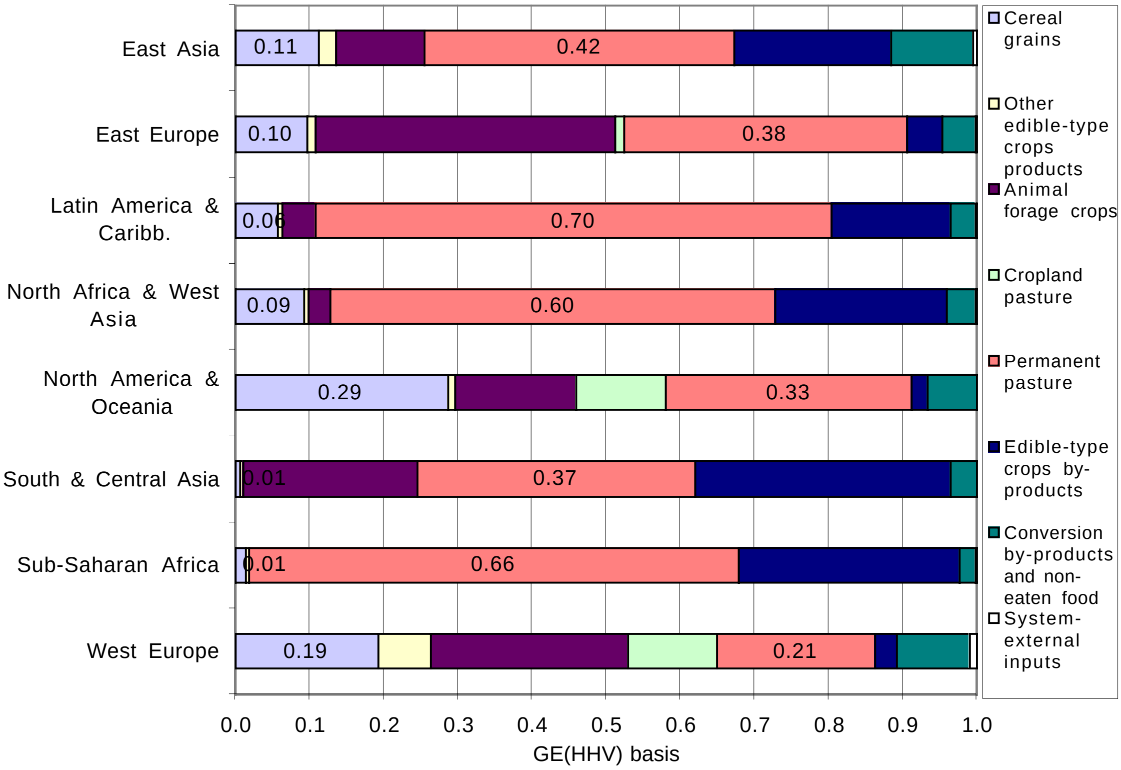

**Figure 3.28** Feed mixes (at intake) for total animal food sector (average for all animal sub-systems). Numbers refer to shares of cereals and permanent pasture, respectively. (The different components appear in the bars in the same order as in the list.).

percent in Latin America. South & Central Asia has the largest share of by-products and residues, 38 percent, followed by Sub-Saharan Africa and East Asia with 32 percent each. In North America & Oceania and West Europe, crop by-products are negligible (2-3 percent). However, in return they have a relatively high degree of use of conversion by-products (cereals milling by-products, oil cakes, etc) — in West Europe such by-products amount to 10 percent of the total feed use. The contribution of non-eaten food is significant only in East Asia, amounting to roughly 5 percent of the total. In all other regions, non-eaten food is less than 1 percent of the total feed use.

Figure 3.29 presents the *global average* feed mixes for each animal food sub-system. Figures 3.30 to 3.34 below give the corresponding *regional* values for each of the systems.

*Ruminant sub-systems.* For the ruminant systems, permanent pasture and crop by-products are the dominating feedstuffs. For *beef cattle* globally, permanent pasture and by-products amount to 58 and 24 percent, respectively, the remainder of 18 percent being various cropland-related feeds (harvested crops plus cropland pasture). *Cattle milk* has a higher share of cropland-related feeds, in total 30 percent, while permanent pasture is 48 percent and by-products 22 percent.

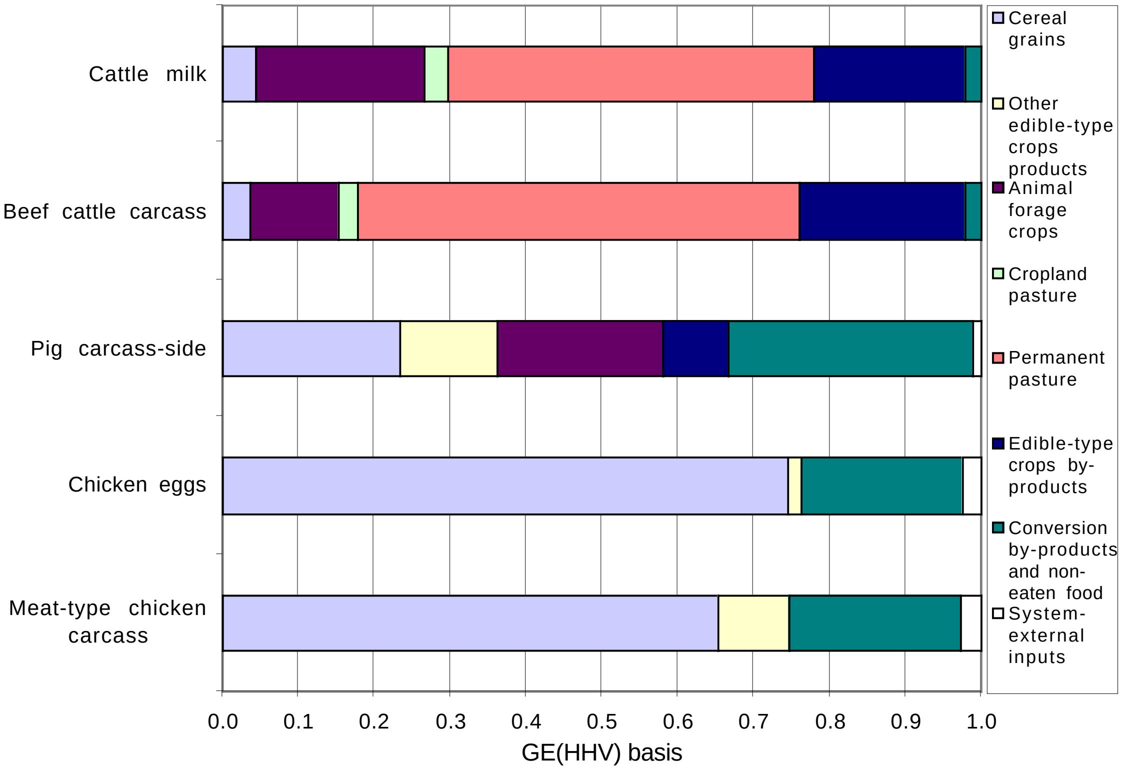

**Figure 3.29** Feed mix (at intake) for each animal sub-system. World averages. (The different components appear in the bars in the same order as in the list.)

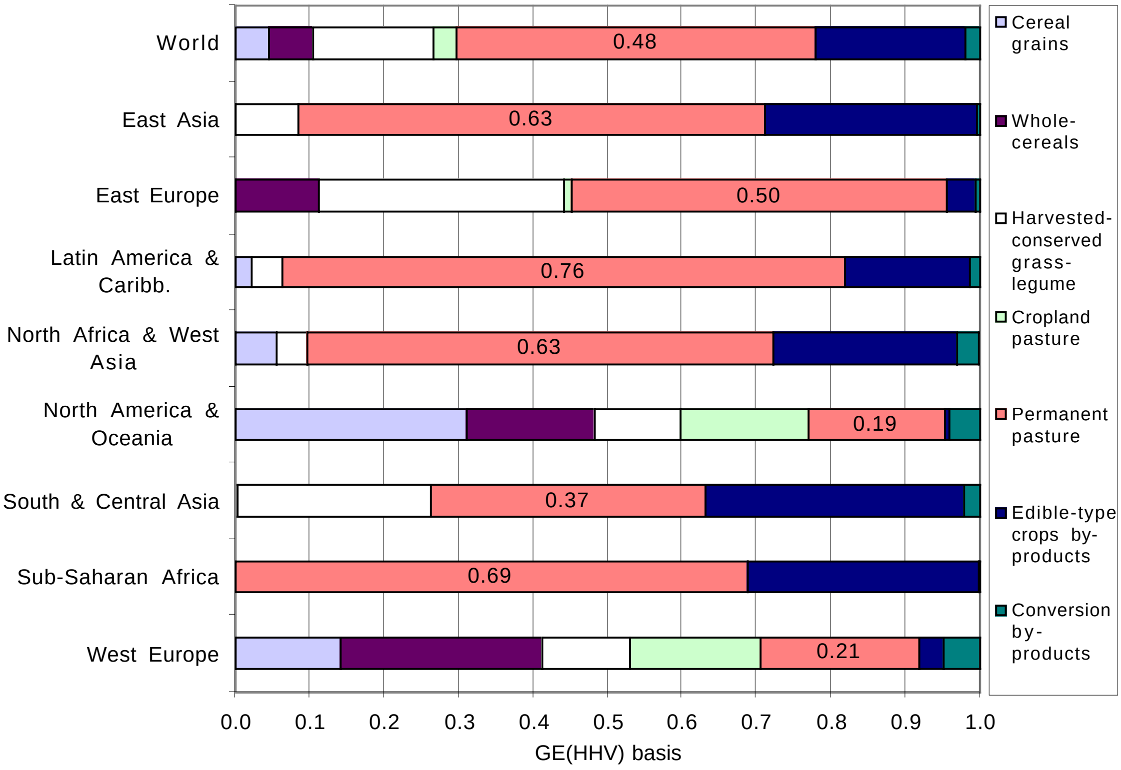

**Figure 3.30** Feed mixes (at intake) for the cattle milk sub-system. Numbers refer to shares of permanent pasture. (The different components appear in the bars in the same order as in the list.)

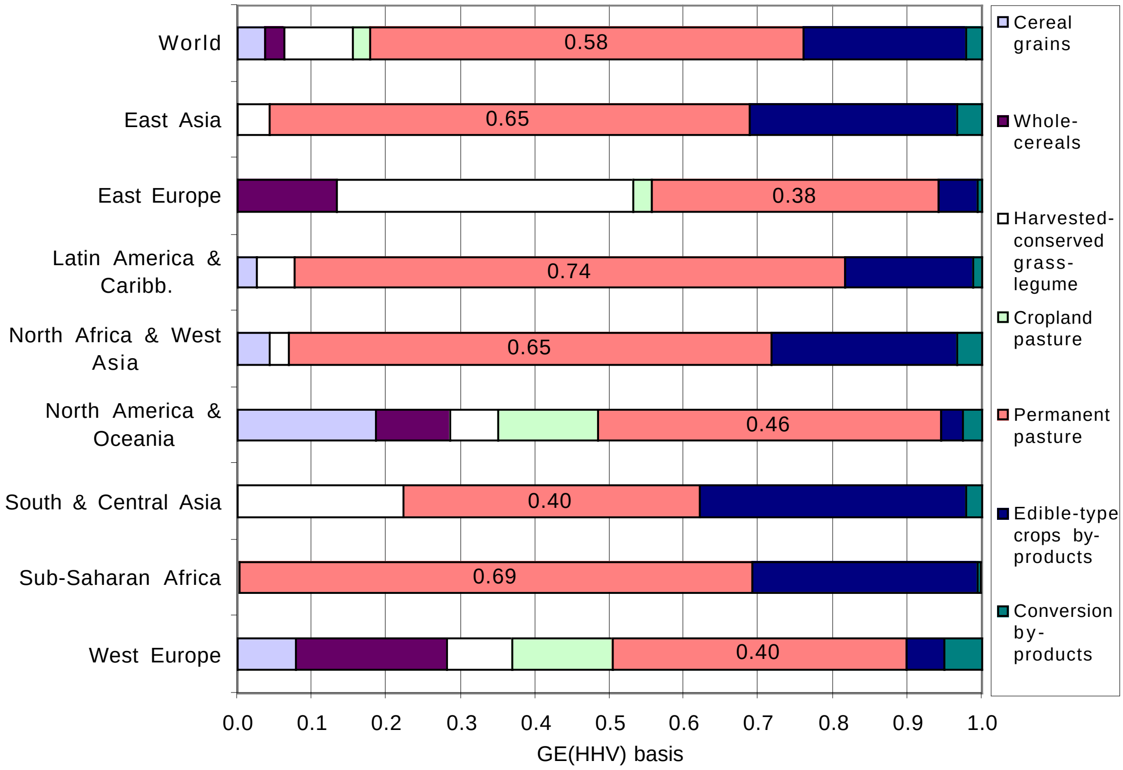

**Figure 3.31** Feed mixes (at intake) for beef cattle sub-system. Numbers refer to shares of permanent pasture. (The different components appear in the bars in the same order as in the list.)

On a regional basis, however, the variation is considerable, especially for the milk system. The share of permanent pasture ranges from about 20 percent for high-yielding milk production systems in North America & Oceania and West Europe, to 70-75 percent in Latin America and Sub-Saharan Africa (Figure 3.30). By-products lies around 30 percent in most non-industrial regions, with South & Central Asia even higher, 38 percent. The share of cropland-related feeds is low in most non-industrial regions, while in North America & Oceania and West Europe it is around 50 percent for the beef system, and 70-75 percent for the milk system.

Notable is the share of cultivated forage for cattle systems in South & Central Asia, around 25 percent, which is high relative to other non-industrial regions. The data basis for these figures, however, is not very solid and should be regarded with caution. In the section ‘Feed use’ (pp. 191 sq.), further comments are given on the significance of the feed use estimates for the region South & Central Asia.

*Pig sub-system.* For the pig system, the global average feed mix consists of 15 percent non-eaten food, 26 percent various by-products, 36 percent concentrate products (cereals grains, etc) and 22 percent of the feed-balancing forage crop ‘forage-vegetables’ (for description, see Section 2.5.1, p. 45).

Behind these averages on the global level are regional values with very diverse feed mixes. The most straightforward feed mixes are to be found in North America &

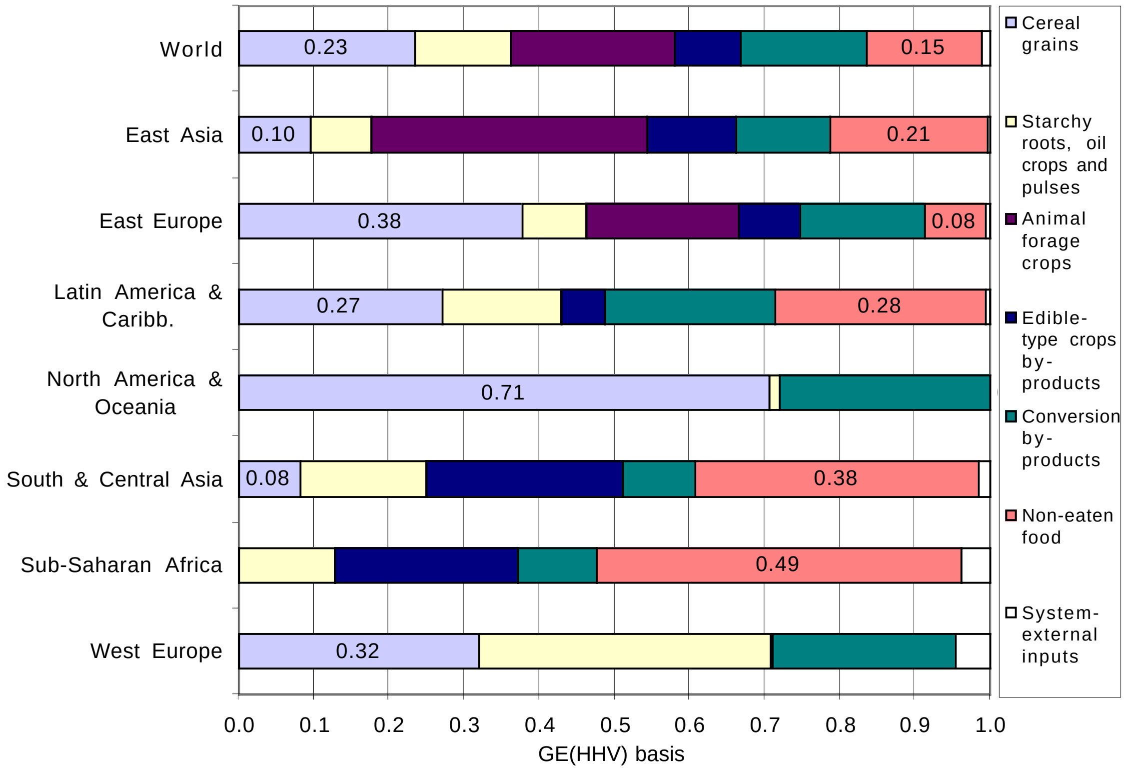

**Figure 3.32** Feed mixes (at intake) for the pig sub-system. Numbers refer to shares of cereals and non-eaten food respectively. (The different components appear in the bars in the same order as in the list.)

Oceania and West Europe, where concentrate products take a share of roughly 70 percent, the remainder being mainly by-products (mostly protein meals). In the other regions, the resulting feed mixes are more complicated. By-products and non-eaten food contribute most significantly, ranging from around 50 percent in East Asia and Latin America to 75-80 percent in South & Central Asia and Sub-Saharan Africa. Non-eaten food is the single largest category of these shares. For the feed use of non-eaten food, however, we had relatively little data to rely on, and therefore the figures should be regarded with caution. Further comments on the estimates of use of non-eaten food as feed are given in the section ‘Feed use’ (pp. 204 sq.). In East Asia, a substantial proportion, 37 percent, is the forage crop ‘forage-vegetables’, which explains most of the global average figure.

*Poultry sub-systems.* For the poultry systems, the feed mixes are relatively straightforward. There is also less variation between regions as compared to the other animal systems. However, the feed mixes are to large extent a result of the principles for allocation of concentrate feeds and by-products between the animal sub-systems (those principles were described in Section 3.1.2, p. 81, above). Therefore, their significance are, at least in some regions, likely to be comparatively low. (Further comments on this issue is given in the section ‘Feed use’, pp. 203 sq.)

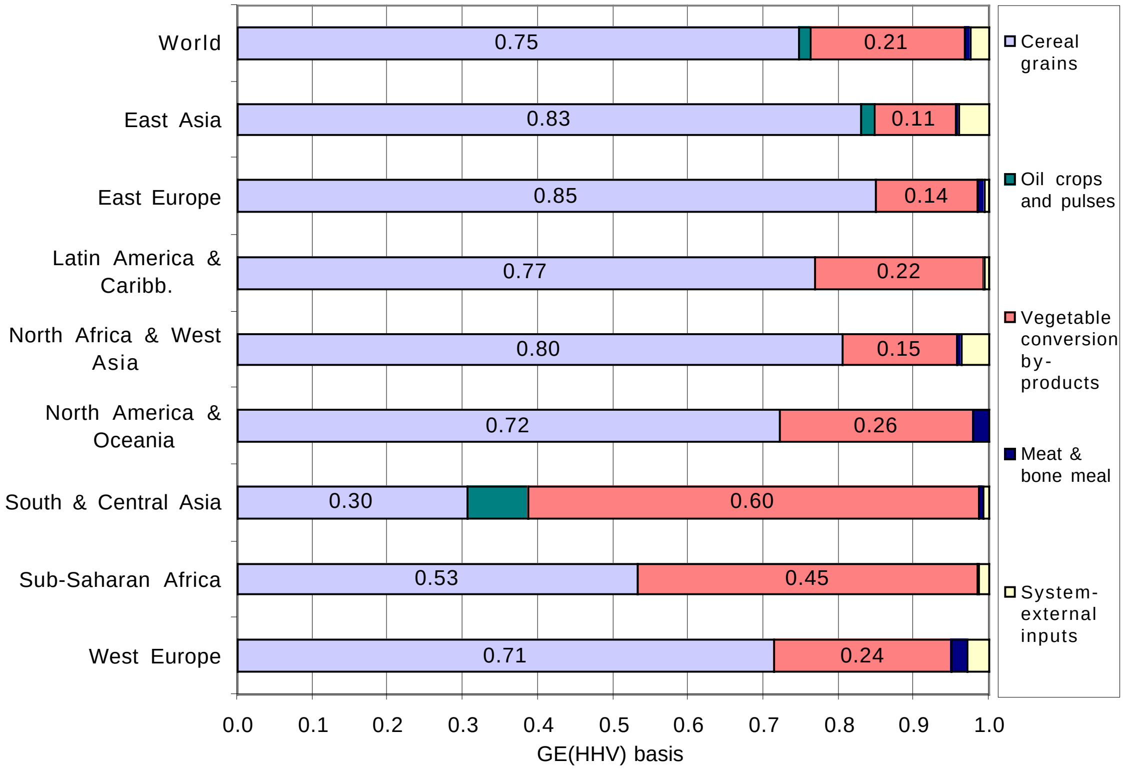

**Figure 3.33** Feed mixes (at intake) for the chicken egg sub-system. Numbers refer to shares of cereals and vegetable conversion by-products respectively. (The different components appear in the bars in the same order as in the list.)

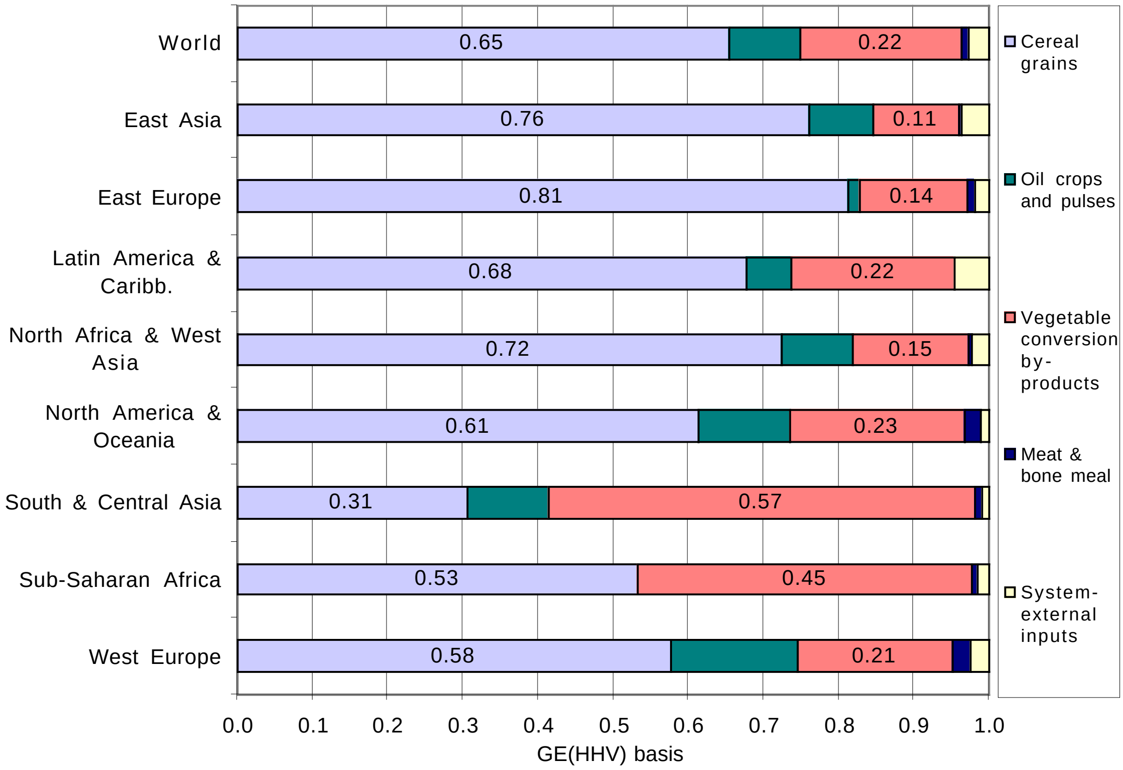

**Figure 3.34** Feed mixes (at intake) for the meat-type chicken carcass sub-system. Numbers refer to shares of cereals and vegetable conversion by-products respectively. (The different components appear in the bars in the same order as in the list.)

**Table 3.23** Feed use (actual feed intake) in animal food production. World totals.

| Flow | All animal food sub-systems | | | | Cattle milk | | | Beef cattle carcass | | | Pig carcass-side | | | Chicken egg | | | Meat-type chicken carcass | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Amount (Tg) | Share of generated | Share of distributed | Share in feed mix | Amount (Tg) | Share of distributed | Share in feed mix | Amount (Tg) | Share of distributed | Share in feed mix | Amount (Tg) | Share of distributed | Share in feed mix | Amount (Tg) | Share of distributed | Share in feed mix | Amount (Tg) | Share of distributed | Share in feed mix |
| ***SUM ALL FLOWS***[a] | 5 600 | 30% | 48% | | 1 840 | 16% | | 3 040 | 26% | | 430 | 3.7% | | 130 | 1.1% | | 160 | 1.4% | |
| **SYSTEM** | | | | | | | | | | | | | | | | | | | |
| ***A. Total all phytomass*** | 5 300 | 41% | 61% | 95% | 1 810 | 21% | 98% | 2 980 | 34% | 98% | 300 | 3.4% | 68% | 98 | 1.1% | 77% | 120 | 1.4% | 75% |
| **A1. Edible-type crops products** | 550 | 22% | 23% | 9.8% | 75 | 3.2% | 4.1% | 100 | 4.3% | 3.3% | 150 | 6.6% | 35% | 98 | 4.2% | 77% | 120 | 5.1% | 75% |
| Cereals grains | 480 | 29% | 31% | 8.5% | 75 | 4.9% | 4.1% | 100 | 6.6% | 3.3% | 98 | 6.4% | 23% | 97 | 6.3% | 76% | 110 | 7.1% | 67% |
| Wheat grains | 58 | 12% | 13% | 1.0% | | | | | | | 25 | 5.5% | 5.8% | 14 | 3.0% | 11% | 20 | 4.4% | 12% |
| Maize grains | 320 | 69% | 72% | 5.7% | 48 | 11% | 2.6% | 80 | 18% | 2.6% | 59 | 13% | 14% | 63 | 14% | 49% | 69 | 16% | 43% |
| Sorghum grains | 32 | 47% | 51% | 0.6% | 1.2 | 1.9% | 0.1% | 3.3 | 5.3% | 0.1% | 5.9 | 9.4% | 1.4% | 6.4 | 10% | 5.0% | 15 | 24% | 9.4% |
| Barley grains | 68 | 46% | 50% | 1.2% | 26 | 19% | 1.4% | 17 | 12% | 0.5% | 8.3 | 6.0% | 1.9% | 14 | 10% | 11% | 4.1 | 3.0% | 2.5% |
| Starchy root tubers | 50 | 32% | 36% | 0.9% | 0.3 | 0.2% | 0.0% | 0.9 | 0.6% | 0.0% | 49 | 35% | 11% | | | | | | |
| Cassava tubers[b] | 26 | 36% | 42% | 0.5% | 0.3 | 0.5% | 0.0% | 0.9 | 1.4% | 0.0% | 25 | 40% | 5.8% | | | | | | |
| Sweet potato tubers | 24 | 51% | 54% | 0.4% | | | | | | | 24 | 54% | 5.5% | | | | | | |
| Oil crops products | 21 | 8.5% | 9.6% | 0.4% | | | | | | | 6.8 | 3.1% | 1.6% | 1.7 | 0.8% | 1.3% | 12 | 5.7% | 7.8% |
| Soybean seeds | 21 | 16% | 18% | 0.4% | | | | | | | 6.8 | 6.0% | 1.6% | 1.7 | 1.5% | 1.3% | 12 | 11% | 7.8% |
| **A2. Animal forage crops** | 840 | 73% | 82% | 15% | 400 | 39% | 22% | 340 | 33% | 11% | 100 | 9.8% | 23% | | | | | | |
| Grass-legume[c] | 560 | 71% | 80% | 10% | 290 | 42% | 16% | 270 | 38% | 8.8% | | | | | | | | | |
| Grass-legume, temp. spp. | 320 | 71% | 80% | 5.6% | 180 | 46% | 9.8% | 140 | 34% | 4.5% | | | | | | | | | |
| Grass-legume, trop. spp. | 250 | 71% | 80% | 4.4% | 110 | 37% | 6.2% | 130 | 43% | 4.3% | | | | | | | | | |
| Whole-cereals | 180 | 71% | 80% | 3.2% | 100 | 46% | 5.6% | 76 | 34% | 2.5% | | | | | | | | | |
| Whole-maize[d] | 180 | 71% | 80% | 3.2% | 100 | 46% | 5.6% | 76 | 34% | 2.5% | | | | | | | | | |
| Other animal forage crops | 100 | 90% | 100% | 1.8% | | | | | | | 100 | 100% | 23% | | | | | | |
| Forage-vegetables | 100 | 90% | 100% | 1.8% | | | | | | | 100 | 100% | 23% | | | | | | |
| **A3. Pasture** | 2 790 | 48% | 100% | 50% | 950 | 34% | 52% | 1 840 | 66% | 61% | | | | | | | | | |
| Cropland pasture | 130 | 65% | 100% | 2.3% | 57 | 44% | 3.1% | 72 | 56% | 2.4% | | | | | | | | | |
| Grass-legume, temp. spp. | 120 | 65% | 100% | 2.2% | 55 | 45% | 3.0% | 67 | 55% | 2.2% | | | | | | | | | |
| Grass-legume, trop. spp. | 7.6 | 65% | 100% | 0.1% | 2.2 | 39% | 0.1% | 5.4 | 71% | 0.2% | | | | | | | | | |
| Permanent pasture | 2 660 | 47% | 100% | 48% | 900 | 34% | 49% | 1 770 | 66% | 58% | | | | | | | | | |
| Native grass-legume, temperate spp. | 1 190 | 50% | 100% | 21% | 430 | 36% | 23% | 760 | 64% | 25% | | | | | | | | | |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oversown grass-legume, temperate spp. | 74 | 55% | 100% | 1.3% | 27 | 36% | 1.5% | 47 | 64% | 1.6% | | | | | | | | | |
| Native grass-legume, tropical spp. | 1 370 | 45% | 100% | 25% | 430 | 31% | 23% | 940 | 69% | 31% | | | | | | | | | |
| Oversown grass-legume, tropical spp. | 32 | 50% | 100% | 0.6% | 8.4 | 27% | 0.5% | 23 | 73% | 0.8% | | | | | | | | | |
| **A4. Edible-type crops by-products** | 1 110 | 32% | 45% | 20% | 380 | 15% | 21% | 690 | 28% | 23% | 41 | 1.7% | 9.6% | | | | | | |
| Cereals straw & stover | 890 | 33% | 46% | 16% | 270 | 14% | 14% | 620 | 32% | 21% | | | | | | | | | |
| Wheat straw | 220 | 31% | 44% | 3.9% | 100 | 21% | 5.7% | 120 | 23% | 3.8% | | | | | | | | | |
| Rice straw | 230 | 42% | 56% | 4.2% | 25 | 5.9% | 1.3% | 210 | 50% | 6.8% | | | | | | | | | |
| Maize stover | 310 | 30% | 42% | 5.6% | 87 | 12% | 4.7% | 230 | 31% | 7.5% | | | | | | | | | |
| Sorghum stover | 89 | 47% | 63% | 1.6% | 38 | 27% | 2.0% | 51 | 36% | 1.7% | | | | | | | | | |
| Barley straw | 37 | 18% | 27% | 0.7% | 13 | 9.6% | 0.7% | 23 | 17% | 0.8% | | | | | | | | | |
| Starchy roots tops | 43 | 30% | 33% | 0.8% | 0.6 | 0.4% | 0.0% | 1.1 | 0.9% | 0.0% | 41 | 32% | 9.6% | | | | | | |
| Cassava leaves | 1.7 | 28% | 31% | 0.0% | 0.6 | 10% | 0.0% | 1.1 | 21% | 0.0% | | | | | | | | | |
| White potato tops | 13 | 34% | 37% | 0.2% | | | | | | | 13 | 37% | 3.0% | | | | | | |
| Sweet potato tops | 28 | 61% | 68% | 0.5% | | | | | | | 28 | 68% | 6.5% | | | | | | |
| Sugar crops tops & leaves | 91 | 45% | 55% | 1.6% | 64 | 39% | 3.5% | 28 | 17% | 0.9% | | | | | | | | | |
| Sugar cane tops & leaves | 75 | 46% | 57% | 1.3% | 55 | 41% | 3.0% | 21 | 16% | 0.7% | | | | | | | | | |
| Sugar beet tops | 16 | 39% | 48% | 0.3% | 8.9 | 27% | 0.5% | 6.6 | 20% | 0.2% | | | | | | | | | |
| Oil crops by-products | 88 | 22% | 36% | 1.6% | 48 | 20% | 2.6% | 40 | 17% | 1.3% | | | | | | | | | |
| Soybean stalks & husks | 39 | 22% | 33% | 0.7% | 17 | 14% | 0.9% | 22 | 19% | 0.7% | | | | | | | | | |
| Groundnut stalks | 25 | 53% | 66% | 0.4% | 20 | 53% | 1.1% | 5.1 | 14% | 0.2% | | | | | | | | | |
| Sunflower stalks & thr. heads | 13 | 15% | 33% | 0.2% | 5.4 | 14% | 0.3% | 7.7 | 20% | 0.3% | | | | | | | | | |
| Canola stalks & husks | 11 | 25% | 39% | 0.2% | 6.4 | 22% | 0.3% | 4.9 | 17% | 0.2% | | | | | | | | | |
| ***B. Total all conversion by-products*** | 230 | 6.0% | 16% | 4.0% | 35 | 2.5% | 1.9% | 60 | 4.3% | 2.0% | 68 | 4.9% | 16% | 26 | 1.9% | 21% | 36 | 2.6% | 22% |
| **B3. Vegetable conv.-by-products** | 220 | 38% | 38% | 3.9% | 35 | 6.1% | 1.9% | 60 | 10% | 2.0% | 66 | 11% | 15% | 25 | 4.4% | 20% | 34 | 5.9% | 21% |
| Cereals milling by-products | 100 | 42% | 42% | 1.9% | 18 | 7.4% | 1.0% | 39 | 16% | 1.3% | 22 | 9.1% | 5.2% | 13 | 5.2% | 10% | 11 | 4.5% | 6.9% |
| Wheat mill run | 46 | 51% | 51% | 0.8% | 9.2 | 10% | 0.5% | 12 | 13% | 0.4% | 13 | 14% | 3.0% | 6.7 | 7.5% | 5.3% | 5.4 | 6.0% | 3.4% |
| Rice hulls | 16 | 40% | 40% | 0.3% | 6.0 | 7.0% | 0.3% | 22 | 26% | 0.7% | | | | | | | | | |
| Rice bran | 28 | 33% | 33% | 0.5% | 1.2 | 3.0% | 0.1% | 1.7 | 4.4% | 0.1% | 6.5 | 17% | 1.5% | 3.6 | 9.3% | 2.8% | 2.6 | 6.7% | 1.6% |
| Maize hominy feed | 11 | 44% | 44% | 0.2% | 1.5 | 6.0% | 0.1% | 2.7 | 11% | 0.1% | 2.6 | 11% | 0.6% | 1.8 | 7.5% | 1.4% | 2.2 | 8.9% | 1.4% |
| Sorghum hominy feed | 2.6 | 42% | 42% | 0.0% | 0.4 | 6.3% | 0.0% | 0.5 | 7.3% | 0.0% | 0.2 | 3.7% | 0.1% | 0.7 | 12% | 0.9% | 0.8 | 13% | 0.5% |

*Table continues on next page.*

**Table 3.23** (continued)

| | All animal food sub-systems | | | | Cattle milk | | | Beef cattle carcass | | | Pig carcass-side | | | Chicken egg | | | Meat-type chicken carcass | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flow | Amount (Tg) | Share of generated | Share of distributed | Share in feed mix | Amount (Tg) | Share of distributed | Share in feed mix | Amount (Tg) | Share of distributed | Share in feed mix | Amount (Tg) | Share of distributed | Share in feed mix | Amount (Tg) | Share of distributed | Share in feed mix | Amount (Tg) | Share of distributed | Share in feed mix |
| Sugar crops conversion by-products | 39 | 22% | 22% | 0.7% | 14 | 8.0% | 0.8% | 21 | 12% | 0.7% | 3.7 | 2.0% | 0.9% | | | | | | |
| Sugar cane bagasse | 15 | 12% | 12% | 0.3% | 4.6 | 3.6% | 0.3% | 10 | 7.8% | 0.3% | | | | | | | | | |
| Sugar cane molasses | 6.8 | 43% | 43% | 0.1% | 2.0 | 12% | 0.1% | 3.4 | 21% | 0.1% | 1.5 | 9.3% | 0.3% | | | | | | |
| Sugar beet pulp | 10 | 69% | 69% | 0.2% | 5.5 | 36% | 0.3% | 4.9 | 33% | 0.2% | | | | | | | | | |
| Sugar beet molasses | 7.0 | 73% | 73% | 0.1% | 2.3 | 23% | 0.1% | 2.6 | 26% | 0.1% | 2.2 | 23% | 0.5% | | | | | | |
| Oilseed conversion by-products | 68 | 54% | 54% | 1.2% | | | | | | | 35 | 28% | 8.2% | 12 | 9.1% | 9.0% | 22 | 17% | 13% |
| Soybean meal | 50 | 76% | 76% | 0.9% | | | | | | | 25 | 38% | 5.9% | 7.8 | 12% | 6.1% | 17 | 26% | 11% |
| Groundnut meal | 2.6 | 49% | 49% | 0.0% | | | | | | | 1.2 | 22% | 0.3% | 0.7 | 13% | 0.5% | 0.7 | 14% | 0.5% |
| Sunflower meal | 8.8 | 76% | 76% | 0.2% | | | | | | | 4.7 | 41% | 1.1% | 1.7 | 15% | 1.3% | 2.4 | 20% | 1.5% |
| Canola meal | 6.9 | 68% | 68% | 0.1% | | | | | | | 4.1 | 41% | 1.0% | 1.3 | 13% | 1.0% | 1.5 | 15% | 0.9% |
| Other vegetable by-products | 8.7 | 43% | 43% | 0.2% | 2.6 | 13% | 0.1% | | | | 4.0 | 20% | 0.9% | 1.0 | 4.8% | 0.8% | 1.2 | 6.0% | 0.7% |
| Brewer’s grains | 8.7 | 55% | 55% | 0.2% | 2.6 | 16% | 0.1% | | | | 4.0 | 25% | 0.9% | 1.0 | 6.0% | 0.8% | 1.2 | 7.5% | 0.7% |
| **B4. Animal conversion-by-products** | 5.8 | 1.8% | 0.7% | 0.1% | | | | | | | 2.9 | 0.4% | 0.7% | 1.0 | 0.1% | 0.8% | 1.9 | 0.2% | 1.2% |
| Carcass by-products[e] | 5.8 | 20% | 22% | 0.1% | | | | | | | 2.9 | 11% | 0.7% | 1.0 | 3.8% | 0.8% | 1.9 | 7.2% | 1.2% |
| Dairy cattle fifth quarter | 1.1 | 21% | 23% | 0.0% | | | | | | | 0.7 | 14% | 0.2% | 0.1 | 3.1% | 0.1% | 0.3 | 6.3% | 0.2% |
| Beef cattle fifth quarter | 1.9 | 22% | 24% | 0.0% | | | | | | | 1.1 | 13% | 0.2% | 0.2 | 2.8% | 0.2% | 0.6 | 8.0% | 0.4% |
| Pig fifth quarter | 1.5 | 21% | 24% | 0.0% | | | | | | | | | | 0.6 | 9.5% | 0.5% | 0.9 | 14% | 0.6% |
| Meat-type chicken fifth quarter | 1.2 | 23% | 25% | 0.0% | | | | | | | 1.2 | 25% | 0.3% | | | | | | |
| ***C. Total all end-use residues*** | 64 | 11% | 14% | 1.2% | | | | | | | 64 | 14% | 15% | | | | | | |
| Non-eaten food | 64 | 16% | 20% | 1.2% | | | | | | | 64 | 20% | 15% | | | | | | |
| **SYSTEM-EXTERNAL INPUTS** | | | | | | | | | | | | | | | | | | | |
| Fish[f] | 6.6 | 25% | 26% | 0.1% | | | | | | | 1.3 | 5.4% | 0.3% | 2.2 | 9.0% | 1.8% | 3.0 | 12% | 1.9% |
| Cotton meal | 5.0 | 31% | 31% | 0.1% | | | | | | | 3.1 | 19% | 0.7% | 0.8 | 5.2% | 0.7% | 1.1 | 6.8% | 0.7% |

Amounts in dry weight (Tg DM/year), shares in percent (DM basis). Amount-numbers are rounded to 2 significant digits, except for values exceeding 1000 (3 significant digits), and for values less than 1 (1 significant digit). It should be observed that for categories and sum of categories, the shares of generated and distributed refer to the *total* for each category, including *all* individual flows belonging to the respective category (for definitions of ‘generated’ and ‘distributed’, see Section 2.1.6, p. 19). Thus, it does *not* refer to the total of the individual flows displayed under each category in this table.

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[a] Refers to sum of all flows displayed in table, that is, both system flows and system-external inputs.

[b] Eaten as raw tuber or meal.

[c] Eaten as hay or silage.

[d] Eaten as silage.

[e] All ‘fifth quarters’ are eaten as meat & bone meal.

[f] Eaten as meal.

**Table 3.24** Feed use (actual feed intake) in animal food production. Regional values for total animal food sector (all animal food sub-systems).

| | East Asia | | | East Europe | | | Latin America & Caribbean | | | North Africa & West Asia | | | North America & Oceania | | | South & Central Asia | | | Sub-Saharan Africa | | | West Europe | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flow | Amount (kg) | Share of gen. | Share in feed | Amount (kg) | Share of gen. | Share in feed | Amount (kg) | Share of gen. | Share in feed | Amount (kg) | Share of gen. | Share in feed | Amount (kg) | Share of gen. | Share in feed | Amount (kg) | Share of gen. | Share in feed | Amount (kg) | Share of gen. | Share in feed | Amount (kg) | Share of gen. | Share in feed |
| ***SUM ALL FLOWS***[a] | 533.5 | 24.0% | — | 1 293.2 | 31.8% | — | 2 404.8 | 33.1% | — | 855.9 | 29.6% | — | 1 942.5 | 28.1% | — | 899.2 | 33.7% | — | 1 036.1 | 32.3% | — | 1 090.1 | 30.5% | — |
| **SYSTEM** | | | | | | | | | | | | | | | | | | | | | | | | |
| ***A. Total all phytomass*** | 476.0 | 31.8% | 89.2% | 1 237.3 | 45.2% | 95.7% | 2 328.5 | 43.8% | 96.8% | 824.2 | 42.5% | 96.3% | 1 820.0 | 35.3% | 93.7% | 870.2 | 48.8% | 96.8% | 1 013.9 | 43.2% | 97.9% | 980.3 | 40.9% | 89.9% |
| **A1. Edible-type crops products** | 66.2 | 16.7% | 12.4% | 131.7 | 31.4% | 10.2% | 136.3 | 22.8% | 5.7% | 76.6 | 22.0% | 8.9% | 542.7 | 38.6% | 27.9% | 7.2 | 2.3% | 0.8% | 16.8 | 5.6% | 1.6% | 272.7 | 42.1% | 25.0% |
| Cereals grains | 54.0 | 19.3% | 10.1% | 116.7 | 45.6% | 9.0% | 122.7 | 47.0% | 5.1% | 73.1 | 31.4% | 8.5% | 527.8 | 52.0% | 27.2% | 5.5 | 2.6% | 0.6% | 13.2 | 9.0% | 1.3% | 201.0 | 44.7% | 18.4% |
| Wheat grains | 3.2 | 6.1% | 0.6% | 28.0 | 20.0% | 2.2% | 4.3 | 10.2% | 0.2% | 8.2 | 5.9% | 1.0% | 37.9 | 11.9% | 1.9% | 1.4 | 1.8% | 0.2% | 0.3 | 3.1% | 0.0% | 65.0 | 28.9% | 6.0% |
| Maize grains | 46.6 | 75.5% | 8.7% | 62.6 | 86.8% | 4.8% | 91.9 | 60.6% | 3.8% | 21.5 | 74.0% | 2.5% | 411.1 | 78.7% | 21.2% | 1.5 | 16.6% | 0.2% | 11.7 | 14.8% | 1.1% | 59.3 | 88.9% | 5.4% |
| Sorghum grains | 3.0 | 91.4% | 0.6% | 0.0 | 0.0% | 0.0% | 26.5 | 126% | 1.1% | 2.3 | 13.3% | 0.3% | 37.0 | 62.8% | 1.9% | 0.2 | 1.6% | 0.0% | 0.9 | 3.5% | 0.1% | 2.8 | 130% | 0.3% |
| Barley grains | 1.3 | 11.6% | 0.2% | 26.1 | 62.8% | 2.0% | 0.0 | 0.0% | 0.0% | 41.1 | 126% | 4.8% | 41.9 | 42.5% | 2.2% | 2.4 | 68.5% | 0.3% | 0.3 | 2.5% | 0.0% | 73.9 | 48.8% | 6.8% |
| Starchy root tubers | 9.8 | 26.8% | 1.8% | 13.6 | 33.0% | 1.1% | 10.8 | 40.4% | 0.4% | 1.1 | 13.9% | 0.1% | 1.8 | 12.5% | 0.1% | 0.0 | 0.0% | 0.0% | 3.6 | 4.9% | 0.4% | 51.1 | 229% | 4.7% |
| Cassava tubers[b] | 0.5 | 3.8% | 0.1% | 0.0 | 7.8% | 0.0% | 10.3 | 53.4% | 0.4% | 1.1 | >>100% | 0.1% | 1.8 | >>100% | 0.1% | 0.0 | 0.0% | 0.0% | 3.4 | 5.1% | 0.3% | 47.9 | >>100% | 4.4% |
| Sweet potato tubers | 9.3 | 47.0% | 1.7% | 13.6 | 99.7% | 1.1% | 0.6 | 40.2% | 0.0% | 0.0 | 0.0% | 0.0% | 0.0 | 0.0% | 0.0% | 0.0 | 0.0% | 0.0% | 0.2 | 4.7% | 0.0% | 3.1 | 94.1% | 0.3% |
| Oil crops products | 2.3 | 8.1% | 0.4% | 1.3 | 2.6% | 0.1% | 2.8 | 2.8% | 0.1% | 2.4 | 9.3% | 0.3% | 13.1 | 7.0% | 0.7% | 1.7 | 7.6% | 0.2% | 0.0 | 0.0% | 0.0% | 20.6 | 35.3% | 1.9% |
| Soybean seeds | 2.3 | 19.7% | 0.4% | 1.3 | 8.9% | 0.1% | 2.8 | 3.7% | 0.1% | 2.4 | 84.8% | 0.3% | 13.1 | 7.7% | 0.7% | 1.7 | 26.1% | 0.2% | 0.0 | 0.0% | 0.0% | 20.6 | 109% | 1.9% |
| **A2. Animal forage crops** | 63.6 | 84.4% | 11.9% | 521.4 | 72.4% | 40.3% | 106.0 | 71.2% | 4.4% | 25.8 | 71.2% | 3.0% | 321.8 | 71.2% | 16.6% | 204.5 | 71.2% | 22.7% | 0.0 | 80.1% | 0.0% | 293.4 | 71.2% | 26.9% |
| Grass-legume[c] | 16.6 | 71.2% | 3.1% | 363.7 | 71.2% | 28.1% | 105.9 | 71.2% | 4.4% | 25.8 | 71.2% | 3.0% | 128.7 | 71.2% | 6.6% | 204.5 | 71.2% | 22.7% | 0.0 | 71.2% | 0.0% | 88.0 | 71.2% | 8.1% |
| Grass-legume, temp. spp. | 8.3 | 71.2% | 1.6% | 363.6 | 71.2% | 28.1% | 31.8 | 71.2% | 1.3% | 20.6 | 71.2% | 2.4% | 115.8 | 71.2% | 6.0% | 61.4 | 71.2% | 6.8% | 0.0 | 71.2% | 0.0% | 88.0 | 71.2% | 8.1% |
| Grass-legume, trop. spp. | 8.3 | 71.2% | 1.6% | 0.1 | 71.2% | 0.0% | 74.1 | 71.2% | 3.1% | 5.2 | 71.2% | 0.6% | 12.9 | 71.2% | 0.7% | 143.2 | 71.2% | 15.9% | 0.0 | 71.2% | 0.0% | 0.0 | 71.2% | 0.0% |
| Whole-cereals | 0.0 | 71.2% | 0.0% | 121.1 | 71.2% | 9.4% | 0.0 | 71.2% | 0.0% | 0.0 | 71.2% | 0.0% | 193.0 | 71.2% | 9.9% | 0.0 | 71.2% | 0.0% | 0.0 | 71.2% | 0.0% | 205.3 | 71.2% | 18.8% |
| Whole-maize[d] | 0.0 | 71.2% | 0.0% | 121.1 | 71.2% | 9.4% | 0.0 | 71.2% | 0.0% | 0.0 | 71.2% | 0.0% | 193.0 | 71.2% | 9.9% | 0.0 | 71.2% | 0.0% | 0.0 | 71.2% | 0.0% | 205.3 | 71.2% | 18.8% |
| Other animal forage crops | 47.0 | 90.3% | 8.8% | 36.5 | 92.2% | 2.8% | 0.1 | 92.2% | 0.0% | 0.0 | 90.3% | 0.0% | 0.1 | 92.2% | 0.0% | 0.0 | 90.3% | 0.0% | 0.0 | 90.3% | 0.0% | 0.2 | 92.2% | 0.0% |
| Forage-vegetables | 47.0 | 90.3% | 8.8% | 36.5 | 92.2% | 2.8% | 0.1 | 92.2% | 0.0% | 0.0 | 90.3% | 0.0% | 0.1 | 92.2% | 0.0% | 0.0 | 90.3% | 0.0% | 0.0 | 90.3% | 0.0% | 0.2 | 92.2% | 0.0% |
| **A3. Pasture** | 227.2 | 47.4% | 42.6% | 520.2 | 50.8% | 40.2% | 1 691.0 | 46.6% | 70.3% | 517.4 | 48.9% | 60.4% | 910.7 | 53.5% | 46.9% | 336.6 | 46.4% | 37.4% | 685.9 | 46.2% | 66.2% | 374.8 | 55.2% | 34.4% |
| Cropland pasture | 0.0 | 65.0% | 0.0% | 13.5 | 65.0% | 1.0% | 0.0 | 65.0% | 0.0% | 0.0 | 65.0% | 0.0% | 239.3 | 65.0% | 12.3% | 0.0 | 65.0% | 0.0% | 0.0 | 65.0% | 0.0% | 133.0 | 65.0% | 12.2% |
| Grass-legume, temp. spp. | 0.0 | 65.0% | 0.0% | 13.5 | 65.0% | 1.0% | 0.0 | 65.0% | 0.0% | 0.0 | 65.0% | 0.0% | 215.4 | 65.0% | 11.1% | 0.0 | 65.0% | 0.0% | 0.0 | 65.0% | 0.0% | 133.0 | 65.0% | 12.2% |
| Grass-legume, trop. spp. | 0.0 | 65.0% | 0.0% | 0.0 | 65.0% | 0.0% | 0.0 | 65.0% | 0.0% | 0.0 | 65.0% | 0.0% | 23.9 | 65.0% | 1.2% | 0.0 | 65.0% | 0.0% | 0.0 | 65.0% | 0.0% | 0.0 | 65.0% | 0.0% |
| Permanent pasture | 227.2 | 47.4% | 42.6% | 506.7 | 50.5% | 39.2% | 1 690.9 | 46.6% | 70.3% | 517.4 | 48.9% | 60.4% | 671.4 | 50.4% | 34.6% | 336.6 | 46.4% | 37.4% | 685.9 | 46.2% | 66.2% | 241.8 | 50.9% | 22.2% |
| Native grass-legume, temperate spp. | 113.6 | 50.0% | 21.3% | 456.0 | 50.0% | 35.3% | 507.3 | 50.0% | 21.1% | 413.9 | 50.0% | 48.4% | 483.4 | 50.0% | 24.9% | 101.0 | 50.0% | 11.2% | 171.5 | 50.0% | 16.5% | 193.4 | 50.0% | 17.7% |

| | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oversown grass-legume, temperate spp. | 0.0 | 55.0% | 0.0% | 50.7 | 55.0% | 3.9% | 0.2 | 55.0% | 0.0% | 0.0 | 55.0% | 0.0% | 120.9 | 55.0% | 6.2% | 0.0 | 55.0% | 0.0% | 0.0 | 55.0% | 0.0% | 48.4 | 55.0% | 4.4% |
| Native grass-legume, tropical spp. | 113.6 | 45.0% | 21.3% | 0.1 | 45.0% | 0.0% | 1124.5 | 45.0% | 46.8% | 103.5 | 45.0% | 12.1% | 53.7 | 45.0% | 2.8% | 235.6 | 45.0% | 26.2% | 514.3 | 45.0% | 49.6% | 0.0 | 45.0% | 0.0% |
| Oversown grass-legume, tropical spp. | 0.0 | 50.0% | 0.0% | 0.0 | 50.0% | 0.0% | 59.0 | 50.0% | 2.5% | 0.0 | 50.0% | 0.0% | 13.4 | 50.0% | 0.7% | 0.0 | 50.0% | 0.0% | 0.0 | 50.0% | 0.0% | 0.0 | 50.0% | 0.0% |
| **A4. Edible-type crops by-products** | 119.1 | 21.8% | 22.3% | 64.1 | 11.2% | 5.0% | 395.3 | 42.2% | 16.4% | 204.4 | 41.1% | 23.9% | 44.8 | 2.8% | 2.3% | 321.8 | 71.3% | 35.8% | 311.2 | 55.7% | 30.0% | 39.5 | 6.0% | 3.6% |
| Cereals straw & stover | 90.1 | 20.4% | 16.9% | 41.5 | 10.1% | 3.2% | 276.8 | 43.2% | 11.5% | 178.8 | 43.2% | 20.9% | 36.1 | 2.9% | 1.9% | 269.0 | 72.8% | 29.9% | 282.1 | 64.7% | 27.2% | 15.5 | 3.1% | 1.4% |
| Wheat straw | 16.9 | 21.7% | 3.2% | 21.1 | 10.1% | 1.6% | 27.2 | 43.5% | 1.1% | 89.8 | 43.1% | 10.5% | 11.5 | 2.9% | 0.6% | 94.9 | 72.8% | 10.6% | 14.8 | 64.4% | 1.4% | 7.2 | 3.2% | 0.7% |
| Rice straw | 27.3 | 18.0% | 5.1% | 0.0 | 0.0% | 0.0% | 17.9 | 43.7% | 0.7% | 8.0 | 43.5% | 0.9% | 0.0 | 0.0% | 0.0% | 121.1 | 72.8% | 13.5% | 18.8 | 64.5% | 1.8% | 0.0 | 0.0% | 0.0% |
| Maize stover | 40.0 | 21.6% | 7.5% | 13.5 | 10.1% | 1.0% | 196.4 | 43.2% | 8.2% | 37.8 | 43.3% | 4.4% | 18.9 | 3.0% | 1.0% | 23.4 | 73.0% | 2.6% | 175.7 | 64.8% | 17.0% | 2.6 | 3.2% | 0.2% |
| Sorghum stover | 2.2 | 22.4% | 0.4% | 0.7 | 12.3% | 0.1% | 27.0 | 42.8% | 1.1% | 22.2 | 43.2% | 2.6% | 2.5 | 2.8% | 0.1% | 24.7 | 72.8% | 2.7% | 58.6 | 64.8% | 5.7% | 0.0 | 0.0% | 0.0% |
| Barley straw | 3.7 | 21.9% | 0.7% | 6.2 | 9.9% | 0.5% | 8.2 | 42.0% | 0.3% | 21.0 | 43.0% | 2.5% | 3.3 | 2.7% | 0.2% | 4.9 | 73.6% | 0.5% | 14.2 | 64.2% | 1.4% | 5.8 | 3.1% | 0.5% |
| Starchy roots tops | 16.3 | 47.9% | 3.1% | 15.0 | 36.2% | 1.2% | 4.1 | 17.6% | 0.2% | 0.0 | 0.0% | 0.0% | 0.0 | 0.0% | 0.0% | 1.2 | 21.4% | 0.1% | 7.1 | 11.5% | 0.7% | 0.0 | 0.0% | 0.0% |
| Cassava leaves | 0.0 | 3.8% | 0.0% | 0.0 | 0.0% | 0.0% | 0.0 | 0.0% | 0.0% | 0.0 | 0.0% | 0.0% | 0.0 | 0.0% | 0.0% | 0.0 | 0.0% | 0.0% | 3.0 | 53.6% | 0.3% | 0.0 | 0.0% | 0.0% |
| White potato tops | 2.1 | 70.6% | 0.4% | 15.0 | 54.3% | 1.2% | 3.4 | 54.3% | 0.1% | 0.0 | 0.0% | 0.0% | 0.0 | 0.0% | 0.0% | 1.1 | 27.0% | 0.1% | 1.4 | 62.8% | 0.1% | 0.0 | 0.0% | 0.0% |
| Sweet potato tops | 14.1 | 71.7% | 2.6% | 0.0 | 0.0% | 0.0% | 0.7 | 54.4% | 0.0% | 0.0 | 0.0% | 0.0% | 0.0 | 0.0% | 0.0% | 0.1 | 26.6% | 0.0% | 2.7 | 63.1% | 0.3% | 0.0 | 0.0% | 0.0% |
| Sugar crops tops & leaves | 6.1 | 30.8% | 1.1% | 7.5 | 26.1% | 0.6% | 50.1 | 48.3% | 2.1% | 8.6 | 36.9% | 1.0% | 8.7 | 9.3% | 0.4% | 26.0 | 71.8% | 2.9% | 9.3 | 64.2% | 0.9% | 23.9 | 58.2% | 2.2% |
| Sugar cane tops & leaves | 6.0 | 32.4% | 1.1% | 0.0 | 0.0% | 0.0% | 50.1 | 48.7% | 2.1% | 5.5 | 48.2% | 0.6% | 0.0 | 0.0% | 0.0% | 26.0 | 73.1% | 2.9% | 9.3 | 64.1% | 0.9% | 0.0 | 0.0% | 0.0% |
| Sugar beet tops | 0.1 | 9.2% | 0.0% | 7.5 | 26.1% | 0.6% | 0.0 | 4.1% | 0.0% | 3.1 | 25.9% | 0.4% | 8.7 | 37.7% | 0.4% | 0.0 | 2.8% | 0.0% | 0.0 | 0.0% | 0.0% | 23.9 | 58.2% | 2.2% |
| Oil crops by-products | 6.5 | 12.7% | 1.2% | 0.0 | 0.0% | 0.0% | 64.3 | 38.3% | 2.7% | 17.1 | 32.4% | 2.0% | 0.0 | 0.0% | 0.0% | 25.7 | 64.0% | 2.9% | 12.7 | 27.4% | 1.2% | 0.0 | 0.0% | 0.0% |
| Soybean stalks & husks | 2.6 | 18.3% | 0.5% | 0.0 | 0.0% | 0.0% | 49.8 | 44.3% | 2.1% | 1.8 | 43.7% | 0.2% | 0.0 | 0.0% | 0.0% | 7.3 | 74.1% | 0.8% | 1.2 | 55.4% | 0.1% | 0.0 | 0.0% | 0.0% |
| Groundnut stalks | 2.4 | 32.8% | 0.4% | 0.0 | 0.0% | 0.0% | 3.2 | 50.4% | 0.1% | 3.9 | 49.4% | 0.5% | 0.0 | 0.0% | 0.0% | 9.6 | 73.8% | 1.1% | 9.2 | 65.1% | 0.9% | 0.0 | 0.0% | 0.0% |
| Sunflower stalks & thr. heads | 0.4 | 11.2% | 0.1% | 0.0 | 0.0% | 0.0% | 11.3 | 27.6% | 0.5% | 10.2 | 27.0% | 1.2% | 0.0 | 0.0% | 0.0% | 2.1 | 38.3% | 0.2% | 2.2 | 40.7% | 0.2% | 0.0 | 0.0% | 0.0% |
| Canola stalks & husks | 1.1 | 15.8% | 0.2% | 0.0 | 0.0% | 0.0% | 0.0 | 0.0% | 0.0% | 1.1 | 40.3% | 0.1% | 0.0 | 0.0% | 0.0% | 6.7 | 58.5% | 0.7% | 0.0 | 0.0% | 0.0% | 0.0 | 0.0% | 0.0% |
| ***B. Total all conv.-by-products*** | 30.1 | 7.7% | 5.6% | 42.1 | 4.5% | 3.3% | 57.0 | 3.6% | 2.4% | 30.5 | 5.2% | 3.6% | 121.0 | 9.8% | 6.2% | 27.3 | 4.6% | 3.0% | 13.9 | 2.2% | 1.3% | 100.4 | 14.7% | 9.2% |
| **B3. Vegetable conv.-by-products** | 29.8 | 33.0% | 5.6% | 40.7 | 46.4% | 3.1% | 56.1 | 29.8% | 2.3% | 30.2 | 36.5% | 3.5% | 113.7 | 59.0% | 5.9% | 27.2 | 28.9% | 3.0% | 13.7 | 26.1% | 1.3% | 96.0 | 74.1% | 8.8% |
| Cereals milling by-products | 20.0 | 35.2% | 3.7% | 19.7 | 58.6% | 1.5% | 11.1 | 36.9% | 0.5% | 19.2 | 40.3% | 2.2% | 24.2 | 86.1% | 1.2% | 20.0 | 40.2% | 2.2% | 9.7 | 34.2% | 0.9% | 24.7 | 85.3% | 2.3% |
| Wheat mill run | 4.9 | 40.1% | 0.9% | 18.8 | 60.2% | 1.5% | 4.2 | 42.1% | 0.2% | 13.8 | 39.9% | 1.6% | 19.5 | 90.0% | 1.0% | 6.7 | 39.8% | 0.7% | 1.5 | 34.9% | 0.1% | 23.0 | 90.2% | 2.1% |
| Rice hulls | 8.2 | 29.9% | 1.5% | 0.0 | 0.0% | 0.0% | 2.4 | 34.3% | 0.1% | 1.7 | 40.5% | 0.2% | 0.0 | 0.0% | 0.0% | 8.2 | 40.2% | 0.9% | 1.6 | 36.2% | 0.2% | 0.0 | 0.0% | 0.0% |
| Rice bran | 4.9 | 40.2% | 0.9% | 0.2 | 60.3% | 0.0% | 1.1 | 34.3% | 0.0% | 0.9 | 51.3% | 0.1% | 1.1 | 100% | 0.1% | 3.5 | 38.6% | 0.4% | 0.7 | 35.3% | 0.1% | 0.4 | 71.9% | 0.0% |
| Maize hominy feed | 1.8 | 41.2% | 0.3% | 0.7 | 67.0% | 0.1% | 3.4 | 36.0% | 0.1% | 1.9 | 44.0% | 0.2% | 3.7 | 100% | 0.2% | 0.8 | 51.1% | 0.1% | 4.3 | 35.0% | 0.4% | 1.4 | 79.6% | 0.1% |
| Sorghum hominy feed | 0.2 | 61.3% | 0.0% | 0.0 | 0.0% | 0.0% | 0.0 | 0.0% | 0.0% | 0.9 | 35.9% | 0.1% | 0.0 | 0.0% | 0.0% | 0.9 | 48.1% | 0.1% | 1.6 | 35.1% | 0.2% | 0.0 | 0.0% | 0.0% |

*Table continues on next page.*

**Table 3.24** (continued)

| | East Asia | | | East Europe | | | Latin America & Caribbean | | | North Africa & West Asia | | | North America & Oceania | | | South & Central Asia | | | Sub-Saharan Africa | | | West Europe | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flow | Amount (kg) | Share of gen. | Share in feed | Amount (kg) | Share of gen. | Share in feed | Amount (kg) | Share of gen. | Share in feed | Amount (kg) | Share of gen. | Share in feed | Amount (kg) | Share of gen. | Share in feed | Amount (kg) | Share of gen. | Share in feed | Amount (kg) | Share of gen. | Share in feed | Amount (kg) | Share of gen. | Share in feed |
| Sugar crops conversion by-products | 2.7 | 15.0% | 0.5% | 9.4 | 42.6% | 0.7% | 14.6 | 15.3% | 0.6% | 4.0 | 22.6% | 0.5% | 19.8 | 23.7% | 1.0% | 5.2 | 15.6% | 0.6% | 1.6 | 12.4% | 0.2% | 23.6 | 75.5% | 2.2% |
| Sugar cane bagasse | 1.9 | 13.3% | 0.4% | 0.0 | 0.0% | 0.0% | 11.1 | 13.8% | 0.5% | 1.2 | 13.1% | 0.1% | 0.0 | 0.0% | 0.0% | 3.8 | 13.6% | 0.4% | 1.2 | 10.8% | 0.1% | 0.0 | 0.0% | 0.0% |
| Sugar cane molasses | 0.6 | 34.3% | 0.1% | 0.0 | 0.0% | 0.0% | 3.4 | 33.9% | 0.1% | 0.5 | 41.8% | 0.1% | 5.8 | 82.7% | 0.3% | 1.4 | 40.3% | 0.2% | 0.4 | 30.5% | 0.0% | 0.0 | 0.0% | 0.0% |
| Sugar beet pulp | 0.0 | 0.0% | 0.0% | 5.7 | 50.6% | 0.4% | 0.0 | 0.0% | 0.0% | 1.4 | 38.4% | 0.2% | 8.4 | 92.9% | 0.4% | 0.0 | 0.0% | 0.0% | 0.0 | 0.0% | 0.0% | 14.3 | 89.5% | 1.3% |
| Sugar beet molasses | 0.1 | 45.1% | 0.0% | 3.7 | 51.1% | 0.3% | 0.0 | 0.0% | 0.0% | 0.9 | 39.8% | 0.1% | 5.6 | 96.6% | 0.3% | 0.0 | 0.0% | 0.0% | 0.0 | 0.0% | 0.0% | 9.3 | 90.4% | 0.9% |
| Oilseed conversion by-products | 6.4 | 50.5% | 1.2% | 8.9 | 35.4% | 0.7% | 29.5 | 50.1% | 1.2% | 6.8 | 41.1% | 0.8% | 63.1 | 87.8% | 3.2% | 1.8 | 17.8% | 0.2% | 1.8 | 22.4% | 0.2% | 38.4 | 68.0% | 3.5% |
| Soybean meal | 4.1 | 80.5% | 0.8% | 1.9 | 77.8% | 0.1% | 26.4 | 60.0% | 1.1% | 2.2 | 80.2% | 0.3% | 60.5 | 90.1% | 3.1% | 0.7 | 24.9% | 0.1% | 0.5 | 68.9% | 0.0% | 23.5 | 90.1% | 2.2% |
| Groundnut meal | 0.6 | 73.7% | 0.1% | 0.0 | 0.0% | 0.0% | 0.3 | 49.5% | 0.0% | 0.4 | 82.5% | 0.0% | 0.3 | 69.5% | 0.0% | 0.5 | 24.8% | 0.1% | 0.9 | 70.3% | 0.1% | 0.2 | 100% | 0.0% |
| Sunflower meal | 0.4 | 93.7% | 0.1% | 6.5 | 80.4% | 0.5% | 2.8 | 60.4% | 0.1% | 3.6 | 80.1% | 0.4% | 0.6 | 79.0% | 0.0% | 0.2 | 25.4% | 0.0% | 0.4 | 70.1% | 0.0% | 7.5 | 90.5% | 0.7% |
| Canola meal | 1.4 | 79.6% | 0.3% | 0.5 | 78.8% | 0.0% | 0.0 | 0.0% | 0.0% | 0.6 | 81.6% | 0.1% | 1.7 | 89.0% | 0.1% | 0.5 | 25.1% | 0.1% | 0.1 | 89.9% | 0.0% | 7.2 | 90.8% | 0.7% |
| Other vegetable by-products | 0.7 | 23.5% | 0.1% | 2.8 | 39.3% | 0.2% | 0.9 | 22.6% | 0.0% | 0.1 | 27.0% | 0.0% | 6.5 | 71.9% | 0.3% | 0.1 | 22.9% | 0.0% | 0.6 | 19.9% | 0.1% | 9.2 | 72.4% | 0.8% |
| Brewer’s grains | 0.7 | 29.5% | 0.1% | 2.8 | 49.2% | 0.2% | 0.9 | 28.3% | 0.0% | 0.1 | 33.9% | 0.0% | 6.5 | 90.1% | 0.3% | 0.1 | 28.7% | 0.0% | 0.6 | 24.9% | 0.1% | 9.2 | 90.8% | 0.8% |
| **B4. Animal conversion-by-products** | 0.3 | 0.1% | 0.1% | 1.4 | 0.2% | 0.1% | 0.9 | 0.1% | 0.0% | 0.2 | 0.0% | 0.0% | 7.4 | 0.7% | 0.4% | 0.1 | 0.0% | 0.0% | 0.2 | 0.0% | 0.0% | 4.4 | 0.8% | 0.4% |
| Carcass by-products[e] | 0.3 | 8.3% | 0.1% | 1.4 | 16.1% | 0.1% | 0.9 | 9.0% | 0.0% | 0.2 | 6.8% | 0.0% | 7.4 | 42.3% | 0.4% | 0.1 | 7.9% | 0.0% | 0.2 | 8.2% | 0.0% | 4.4 | 42.2% | 0.4% |
| Dairy cattle fifth quarter | 0.0 | 10.1% | 0.0% | 0.5 | 15.8% | 0.0% | 0.2 | 9.5% | 0.0% | 0.1 | 8.9% | 0.0% | 0.9 | 48.7% | 0.0% | 0.1 | 8.6% | 0.0% | 0.1 | 8.6% | 0.0% | 1.1 | 47.8% | 0.1% |
| Beef cattle fifth quarter | 0.1 | 8.8% | 0.0% | 0.2 | 18.3% | 0.0% | 0.4 | 9.4% | 0.0% | 0.1 | 9.2% | 0.0% | 3.3 | 45.5% | 0.2% | 0.1 | 9.0% | 0.0% | 0.1 | 8.7% | 0.0% | 0.9 | 46.8% | 0.1% |
| Pig fifth quarter | 0.2 | 9.5% | 0.0% | 0.5 | 18.1% | 0.0% | 0.1 | 12.8% | 0.0% | 0.0 | 0.0% | 0.0% | 1.3 | 46.0% | 0.1% | 0.0 | 0.0% | 0.0% | 0.0 | 12.8% | 0.0% | 1.5 | 44.7% | 0.1% |
| Meat-type chicken fifth quarter | 0.0 | 7.4% | 0.0% | 0.2 | 20.6% | 0.0% | 0.2 | 9.2% | 0.0% | 0.0 | 2.7% | 0.0% | 2.0 | 44.4% | 0.1% | 0.0 | 9.6% | 0.0% | 0.0 | 7.8% | 0.0% | 0.8 | 43.3% | 0.1% |
| ***C. Total all end-use residues*** | 24.9 | 26.3% | 4.7% | 12.3 | 9.1% | 0.9% | 16.3 | 15.1% | 0.7% | 0.0 | 0.0% | 0.0% | 0.0 | 0.0% | 0.0% | 1.5 | 2.1% | 0.2% | 7.5 | 10.1% | 0.7% | 0.0 | 0.0% | 0.0% |
| Non-eaten food | 24.9 | 36.5% | 4.7% | 12.3 | 12.1% | 0.9% | 16.3 | 20.3% | 0.7% | 0.0 | 0.0% | 0.0% | 0.0 | 0.0% | 0.0% | 1.5 | 3.2% | 0.2% | 7.5 | 16.2% | 0.7% | 0.0 | 0.0% | 0.0% |
| **SYSTEM-EXTERNAL INPUTS** | | | | | | | | | | | | | | | | | | | | | | | | |
| Fish[f] | 1.7 | 23.8% | 0.3% | 0.3 | 7.8% | 0.0% | 2.3 | 42.4% | 0.1% | 0.6 | 27.2% | 0.1% | 1.5 | 26.1% | 0.1% | 0.2 | 15.4% | 0.0% | 0.3 | 15.2% | 0.0% | 2.9 | 29.9% | 0.3% |
| Cotton meal | 0.7 | 31.7% | 0.1% | 1.2 | 50.7% | 0.1% | 0.7 | 30.9% | 0.0% | 0.7 | 30.1% | 0.1% | 0.0 | 0.0% | 0.0% | 0.0 | 0.0% | 0.0% | 0.6 | 24.9% | 0.1% | 6.5 | 90.2% | 0.6% |

Amounts in kg dry weight per capita (kg DM/capita & year); share of generated and share in feed mix in percent (DM basis). All values are given with one decimal. Share of generated refers to feed intake as share of generated *within* each region. Due to import, therefore, this parameter may exceed 100% (those cases where the use as feed is much larger than the region-domestic generation are designated ‘>>100%’). It should be observed that for categories and sum of categories, the shares of generated and distributed refer to the *total* for each category, including *all* individual flows belonging to the respective category (for definitions of ‘generated’ and ‘distributed’, see Section 2.1.6, p. 19). Thus, it does *not* refer to the total of the individual flows displayed under each category in this table.

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[a] Refers to sum of all flows displayed in table, that is, both system flows and system-external inputs.

[b] Eaten as raw tuber or meal.

[c] Eaten as hay or silage.

[d] Eaten as silage.

[e] All ‘fifth quarters’ are eaten as meat & bone meal.

[f] Eaten as meal.

### *Feed energy requirements*

As we described in Section 3.1.2 above, in this study, the procedure to estimate feed matter intake from calculated feed energy requirements involved many steps of assumptions and matching. As a measure to increase the transparency of this study, we present the estimated feed energy requirements separately (Table 3.25). For the same reason, the estimates on additional energy requirements for *grazing* are specified separately in the table. It should be noted that feed energy requirements related to performance of draft work is not included in these numbers.

**Table 3.25** Feed energy requirements of animal food production.

| Sub-system | Unit | Allowance category | World total | East Asia | East Europe | Latin America & Carib. | North Africa & W. Asia | North America & Oc. | South & Central Asia | Sub-Saharan Africa | West Europe |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cattle milk | $NE_l$ | Base requirements | 4 400 | 170 | 870 | 550 | 300 | 470 | 1 080 | 290 | 680 |
| | | Add. grazing requirements | 240 | 8.8 | 49 | 59 | 25 | 3.7 | 49 | 32 | 11 |
| | | *Total* | *4 640* | *180* | *920* | *610* | *320* | *470* | *1 130* | *320* | *690* |
| | $NE_m$ | Base requirements | 3 020 | 150 | 320 | 530 | 210 | 190 | 1 040 | 300 | 270 |
| | | Add. grazing requirements | 330 | 23 | 34 | 77 | 27 | 18 | 80 | 42 | 23 |
| | | *Total* | *3 350* | *170* | *360* | *610* | *240* | *210* | *1 120* | *350* | *300* |
| | $NE_g$ | | 530 | 21 | 100 | 90 | 33 | 72 | 75 | 31 | 110 |
| Beef cattle carcass | $NE_m$ | Base requirements | 9 160 | 1 500 | 350 | 2 010 | 390 | 1 610 | 1 820 | 1 010 | 460 |
| | | Add. grazing requirements | 1060 | 190 | 28 | 300 | 50 | 170 | 140 | 140 | 43 |
| | | *Total* | *10 200* | *1 690* | *380* | *2 310* | *440* | *1 780* | *1 960* | *1 150* | *510* |
| | $NE_g$ | | 1 030 | 130 | 48 | 240 | 34 | 340 | 74 | 61 | 100 |
| Pig carcass-side | ME | | 5 550 | 2 780 | 780 | 380 | 0.8 | 580 | 62 | 90 | 870 |
| Chicken egg | ME | | 1 760 | 850 | 190 | 150 | 67 | 140 | 140 | 59 | 160 |
| Meat-type chicken carcass | ME | | 2 230 | 570 | 120 | 370 | 130 | 570 | 100 | 100 | 260 |

All values are given in PJ/year. For definitions of allowance categories for cattle, see Section 2.3.1 (p. 28).

Relation between intake of animal food commodities and feed use and phytomass appropriation

In Section 3.2.1 above, we presented some results for vegetable and animal food commodities regarding differences in the relative contribution to the phytomass appropriation of the food system. In this section we look more into the details of the animal food commodities. A major intention is to give a basis for an understanding of the regional differences in feed use and phytomass appropriation for the animal food sector.

*Comparisons between the animal sub-systems*

What differences are there in required feed use and phytomass appropriation per produced unit for the separate animal sub-systems? We begin with a brief overview. In Figure 3.12 (p. 117) we could see that animal food accounts for about two thirds of the total phytomass appropriation of the food system, while contributing only approximately 13 percent to the food intake (both numbers on a GE basis). In Figure 3.35 these relations are shown with specification of each animal sub-system, and with the feed-use step added.

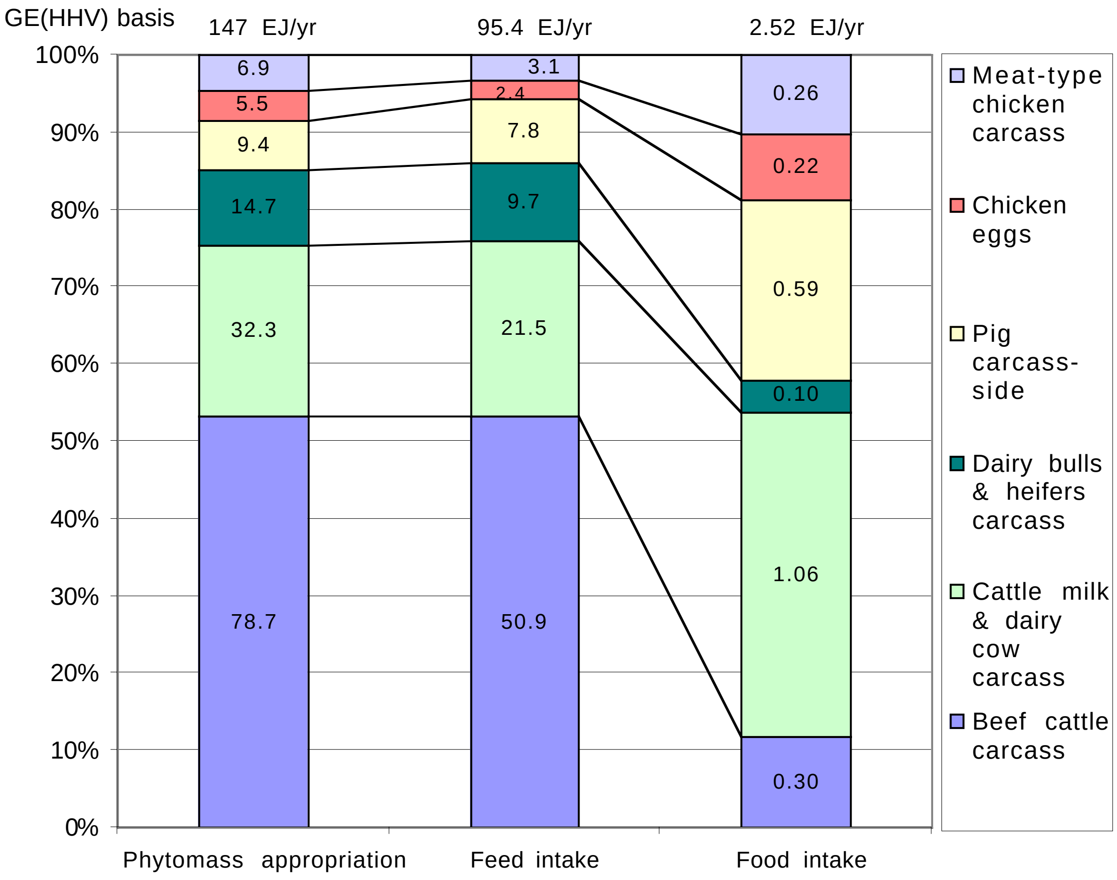

**Figure 3.35** Phytomass appropriation, feed use (actual intake), and food intake related to separate animal sub-systems. World totals. Numbers shown in bars refer to absolute values for each category and sub-system. (The different components appear in the bars in the same order as in the list.)

From Figure 3.35 it is evident that ruminant carcass systems are highly phytomass resource demanding in relation to their output in terms of food (as we already could note from Figures 3.16 to 3.18 above). It is also obvious that there are large differences in overall and conversion efficiency between the separate animal sub-systems (which also already was illustrated in Figure 3.19 and Figure 3.22 above).

What does the *mix* of phytomass appropriation and feed use *per output* look like for the different animal sub-systems? In Figure 3.36 and Figure 3.37 are shown global averages of the amount of *phytomass appropriation*, as well as the amount of *feed intake* — both specified by major category — per the amount of *food intake* related to each of the animal sub-systems. For explanation of these concept, consider Figure 3.35 above. The ‘appropriation of phytomass per food intake’ (Figure 3.36) is the quota between the quantities ‘phytomass appropriation’ and ‘food intake’ in Figure 3.35 for each of the sub-systems, specified by major phytomass category. Similarly, the ‘feed use per food intake’ (Figure 3.37) is the quota between the quantities ‘feed intake’ and ‘food intake’ in Figure 3.35 for each of the sub-systems, specified by major feed category. (This type of concept was first introduced in Figure 3.15 (p.119) — see also explanations in connection to that figure.)

From Figure 3.35 it is apparent that, on average, the appropriation of cropland-related phytomass alone for the ruminant carcass systems is most considerable, if considered in relation to the amount of food supplied from the system. In fact, the appropriation of cropland-related phytomass per unit of food intake is, on average, higher than that of the pig and chicken systems. (These relations are further discussed in the section ‘Efficiency and specific biomass use’, p. 231.)

Since the global figures are averages for very different systems we also give examples from two regions, one non-industrial, Sub-Saharan Africa, Figure 3.38 and Figure 3.39, and one industrial, West Europe, Figure 3.40 and Figure 3.41.

For West Europe, it can be noted that, for the ruminant carcass systems, the appropriation of cropland-related phytomass per food intake is much higher than for the other sub-systems. Compared to the other major meat systems, pig and broiler, the production of beef cattle carcass appropriates roughly three times more of *cultivated* phytomass. If we compare the appropriation of *total cropland-related* phytomass, that is, if we include also cropland pasture, the difference increases to roughly a factor of four.

For Sub-Saharan Africa the low phytomass appropriation per intake for the pig system is striking. The major reason behind this low figure is the large share of non-eaten food assumed for the feed mix (see Figure 3.32). However, as mentioned above, for the feed use of non-eaten food we had relatively few data to rely on, and therefore the figure for the pig system should be regarded with caution. (Further comments on the feed use for non-eaten food are given the section ‘Feed use’, pp. 204 sq.)

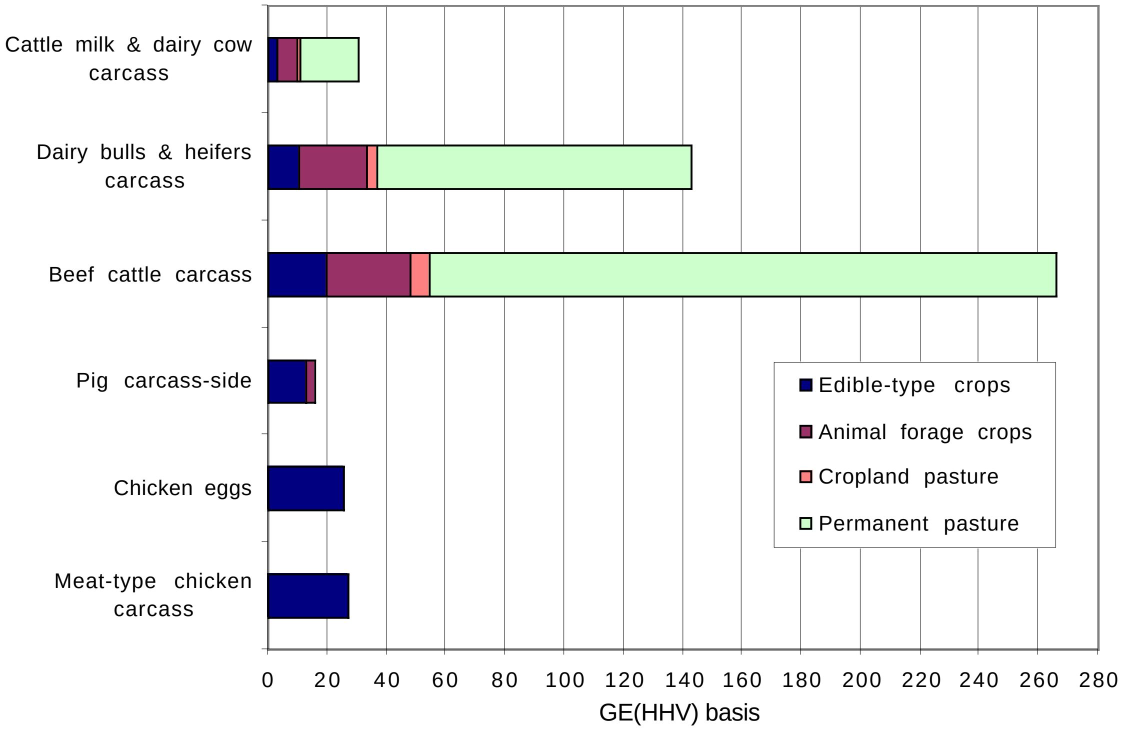

**Figure 3.36** Appropriation of phytomass per food intake for separate animal sub-systems. World averages. (The different components appear in the bars in the same order as in the list.)

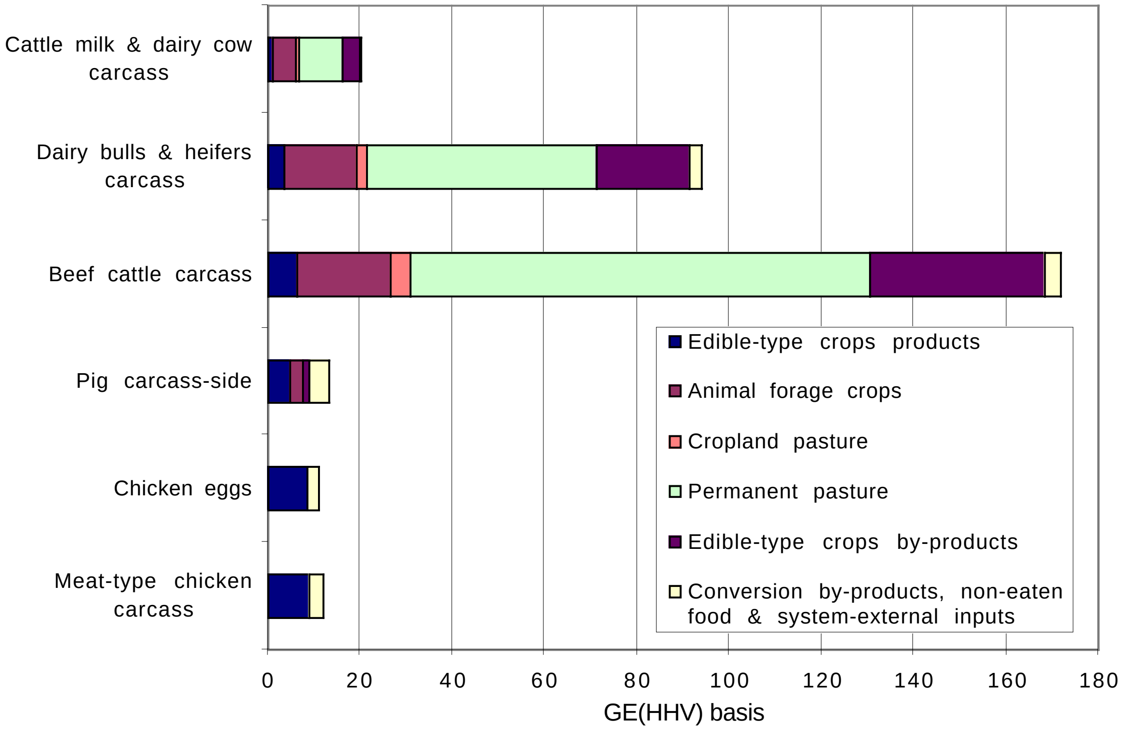

**Figure 3.37** Feed use (actual intake) per food intake for separate animal sub-systems. World averages. (The different components appear in the bars in the same order as in the list.)

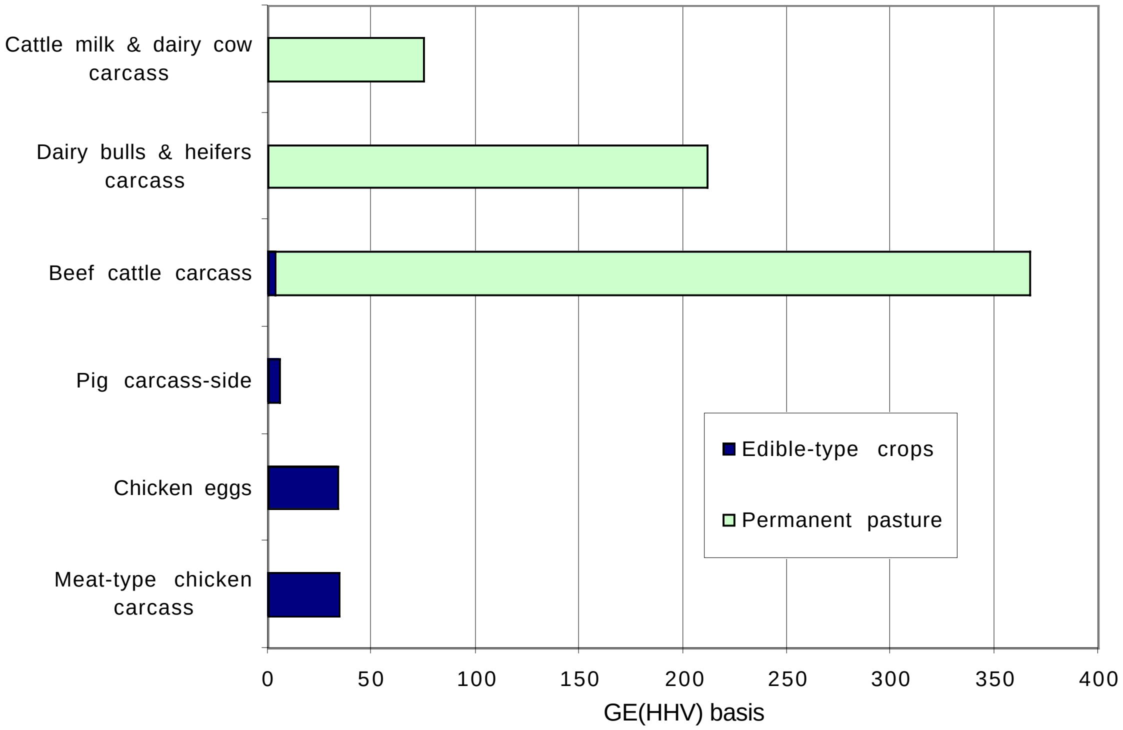

**Figure 3.38** Appropriation of phytomass per food intake for separate animal sub-systems. Values (trade-neutral) for Sub-Saharan Africa as an example of a non-industrial region. (The different components appear in the bars in the same order as in the list.)

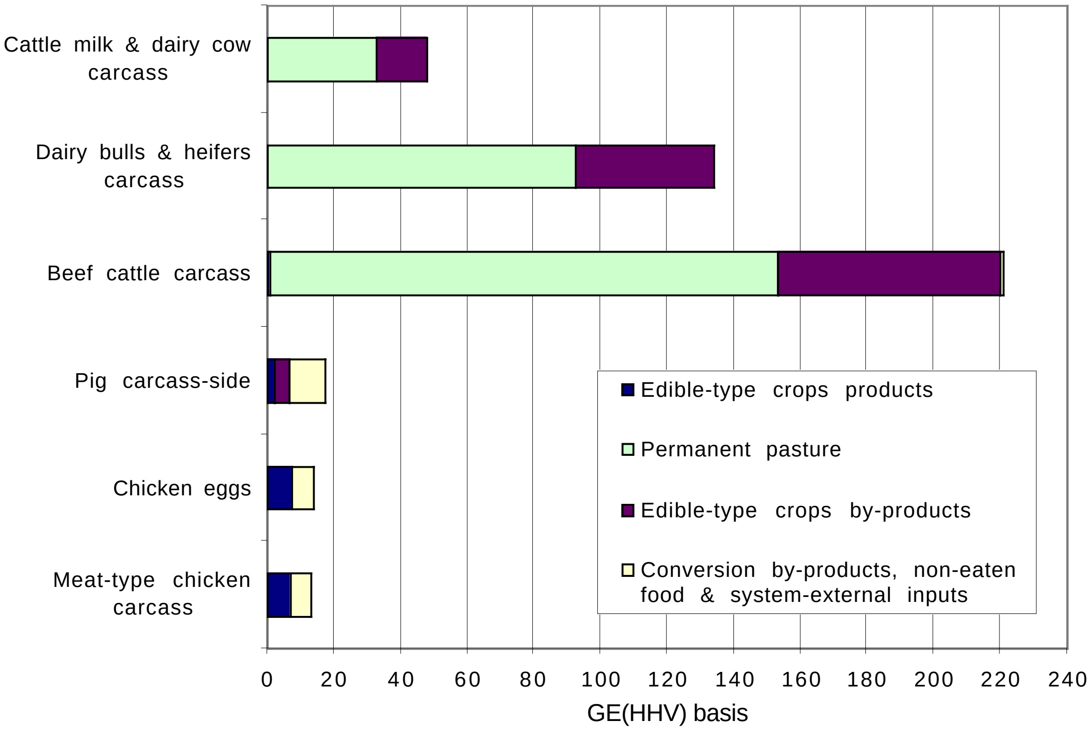

**Figure 3.39** Feed use (actual intake) per food intake for separate animal sub-systems. Values (trade-neutral) for Sub-Saharan Africa as an example of a non-industrial region. (The different components appear in the bars in the same order as in the list.)

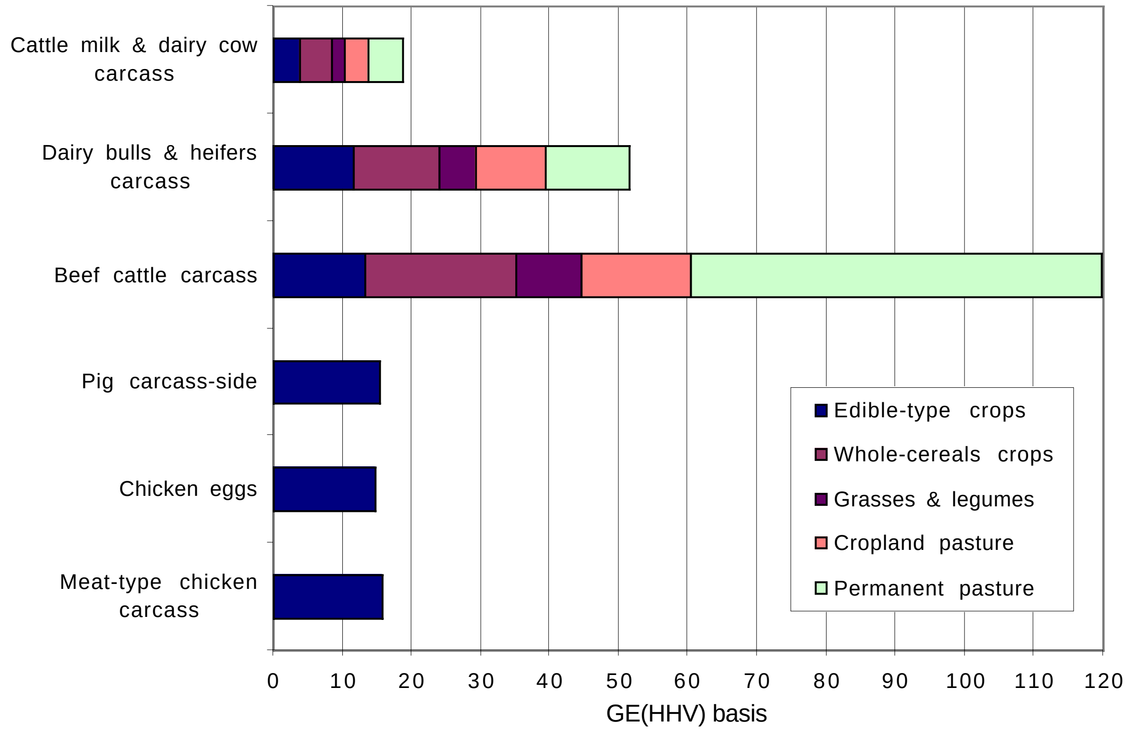

**Figure 3.40** Appropriation of phytomass per food intake for separate animal sub-systems. Values (trade-neutral) for West Europe as an example of an industrial region. (The different components appear in the bars in the same order as in the list.)

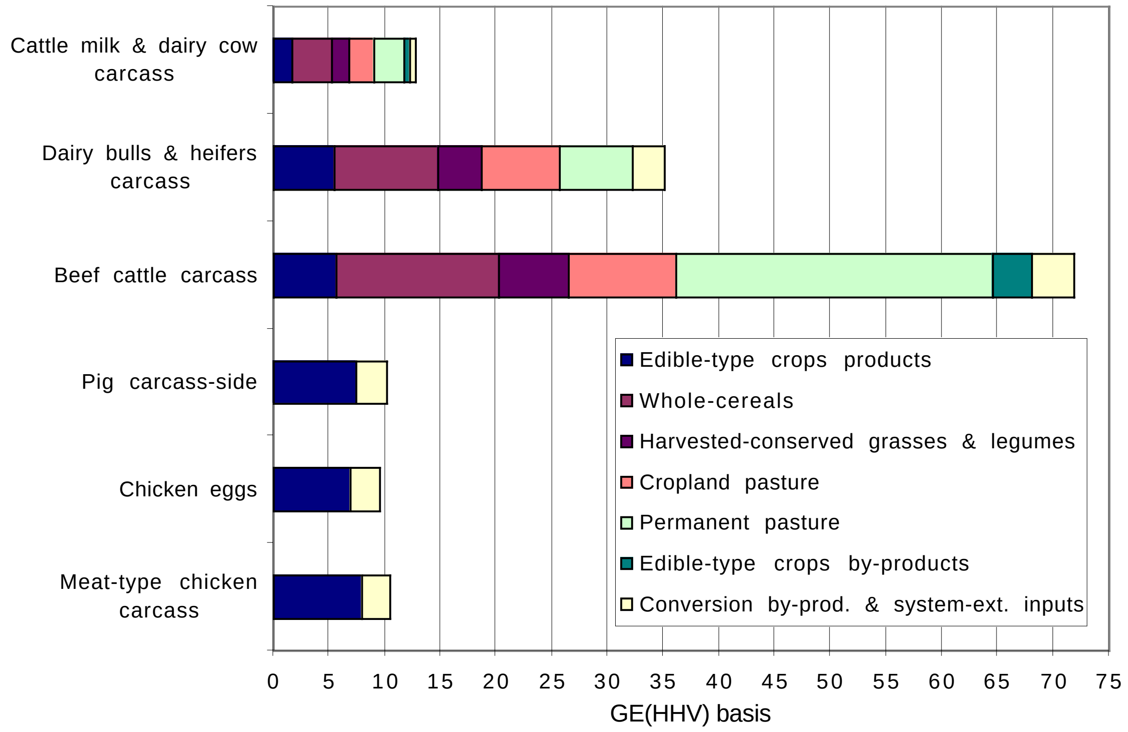

**Figure 3.41** Feed use (actual intake) per food intake for separate animal sub-systems. Values (trade-neutral) for West Europe as an example of an industrial region. (The different components appear in the bars in the same order as in the list.)

The numbers in Figure 3.35 above refer to the *marginal* phytomass appropriation for each animal sub-system. In Table 3.26 the corresponding *net* phytomass appropriation is shown. (The difference between these two quantities was described in the section 'Marginal and net phytomass appropriation', p. 135.) To give a picture of the relative importance of the absolute values of the use of crop by-products, these numbers are also shown.

As can be seen in the table, due to extensive use of crop by-products as feed, the dominance of the ruminant carcass systems is even larger on a net-value basis than on a marginal-value basis. On a net basis, ruminant carcass systems account for 47 percent of the total phytomass appropriation of the food system, whereas on a marginal basis they account for 42 percent. On the contrary, for the pig and poultry systems the net phytomass appropriation is lower than the marginal value. Thus, these systems provide with a surplus of crop by-products.

**Table 3.26** Marginal and net phytomass appropriation for separate animal sub-systems. World totals.

| Sub-system | Marginal phytomass appropriation | Use of crop by-products as feed (actual intake) | Use of crop by-products for animal bedding | Net-use of crop by-products | Net phytomass appropriation |
|---|---|---|---|---|---|
| Cattle milk & dairy cow carcass | 32 | 4.2 | 1.1 | 3.3 | 36 |
| Dairy bulls & heifers carcass | 15 | 2.1 | 0.27 | 1.6 | 16 |
| Beef cattle carcass | 79 | 11 | 1.7 | 8.9 | 88 |
| Pig carcass-side | 9.4 | 0.67 | 1.1 | -3.0 | 6.4 |
| Chicken eggs | 5.5 | 0 | 0.20 | -3.5 | 2.0 |
| Meat-type chicken carcass | 6.9 | 0 | 0.22 | -4.4 | 2.5 |
| *Total all sub-systems* | 147 | 18 | 4.5 | 3.0 | 150 |

All values in EJ GE(HHV).

We can also see from Table 3.26 that although the dominating use of crop by-products is for feed purposes, use of crop by-products for animal bedding is also significant. The total of 4.5 EJ corresponds to 270 Tg DM, which is roughly 11 percent of the distributed amount crop by-products (Table 3.21, p. 126). To give a picture of the relative magnitudes of the numbers for separate animal sub-systems, the global total values of litter use for animal bedding is shown together with the total feed use in Figure 3.42 below.

Clearly, on a global basis, animal bedding requires little biomass in comparison with feed. On a dry weight basis, global use for animal bedding is equal to 4.9 percent of the feed intake. In some regions, as East Asia and West Europe, use is somewhat higher, reaching 7 to 7.5 percent of the feed use. The pig sub-system is the system with the highest use for animal bedding in relation to feed intake. Despite this, biomass use for bedding in relation to the food output of this system is lower than in the ruminant

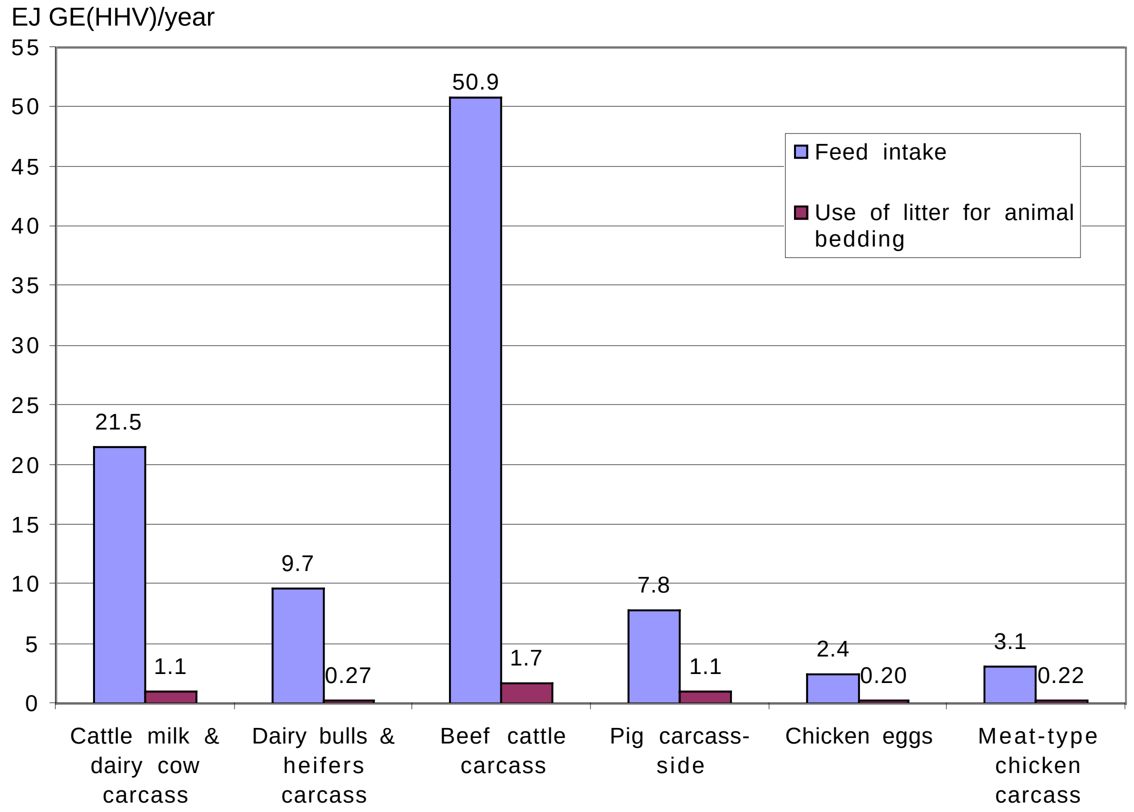

**Figure 3.42** Use of litter for animal bedding in comparison with feed intake. World totals.

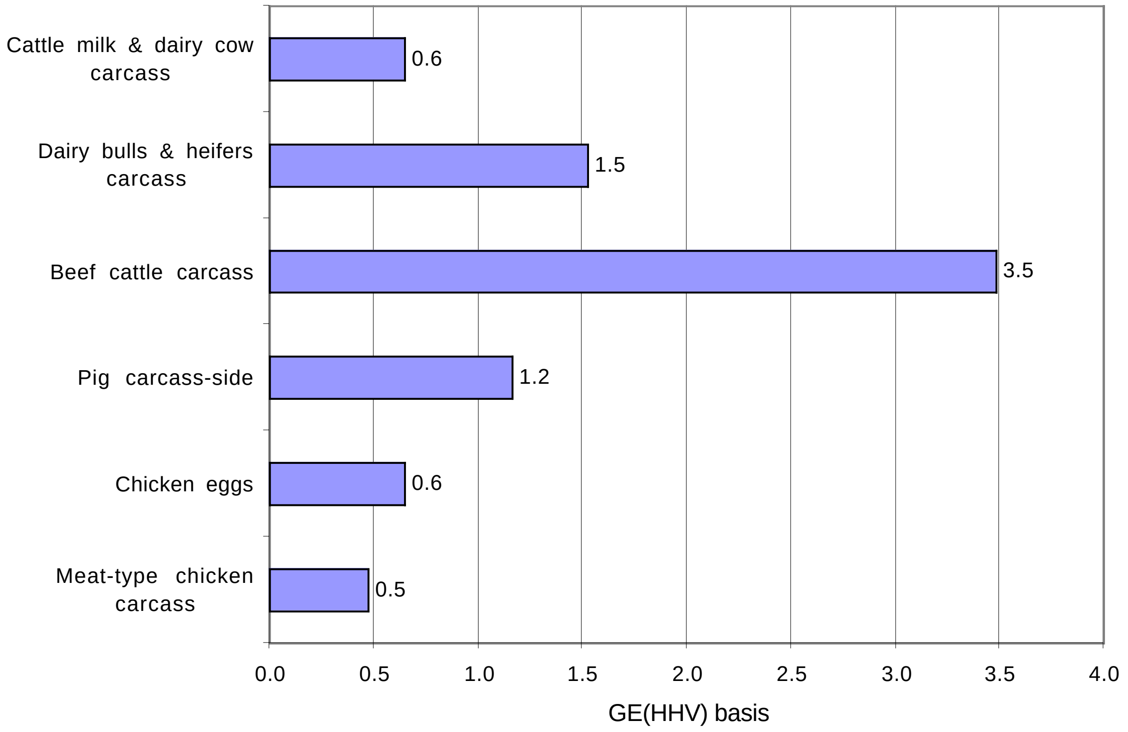

**Figure 3.43** Use of litter for bedding per generation of food products for separate animal sub-systems. World averages.

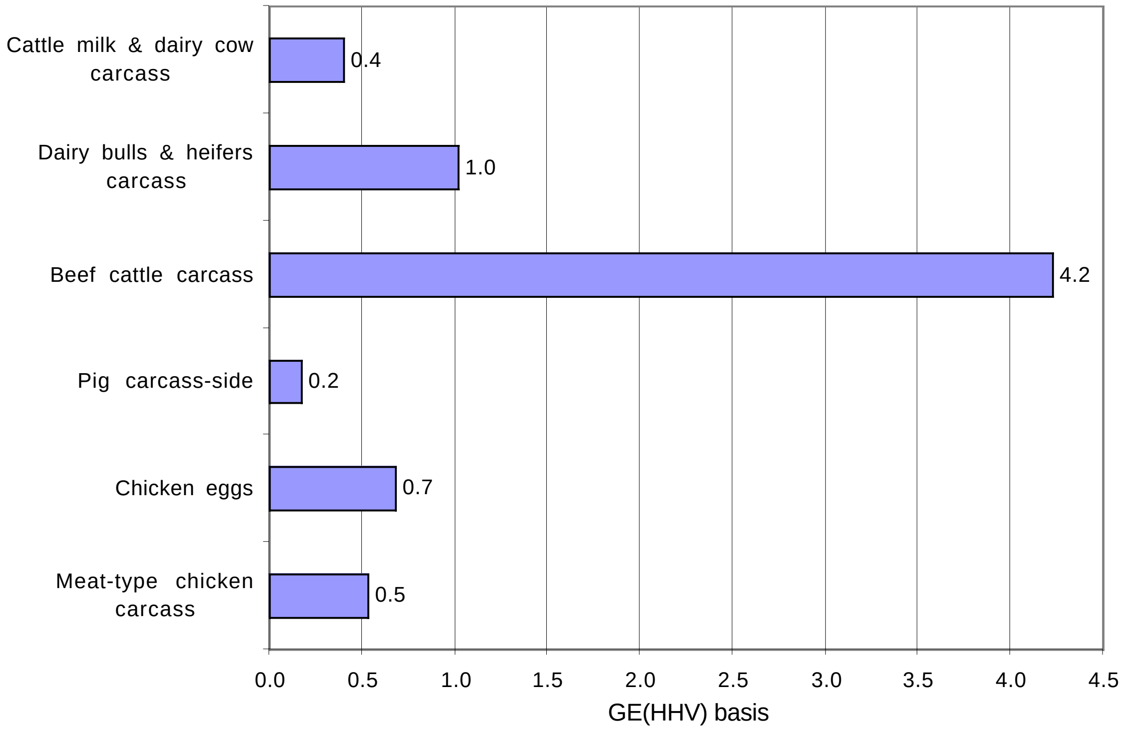

**Figure 3.44** Use of litter for bedding per generation of food products for separate animal subsystems. Values for West Europe.

carcass systems, see Figure 3.43. Since the values in Figure 3.43 are global averages for very diverse types of production systems, of which some involve practically no use of animal bedding, we also give an example from a single region, West Europe (Figure 3.44). In this region, the differences between the beef cattle carcass system and the other systems are even more pronounced.

It should be observed that for these figures, Figure 3.43 and Figure 3.44, the values refer to per food product *generated* and not to per food *intake* as is the case in preceding figures. More specifically, this means that the values in the figures refer to litter use per whole carcass, whole milk and whole egg generated, respectively. In the case of carcass, this implies that also the gross energy content of bones is included in the ‘product’, and not merely the edible parts, lean and fatty tissue. This means that the numbers are somewhat biased in favor of the carcass systems as compared to the other systems.

### *Comparisons between the regions*

So far we have focused specifically on the differences between separate animal systems in terms of feed use and phytomass appropriation per output. In this section we will look into the *regional differences*, with particular emphasis on the most important subsystems — ruminant carcass, milk and pig. The basic idea is to give a picture of the regional differences in phytomass appropriation per capita for animal food (which was illustrated in Figure 3.13, p. 117) by comparing the animal *food intake per capita* as well as the *efficiency* of each of the animal systems. In focus here is each region’s

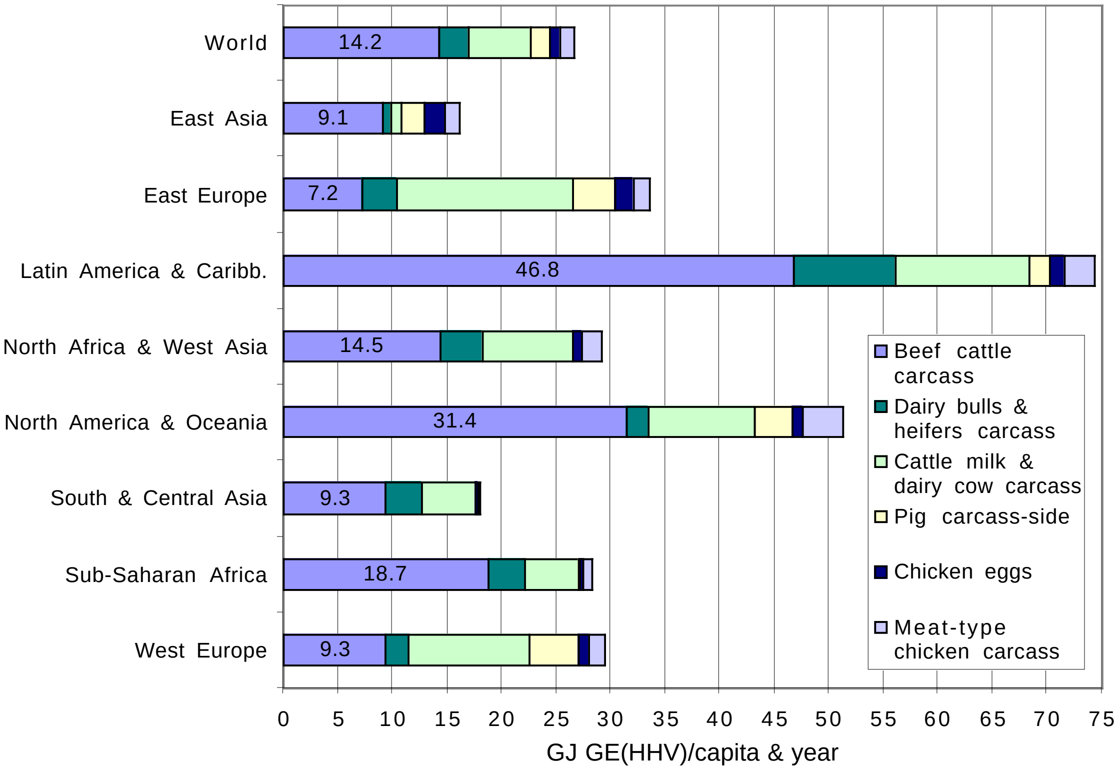

**Figure 3.45** Terrestrial phytomass appropriation related to separate animal food sub-systems. Trade-neutral values. Numbers shown refer to beef cattle carcass. (The different components appear in the bars in the same order as in the list.)

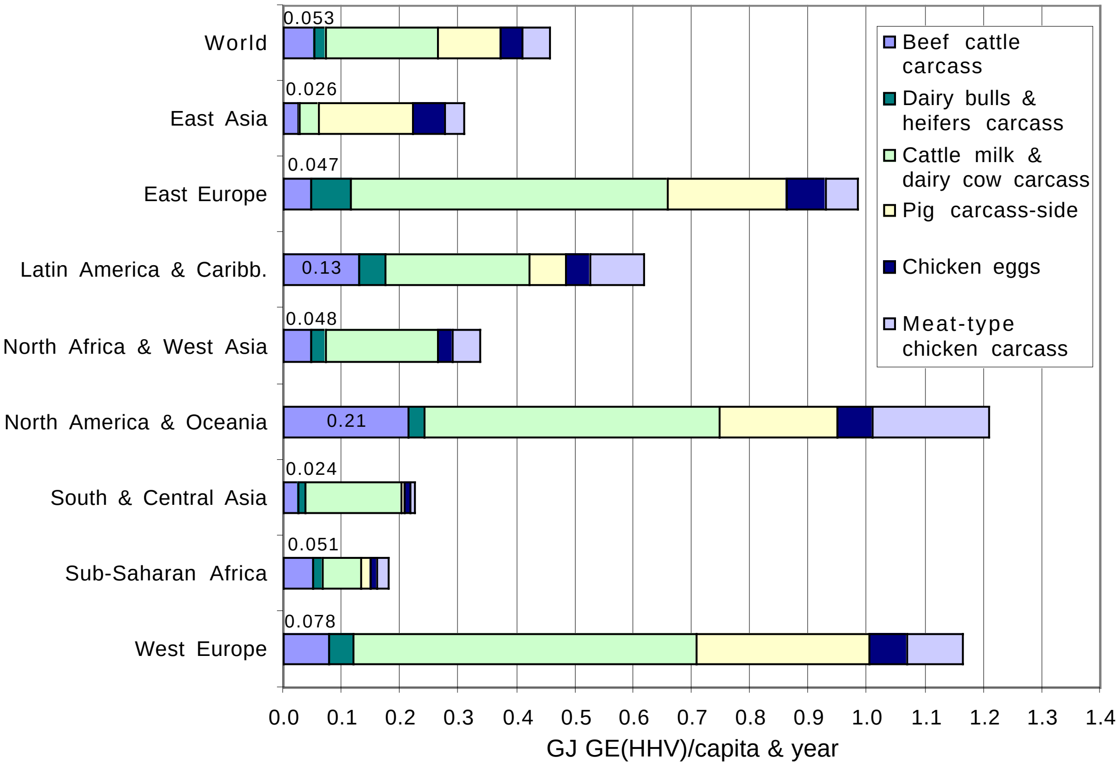

**Figure 3.46** Food intake related to separate animal food sub-systems. Numbers shown refer to beef cattle carcass. (The different components appear in the bars in the same order as in the list.)

inherent characteristics in terms of animal food use per capita, and productivity and efficiency of the animal food systems, and therefore all figures below are *trade-neutral* values. As a general rule, we present efficiency not only in terms of overall efficiency but also feed conversion efficiency, since this is the most essential step from an efficiency point of view in the animal food production-chain. (For explanations of these two efficiency concepts, see pp. 114 sq.)

Figure 3.45 and Figure 3.46 illustrate the regional per-capita values of phytomass appropriation and food intake, respectively, for the separate animal sub-systems. These figures are analogous to Figure 3.16 and Figure 3.17 above (explaining comments are given in connection to these figures (p. 120)).

*Ruminant carcass.* As we could see in the preceding section, the ruminant carcass systems require much more phytomass in relation to the output in terms of food than do other animal sub-systems. Therefore, these systems dominate the phytomass appropriation in most regions despite the relatively low consumption level of ruminant carcass commodities. This is further illustrated by the relations (for *beef cattle carcass*) shown in Figure 3.47.

However, in some regions, as East Europe and West Europe, the phytomass appropriation for ruminant carcass is relatively low. This is due to a modest consumption level combined with a relatively high efficiency. Figure 3.48 shows the conversion efficiency and overall efficiency for the beef cattle carcass systems in each

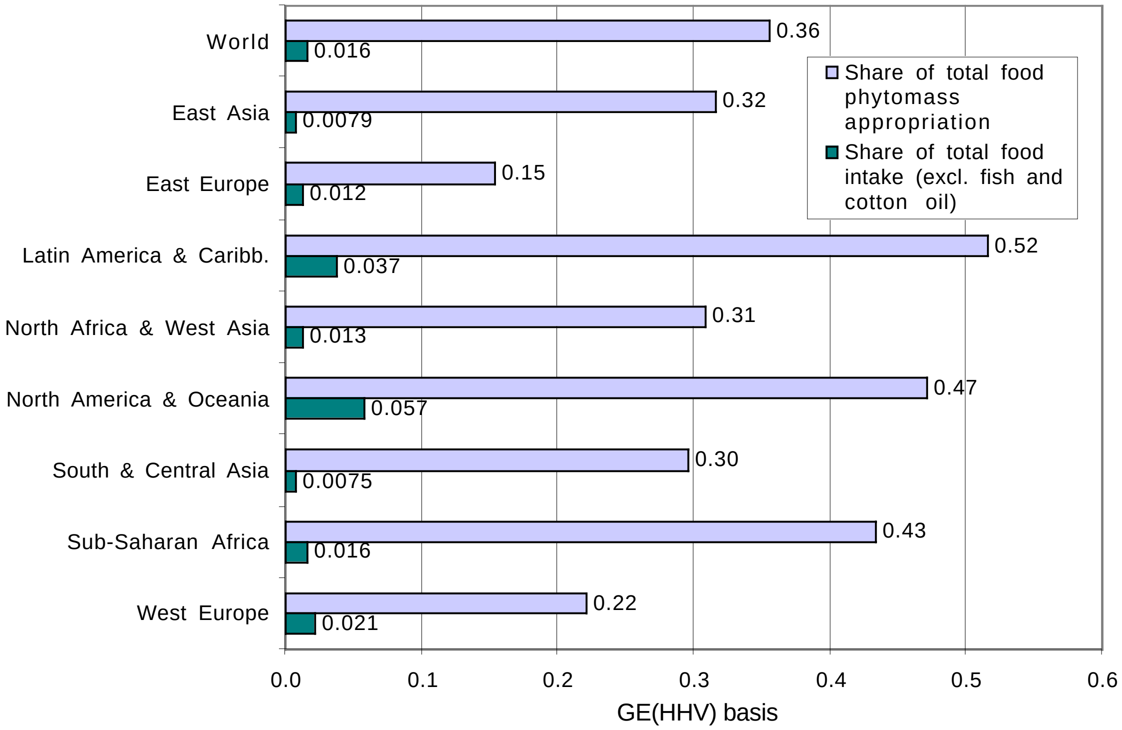

**Figure 3.47** Share of total food-driven terrestrial phytomass appropriation for beef cattle carcass, and share of total food intake for beef cattle carcass.

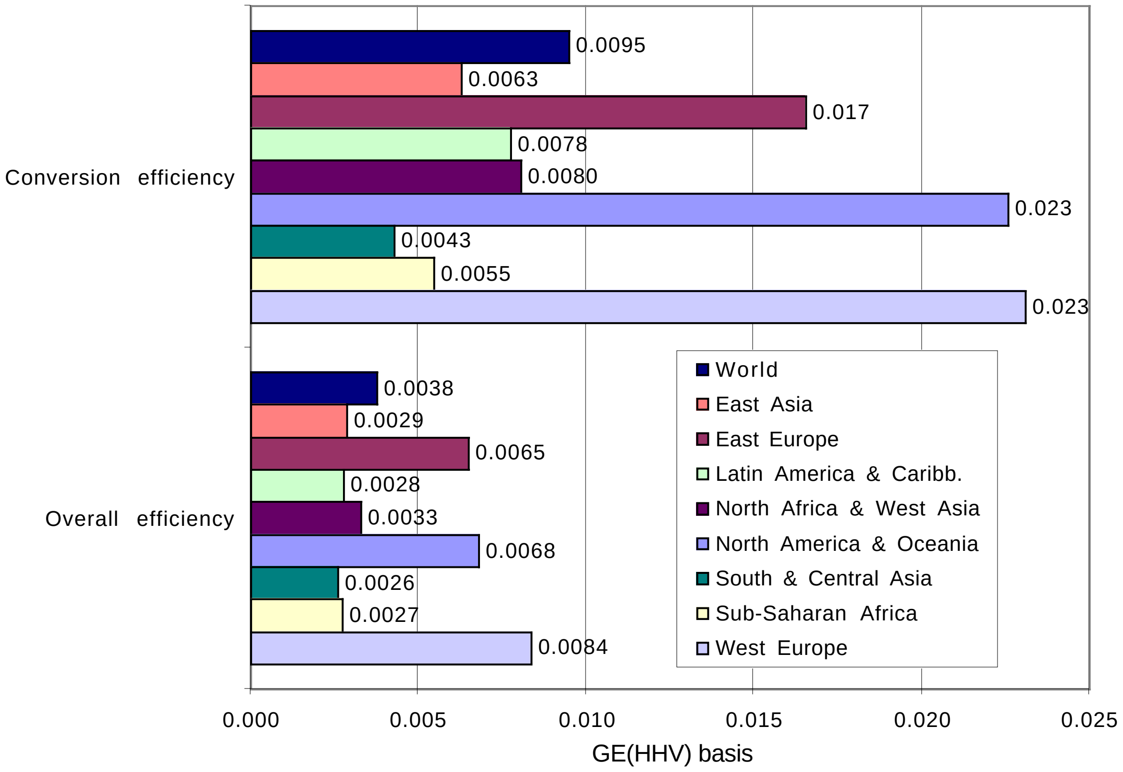

**Figure 3.48** Conversion efficiency and overall efficiency for the beef cattle carcass sub-system. Trade-neutral values. (The different components appear in the bars in the same order as in the list.)

region. West Europe and North America & Oceania have the highest efficiencies followed by East Europe, whereas South & Central Asia and Sub-Saharan Africa have the lowest. On an overall-efficiency basis, the efficiency gap between industrial and non-industrial regions tends to be smaller. This is mainly due to two reasons. Firstly, losses at end-use are smaller in the non-industrial regions, and secondly, use of by-products as feed is more extensive in the non-industrial regions. These both factors partly offset the lower conversion efficiency.

Since differences in feed conversion efficiency partly depend on the quality of the feed, we also show the corresponding values on phytomass appropriation and feed intake per food intake for the beef cattle carcass system (Figure 3.49 and Figure 3.50). (These concepts were explained in connection with Figure 3.35, pp. 153 sq.) As one might expect, the regions with high feed conversion efficiency appropriate more cropland-related phytomass per output than the regions with low conversion efficiency. On the other hand, the regions with low conversion efficiency appropriate vast amounts of permanent pasture per food output. One region, South & Central Asia, diverges from this pattern. This is due to the relatively high share of forage in the feed mix as presented above (see Figure 3.31, p. 141), but, as was already pointed out there, the data basis for this assumption is not very solid. (Comments on the significance of the feed use estimates are given in the section ‘Feed use’, pp. 191 sq.)

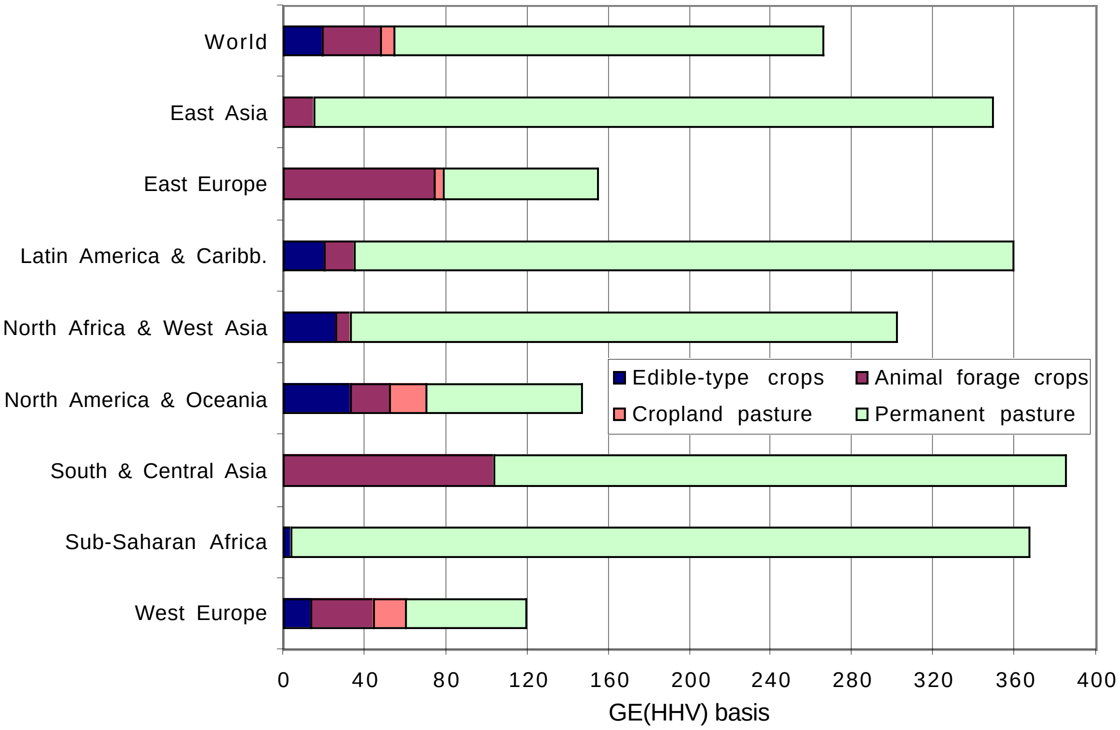

**Figure 3.49** Appropriation of phytomass per food intake for the beef cattle carcass sub-system. Trade-neutral values. (The different components appear in the bars in the same order as in the list.)

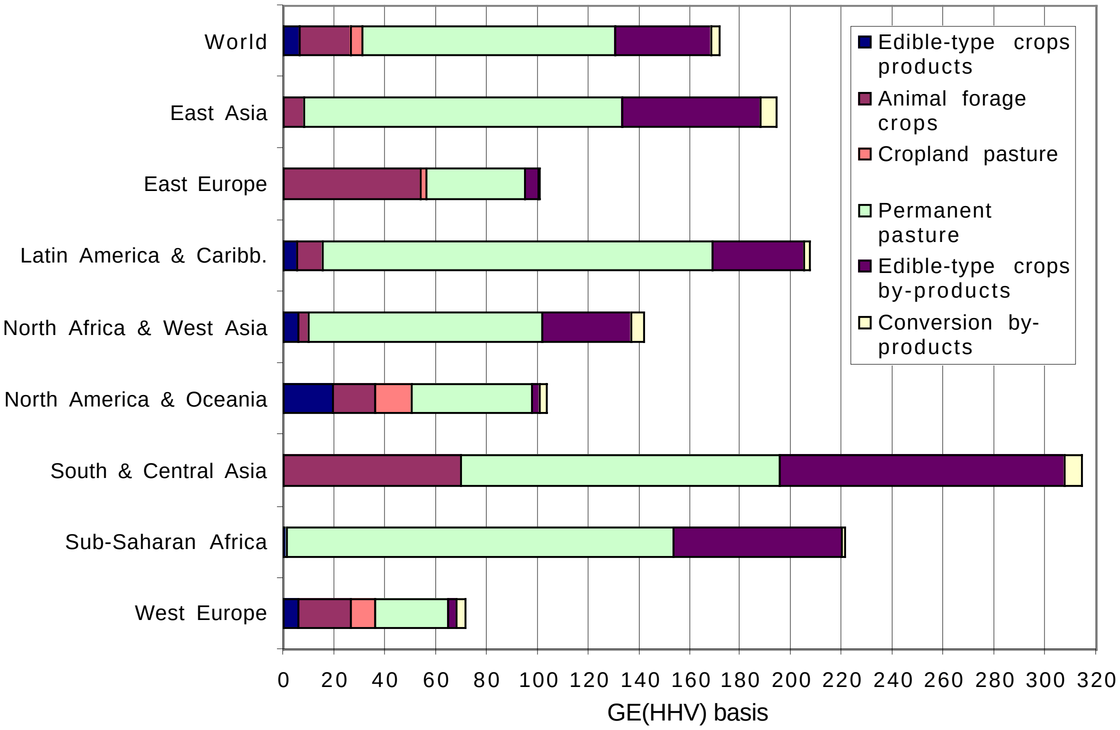

**Figure 3.50** Feed use (actual intake) per food intake for the beef cattle carcass sub-system. Trade-neutral values. (The different components appear in the bars in the same order as in the list.)

One aspect illustrated in Figure 3.50 is the relative importance of by-products to mitigate the requirement of phytomass per product output. Despite an extensive use of crop by-products in some regions, particularly South & Central Asia and Sub-Saharan Africa, this can not more than partly help to offset the relatively low conversion efficiency and, thus, the high phytomass requirement per product output. (Which is what also is reflected in Figure 3.49.)

Above we have given some results for the beef cattle carcass system. The efficiency level for the other ruminant carcass sub-system included in this study, ‘dairy bulls & heifers carcass’, is generally higher, as we could see in Section 3.2.1 (see, for instance, Figure 3.22, p. 123). However, the pattern in the regional differences is very similar to the beef cattle carcass system, and therefore we have chosen not to present any details specifically for the dairy bulls & heifers carcass sub-system.

*Milk.* Milk commodities represent the single largest fraction of the animal food consumption in all regions except East Asia (Figure 3.46, p. 161). Therefore, despite a relatively high average efficiency (compare Figure 3.36 and Figure 3.37, p. 155), the milk sub-system accounts for a relatively large share of the phytomass appropriation in these regions (Figure 3.45, p. 161).

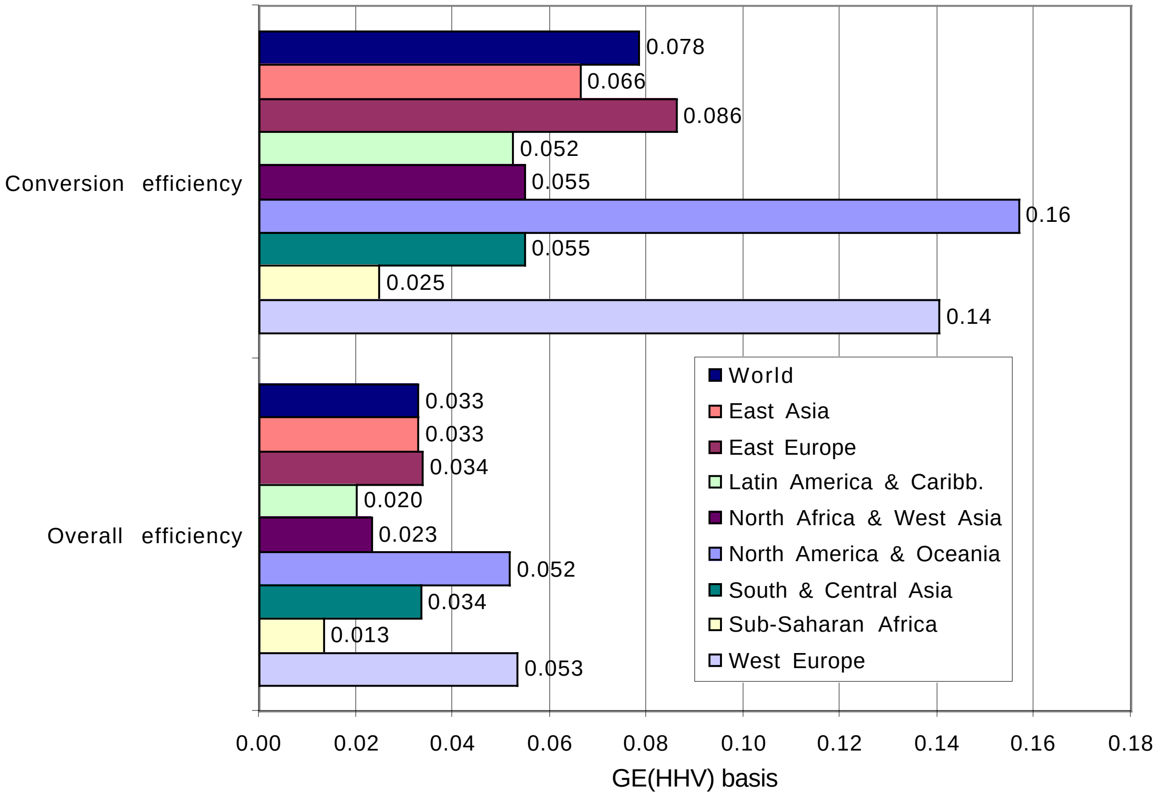

**Figure 3.51** Conversion efficiency and overall efficiency for the cattle milk & dairy cow carcass sub-system. Trade-neutral values. (The different components appear in the bars in the same order as in the list.)

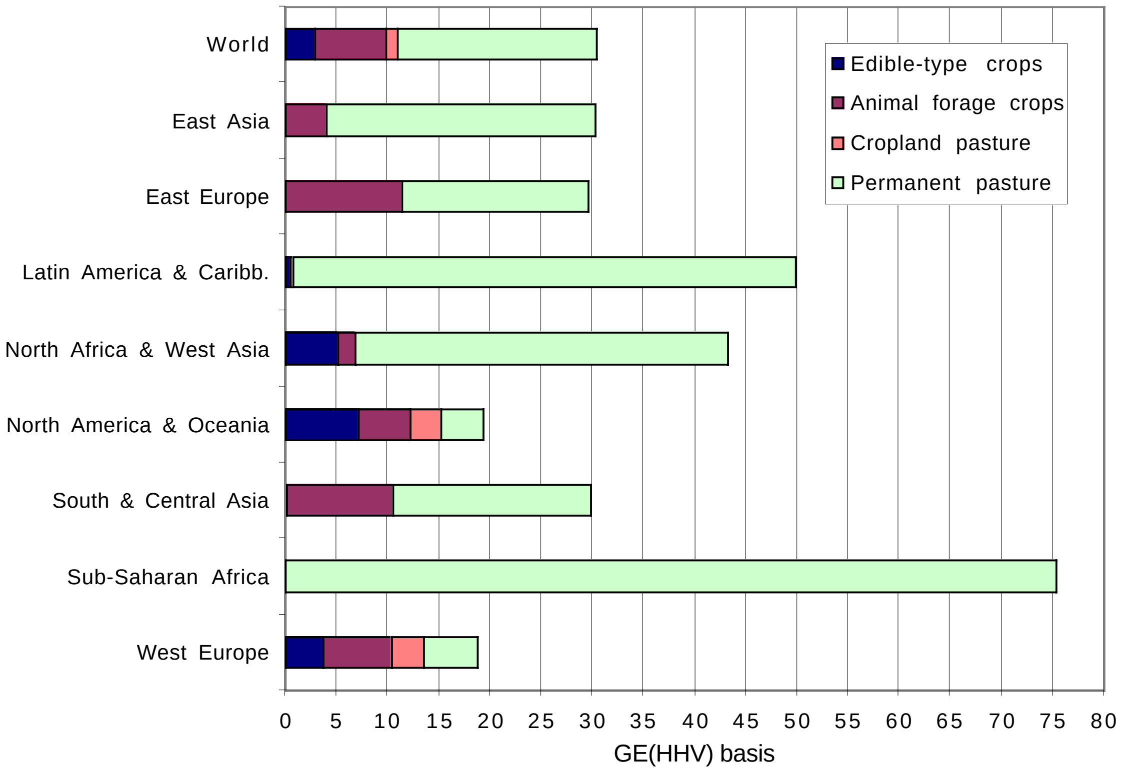

**Figure 3.52** Appropriation of phytomass per food intake for the cattle milk & dairy cow carcass sub-system. Trade-neutral values. (The different components appear in the bars in the same order as in the list.)

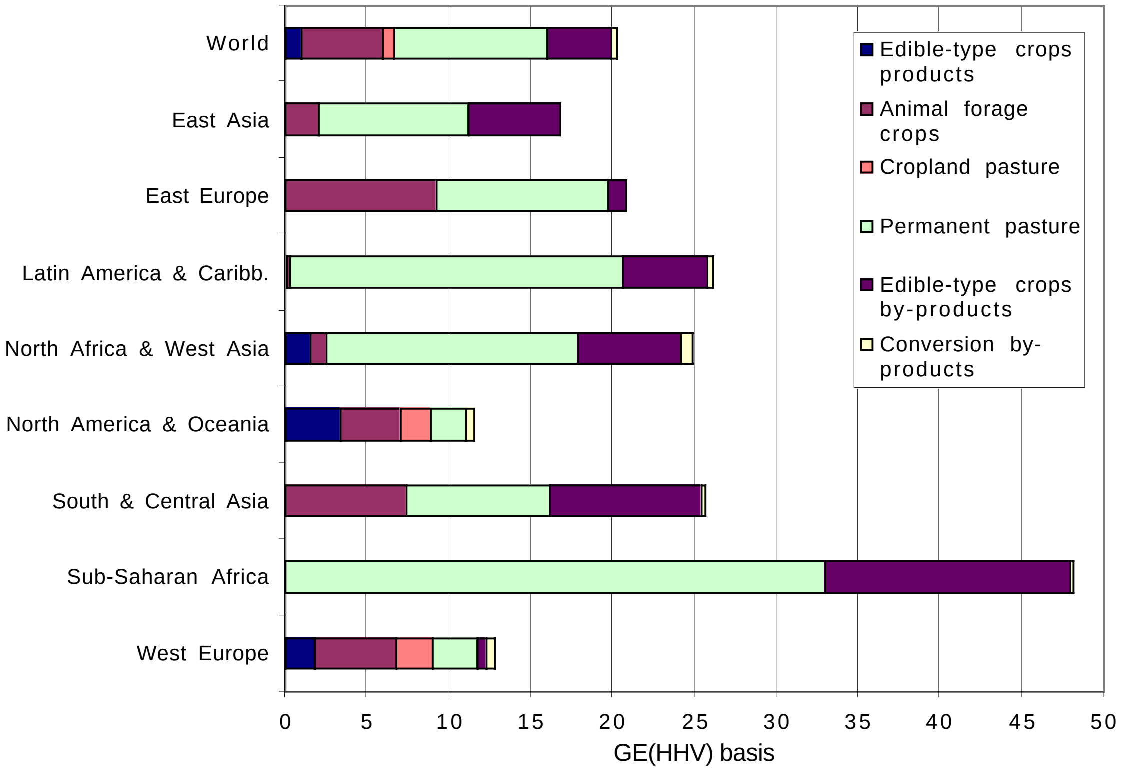

**Figure 3.53** Feed use (actual intake) per food intake for the cattle milk & dairy cow carcass sub-system. Trade-neutral values. (The different components appear in the bars in the same order as in the list.)

The regional pattern in efficiency and phytomass appropriation and feed use per output is similar to that of the beef cattle carcass system, although the efficiency gap between industrial and non-industrial regions is somewhat smaller (see Figures 3.51 to 3.53 above). Another difference is the extremely low conversion efficiency in Sub-Saharan Africa which gives an overall efficiency considerably below all other regions, including the other non-industrial regions. Notable is also the conversion efficiency for South & Central Asia, which is relatively high compared to the general performance of ruminant systems in that region. This efficiency, together with a considerable fraction of crop by-products (see Figure 3.53) and a relatively high end-use efficiency, gives the highest overall efficiency among the non-industrial regions. (Together with East Asia which, however, has a very small milk sector.)

Analogous to the beef cattle carcass system, the regions with high feed conversion efficiency appropriate more cropland-related phytomass per output than the regions with low conversion efficiency. However, the regional differences in this respect tend to be somewhat smaller. South & Central Asia, again, is an exception with its relatively high share of animal forage crops (compare the comments regarding the beef cattle carcass system above).

*Pig carcass.* The regional variations in per-capita consumption of pig commodities are larger than for any other of the major animal food commodities. In East Asia, pig commodities accounts for about half of the intake of animal food, whereas in North

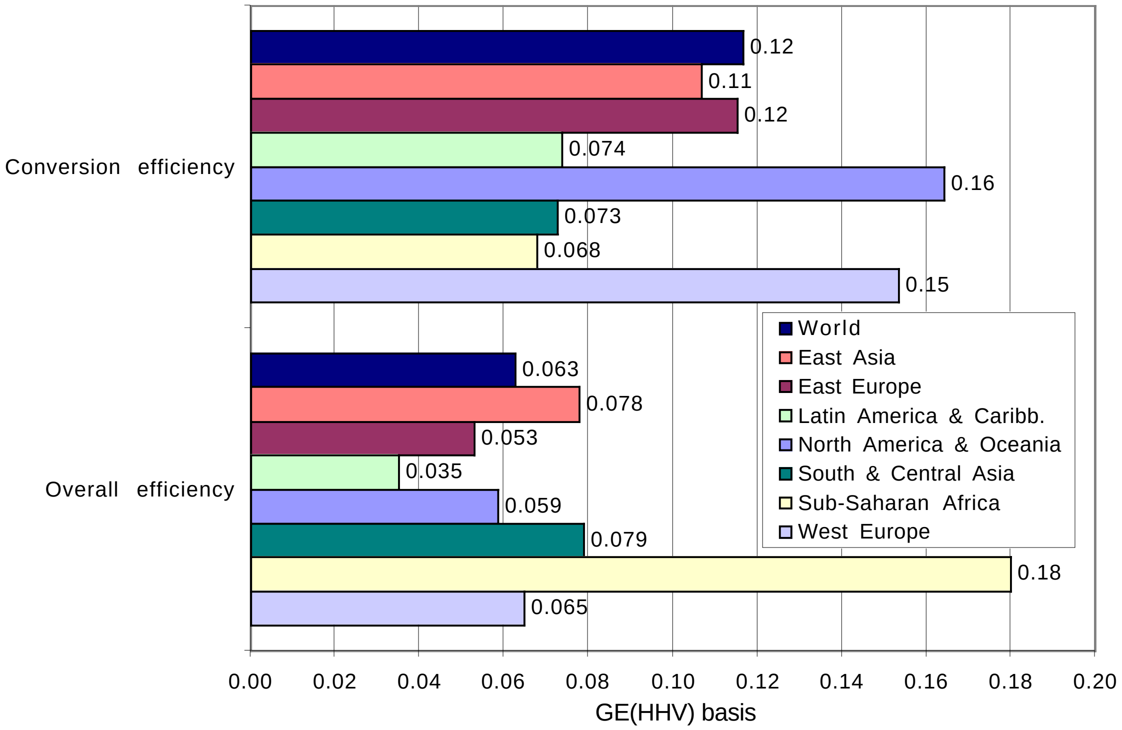

**Figure 3.54** Conversion efficiency and overall efficiency for the pig carcass-side sub-system. Trade-neutral values. (The different components appear in the bars in the same order as in the list.)

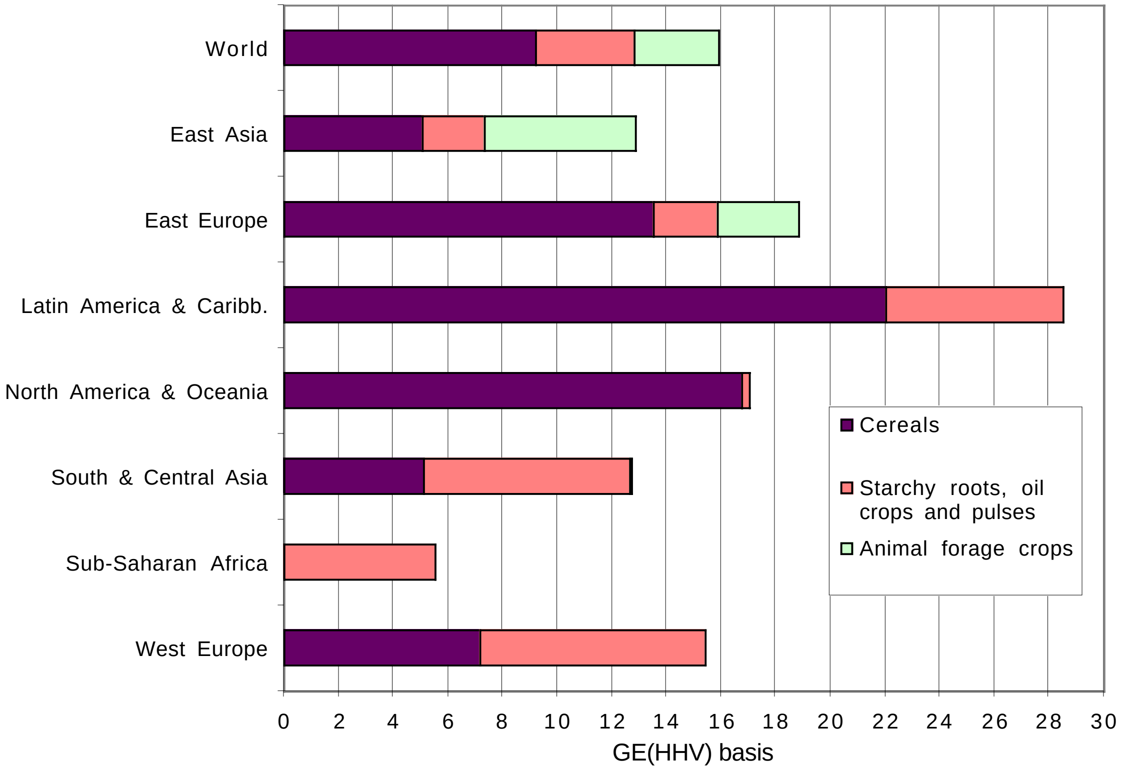

**Figure 3.55** Appropriation of phytomass per food intake for the pig carcass-side sub-system. Trade-neutral values. (The different components appear in the bars in the same order as in the list.)

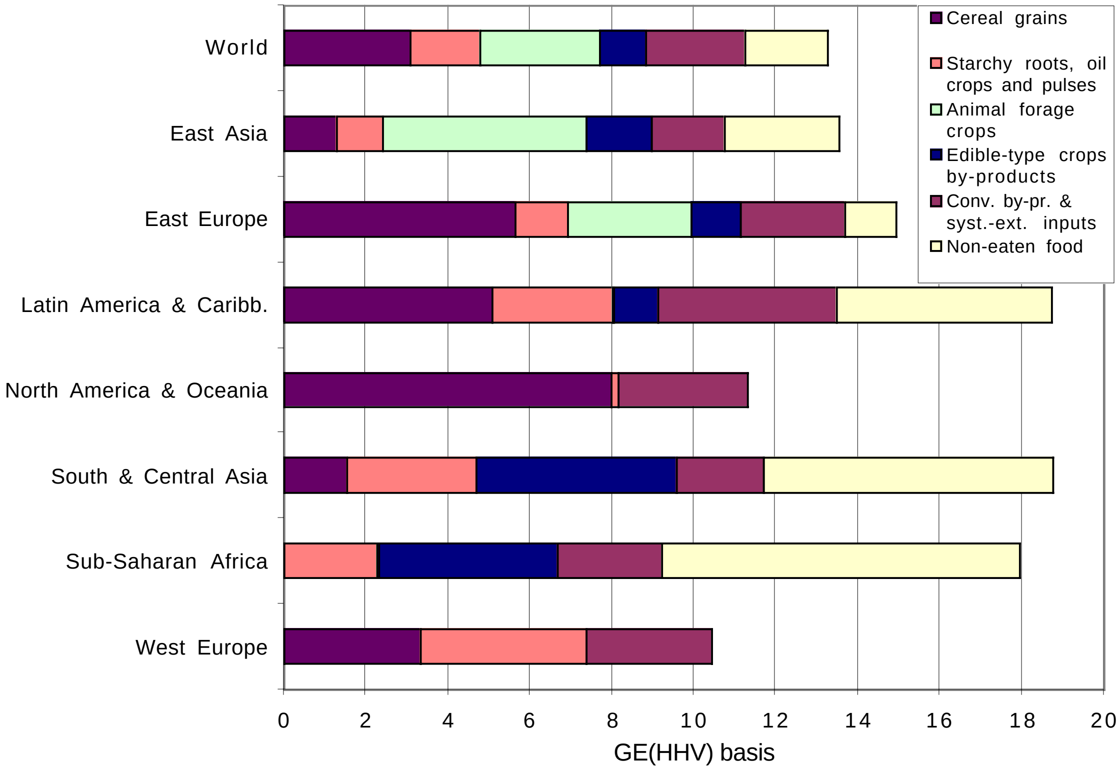

**Figure 3.56** Feed use (actual intake) per food intake for the pig carcass-side sub-system. Trade-neutral values. (The different components appear in the bars in the same order as in the list.)

Africa & West Asia pig consumption is practically non-existent (due to Islam-based attitudes towards pig meat).

In comparison with the ruminant systems, the regional differences in efficiency are generally much smaller for the pig system (see Figures 3.54 to 3.56 above). In terms of feed conversion efficiency, the level in the industrial regions is clearly higher than in the non-industrial regions. However, on an overall-efficiency basis there is no such pattern. In fact, the regions with the lowest conversion efficiency, South & Central Asia and Sub-Saharan Africa, surpass all other regions in terms of overall efficiency, Sub-Saharan Africa having the notably high value of 18 percent.

The principal reason behind this is the most substantial occurrence of by-products and residues in the feed mixes in the non-industrial regions (Figure 3.32 above, p. 142). As can be seen in Figure 3.56, this use of by-products and residues implies that the requirement of phytomass products is lessened to levels well below those of the industrial regions. We can also see that for the extreme cases South & Central Asia and Sub-Saharan Africa, non-eaten food accounts for the largest part of this mitigating effect. As we pointed out above, however, for the feed use of non-eaten food we had relatively few data to rely on. Therefore, the relatively high overall efficiency values for South & Central Asia, and in particular for Sub-Saharan Africa, must be regarded with caution. (Comments on the feed use estimate for non-eaten food are given in the section ‘Feed use’, pp. 204 sq.)

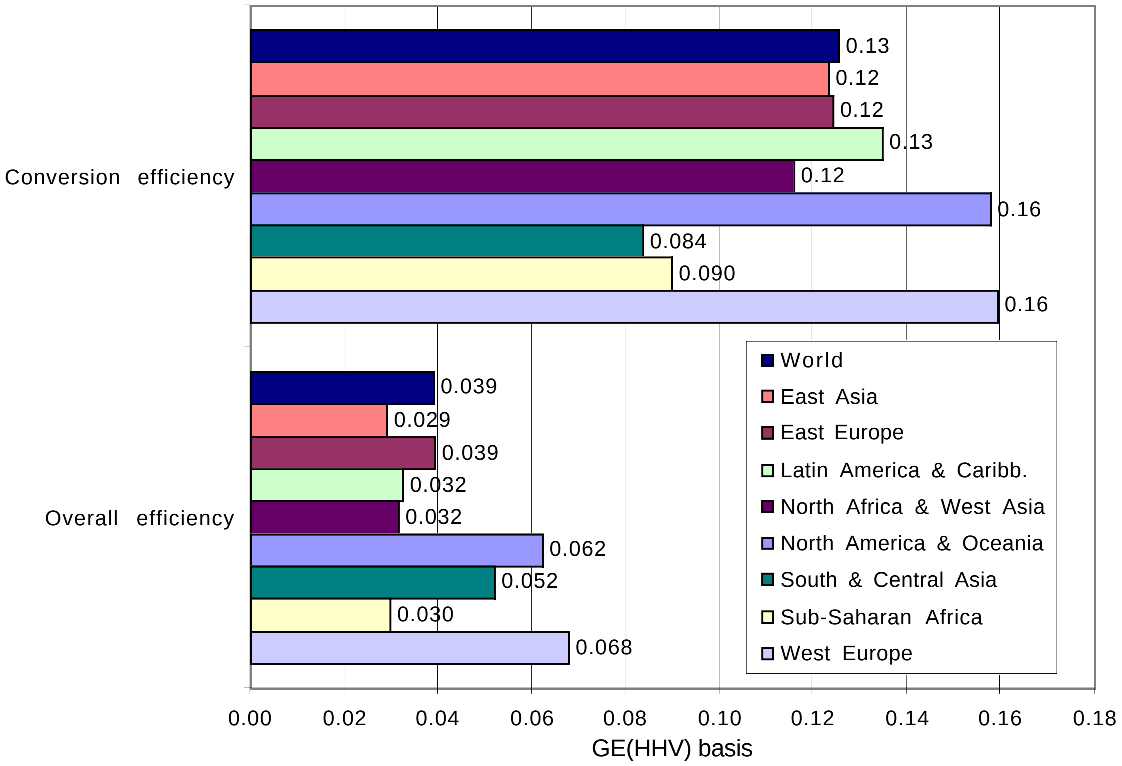

**Figure 3.57** Conversion efficiency and overall efficiency for the chicken egg sub-system. Trade-neutral values. (The different components appear in the bars in the same order as in the list.)

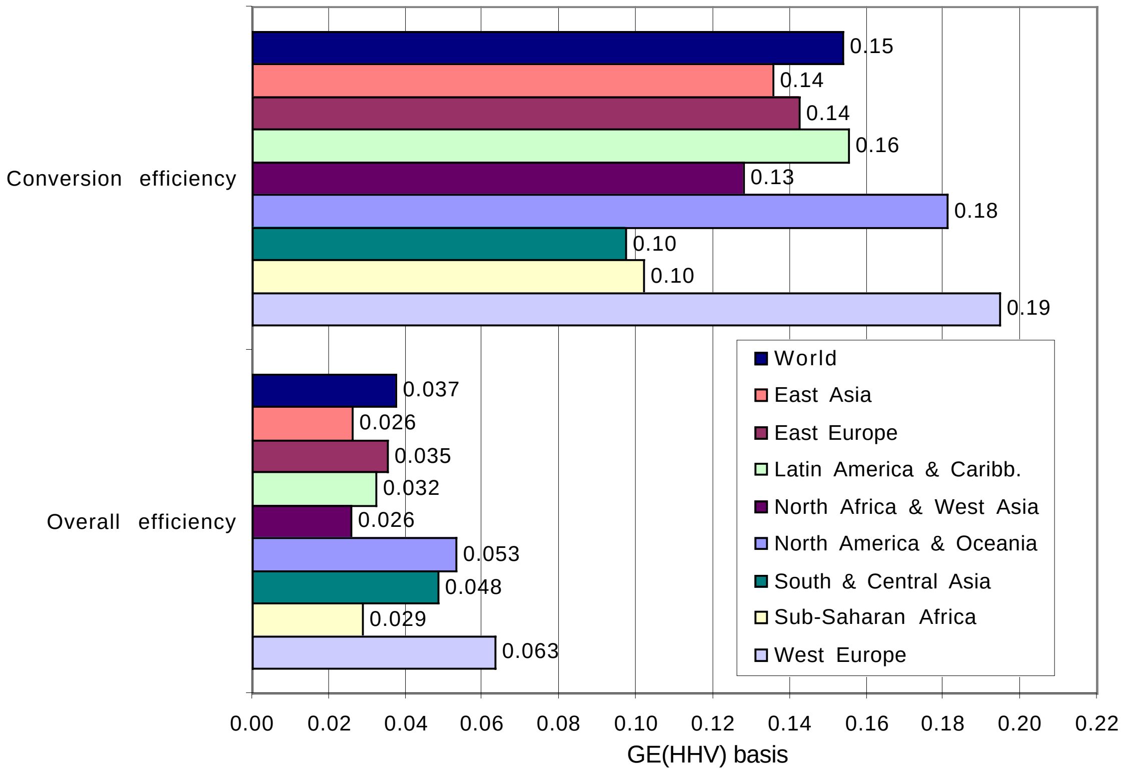

**Figure 3.58** Conversion efficiency and overall efficiency for the meat-type chicken carcass sub-system. Trade-neutral values. (The different components appear in the bars in the same order as in the list.)

*Poultry*. The poultry systems exhibit smaller regional differences in efficiency than do other animal sub-systems included in this study (see Figure 3.57 and Figure 3.58 above). The feed conversion efficiency is higher in the industrial regions than in the non-industrial, but the difference is rather small, except for South & Central Asia and Sub-Saharan Africa which lag behind. This pattern is similar also on an overall-efficiency basis, with the exception, however, of South & Central Asia. The main reason is an extensive occurrence of conversion by-products in the feed mixes in this region.

Generation of manure and methane

In the two previous sections, we have put emphasis on the resource-use side of the animal food production. In this section we will present some data regarding the waste side (or by-products side) of the production systems. The intention is to give a picture of the differences regarding the amount of waste generated for the separate animal sub-systems.

*Manure*

Figure 3.59 below gives an overview of the total amount of manure (including used litter) generated globally. Note that the numbers refer to the amount *generated* and not to the amount *distributed*, which is, naturally, lower. The total amount generated, for the entire animal food sector, is some 47 EJ GE per year globally, which corresponds to about 3.1 Pg DM in dry weight terms. Of this amount, 43 EJ is feces and urine, whereas the rest consists of used litter, that is, material that has been used for animal bedding and thereby has been mixed with the feces and urine.

As we can see from Figure 3.59, the beef cattle carcass sub-system dominates the production of manure, accounting for about 55 percent of the global total. In relation to the food output, the beef cattle carcass systems generate much more manure than other animal systems (Figure 3.60 below). These general differences between the separate animal sub-systems explain a great part of the regional differences in average generation of manure per food output as shown in Figure 3.61. It should be noted that for Figure 3.60 and Figure 3.61, values refer to per food product *generated* and not per food *intake*. This means that the numbers are somewhat biased in favor of the carcass systems compared to the other systems (this was already further explained in connection with Figure 3.43, p. 159).

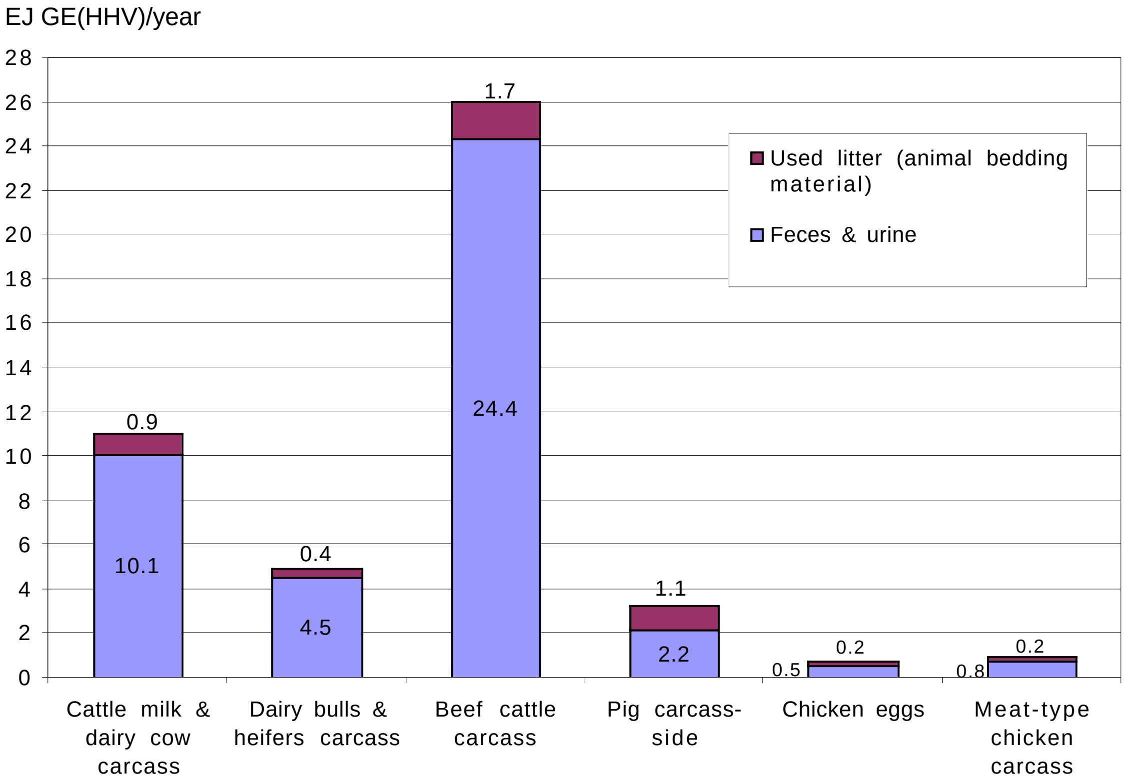

**Figure 3.59** Total generation of manure (feces & urine and used litter) from animal food sub-systems. World totals. Numbers at top of column refer to the amount of used litter.

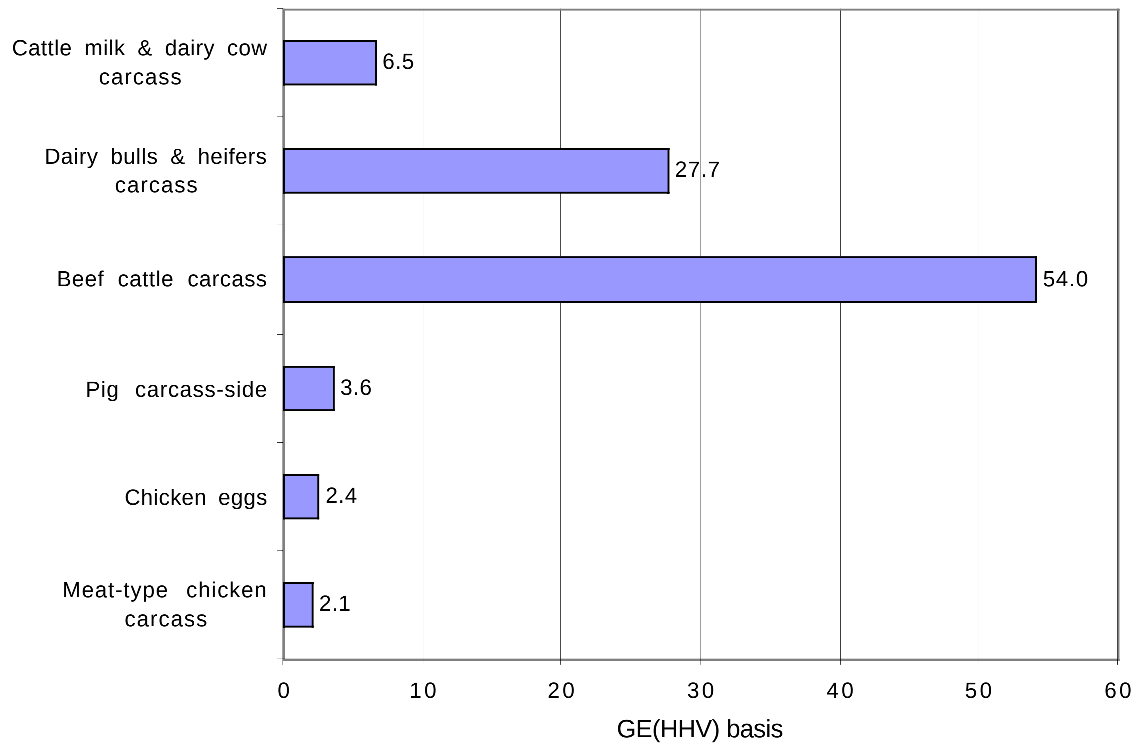

**Figure 3.60** Generation of manure (used litter included) per generation of food products for separate animal sub-systems (see text for explanations). World averages.

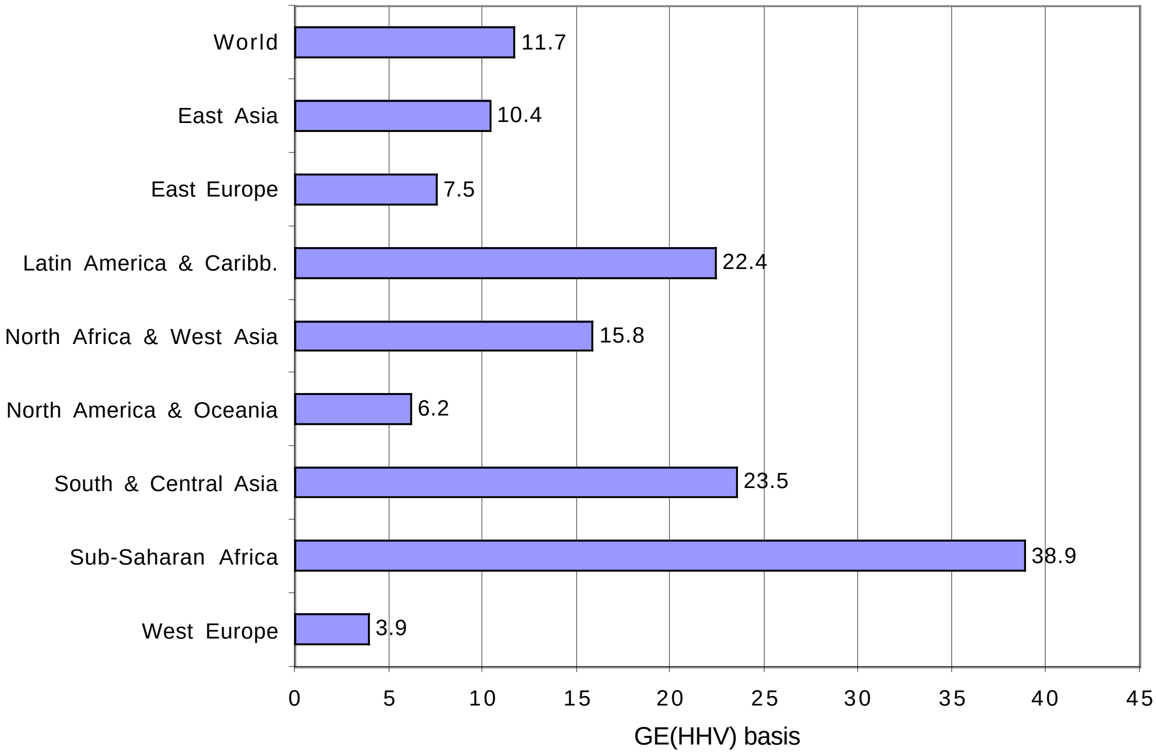

**Figure 3.61** Generation of manure (used litter included) per generation of food products for the total animal food sector (average for all animal sub-systems). Actual values.

*Methane*

Methane from enteric fermentation is another significant waste flow. Figure 3.62 shows the generation of methane of this origin on a per-capita basis. Note that the numbers are *actual values*, that is, they refer to the methane emissions generated from the actual production of animal commodities within the region. In the case of net-export of commodities, this means that methane emissions induced by the net-export also is included. Inversely, in the case of net-import, this means that the per-capita emissions are lower than if the end-use of animal commodities were to be met by production *within the region alone* — that is, the 'trade-neutral' emissions, if using the terminology in this study (this concept was defined in connection with Figure 3.8, p. 112). A per-capita comparison of the 'trade-neutral' emissions would be more adequate. In the current model construction, however, those emissions were not possible to separate from the total emissions.

The global methane emissions originating from enteric fermentation related to the food production amount to 5.3 EJ GE(HHV) per year, or approximately 96 Tg if expressed in weight. The main part of this is related to the ruminant carcass production. Generally speaking, the beef cattle carcass systems generate far more enteric methane per food output than do the cattle milk systems (Figure 3.63 below). However, the regional variation is very large: beef cattle in South & Central Asia generate roughly six times more methane per food unit produced than in North America & Oceania and West Europe. (Note that values here refer to per food product *generated* as opposed to per food *intake* — see explanations in association with Figure 3.43, p. 159.)

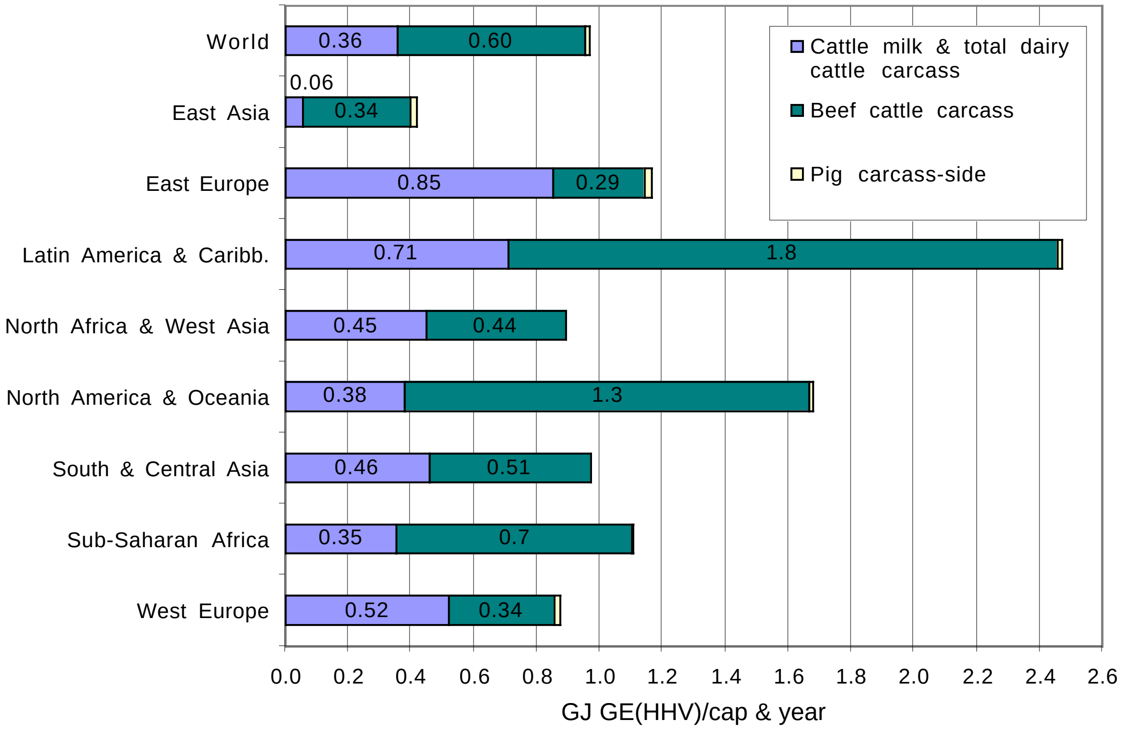

**Figure 3.62** Generation of methane from enteric fermentation per capita. Actual values. (The different components appear in the bars in the same order as in the list.)

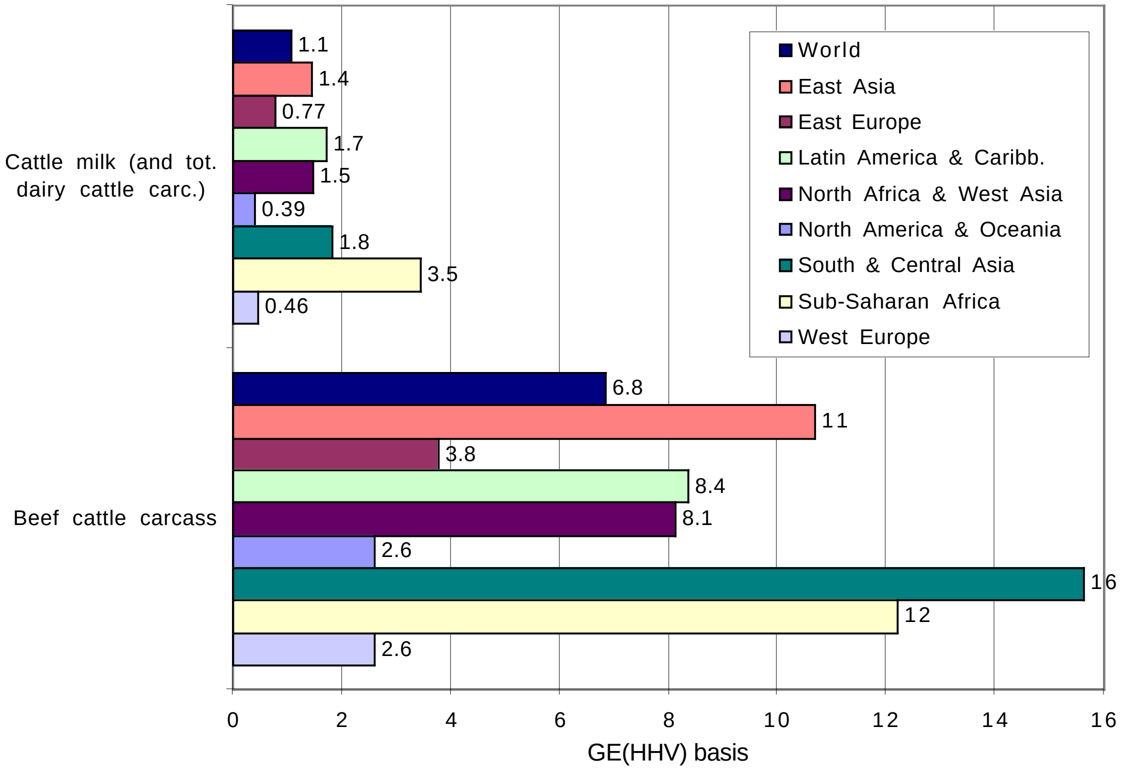

**Figure 3.63** Generation of methane from enteric fermentation per generation of food products for separate animal sub-systems and regions. Actual values. (The different components appear in the bars in the same order as in the list.)

### 3.2.3 By-products and residues

In the preceding sections, we have essentially presented results related to specific *parts* of the system. In this section we present data from an other division of the system, namely along the flows of by-products and residues.

<u>General picture</u>

Figure 3.64 below gives an overview of the amount of by-products and residues generated globally. The global total is roughly 125 EJ GE per year, which corresponds to about 7.7 Pg DM in dry weight terms. Evidently, manure, and cereals straw and stover, and other crop by-products dominate the generation of by-products and residues, making up nearly 83 percent of the total amount. The category ‘vegetable conversion by-products’ is dominated by cereals milling by-products — these make up nearly half of the amount. Of the category ‘other edible-type crops by-products’, oil crops by-products (such as oil cakes) account for the main part. The category ‘other animal conversion by-products’ consists principally of carcass fifth quarters, but also of dairy cattle carcass and leghorn-type chicken carcass, which formally are by-products in the FPD model.

The above-given numbers refer to the *generation* step in the system. What is the further course of the by-products and residues through the system, after having been produced?

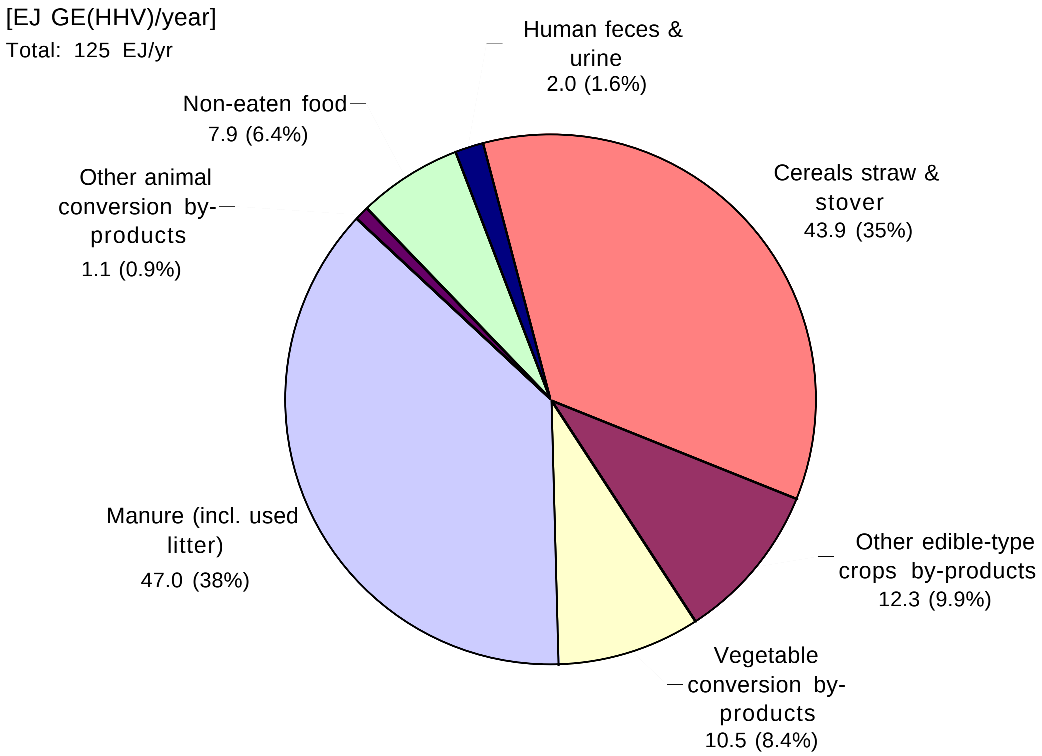

**Figure 3.64** Generation of by-products and residues of phytomass origin in the food system (excluding heat and methane). World totals.

Figure 3.65 below shows the further 'fates' of the by-products and residues after their generation. The concept 'fate' is here used in the same sense as in Figure 3.9 above (p. 114). As mentioned there, the different fates are to a great extent a consequence of the system-boundaries of the FPD model. Of course, with a different focus of interest than in this study, a different division might be more adequate. The relevance of the FPD model's system boundaries for the by-products and residues, as well as the estimates of the magnitudes of the different fates, is further discussed in the section 'Food-system-internal uses and fates in relation to other systems' (p. 224).

Looking at the sum of all by-products and residues (the topmost bar), we can see that a large part, 37 percent, is 'not recovered' from where it is produced, that is, not made available for further use within or outside the system (for definition of ' recovery', see Section 2.1.6, p. 19). However, a large part of this amount, nearly three quarters, consists of manure, for which, as can be seen in Figure 3.65, the share 'not recovered' is very high, nearly 73 percent of the amount generated. This number is, however, not a significant result since the underlying assumption in this study was that there is no recovery of manure from pastures. In the real system, collection of manure from pastures does occur. Therefore, the magnitude presented here of the amount as well as of the share of 'not recovered' is an overestimate to some extent (see further the section 'Food-system-internal uses and fates in relation to other systems', p. 224).

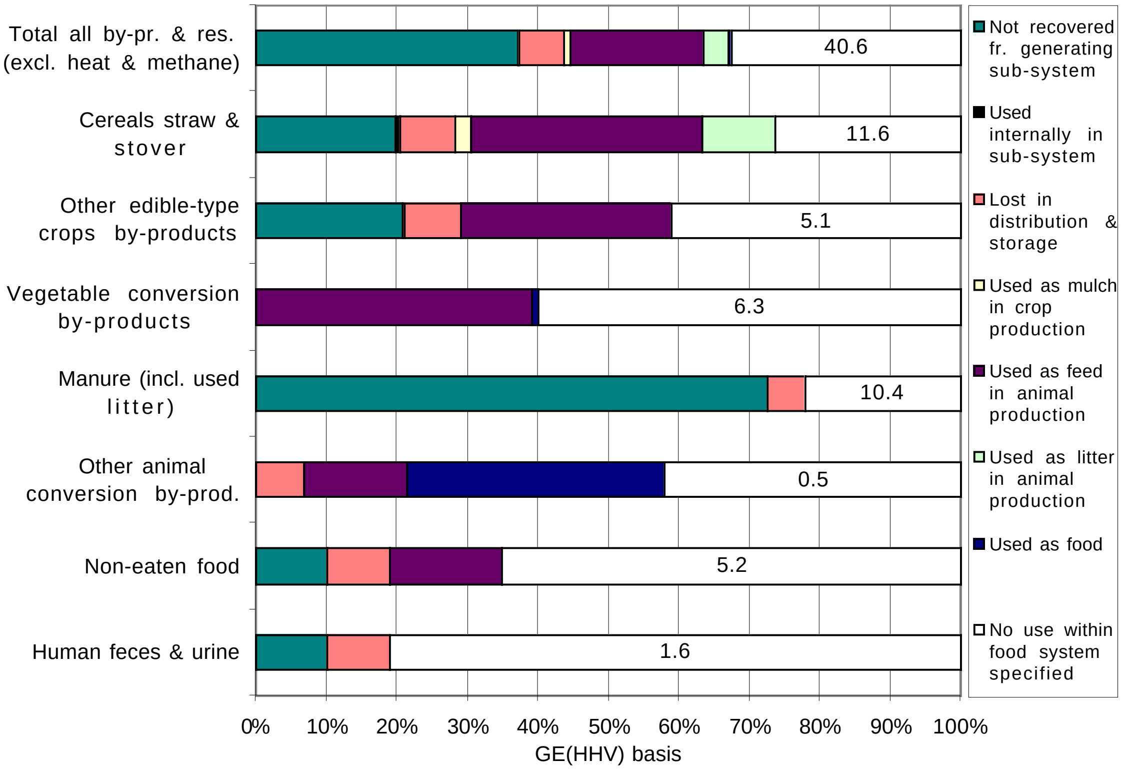

**Figure 3.65** Fates of generated by-products and residues (excluding heat and methane). World values. Numbers refer to amount by-products and residues (in EJ GE(HHV)) for which no use within food system was specified. (The different components appear in the bars in the same order as in the list.)

We can also note that substantial amounts of by-products and residues — 41 EJ GE per year, corresponding to 33 percent of total amount generated — are not used or tied-up within the food system (the category 'no use within the food system specified'). Hence, this amount can be considered as a surplus of by-products and residues from the food system which, to varying extent, is usable in other systems. As was touched upon already in Section 3.1.6 (p. 100), in the real system, use in other systems of by-products originating from the food system do occur, particularly as fuel and building materials.

The by far largest internal use of by-products and residues is the use as feed, amounting to totally 24 EJ GE per year, which is nearly 20 percent of the total amount generated. Vegetable conversion by-products has the highest *degree* of use as feed, nearly 40 percent of the amount generated, whereas the category cereals straw & stover accounts for the largest *amount*, about 14 EJ GE per year, which is some 33 percent of the amount generated. Further details on the use of by-products and residues as feed can be found in Table 3.23 (p. 144) and Table 3.24 (p. 148).

### Regional differences

Figure 3.66 gives an overview of the regional patterns, showing the averages for the sum of *all* by-products and residues. Figure 3.67 shows the regional differences in fates

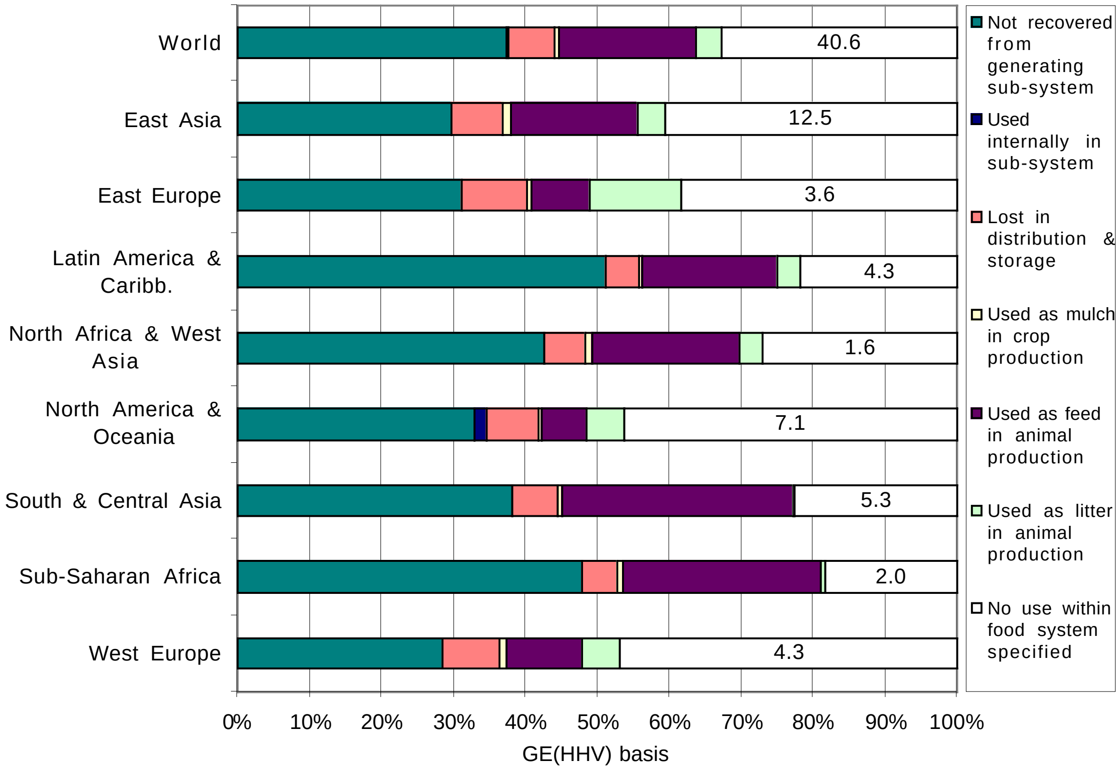

**Figure 3.66** Fates of generated by-products and residues. This figure refers to all by-products and residues (excluding heat and methane). Numbers refer to the amounts of by-products and residues (in EJ GE(HHV)) for which no use within food system was specified.

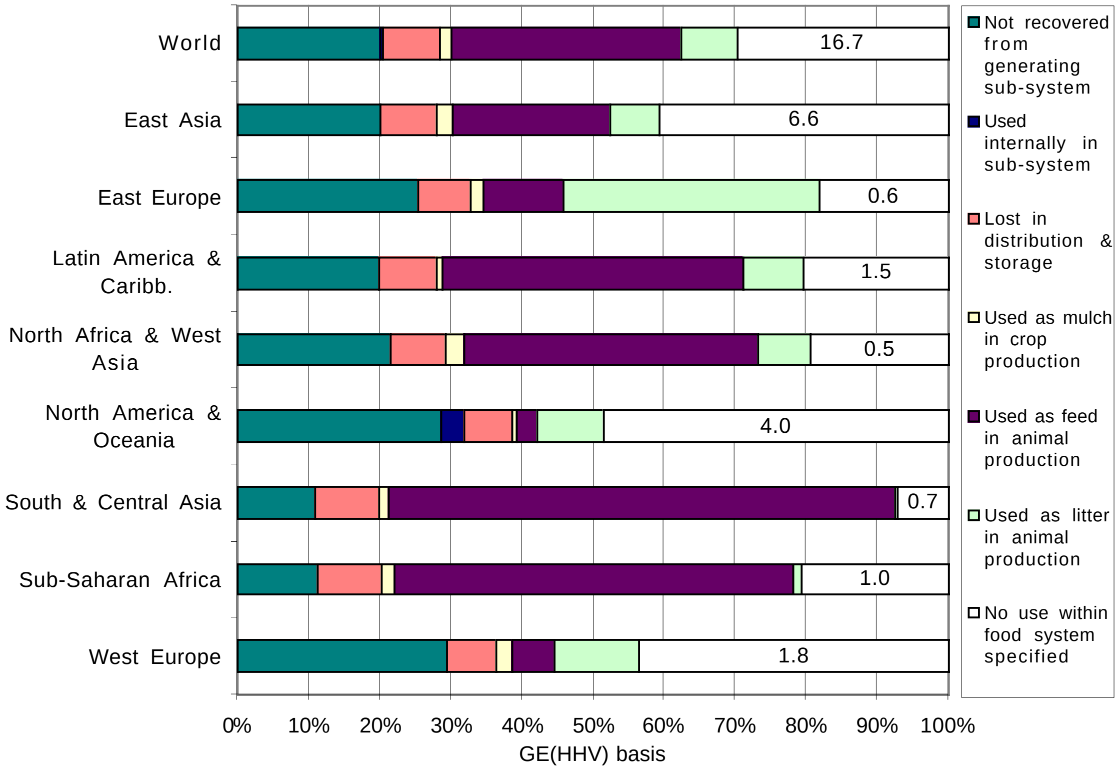

**Figure 3.67** Fates of generated edible-type crops by-products. Numbers refers to the amounts of by-products and residues (in EJ GE(HHV)) for which no use within food system was specified. (The different components appear in the bars in the same order as in the list.)

for all *crop by-products*. This category is of particular interest due to its large magnitude compared to other by-products and residues, combined with a relatively extensive use within the food system. Use as food is not included in these figures since this category is insignificant in these contexts.

The differences in the shares of by-products and residues *not recovered* as shown in Figure 3.66 are to a large extent dependent on the recovery rate for manure. The regions with a high share not recovered in Figure 3.66, such as Latin America & Caribbean, have a relatively large production of manure which is not recovered. This is due to a large cattle sector with grazing as predominant feeding system. However, as we mentioned above, the zero-value in this study on recovery of manure from pastures is very likely to be a substantial underestimate, at least in some regions (see further the section ‘Food-system-internal uses and fates in relation to other systems’, p. 224).

The largest regional variations pertain to the share *used as feed*, which ranges from 5 to 10 percent in the industrial regions to, at the most, around 30 percent in the non-industrial regions. The main reason behind this variation is, quite obviously, the variation in the use of *crop by-products* as feed. The share of crop by-products used as feed is very large in all non-industrial regions — except in East Asia owing to a relatively small cattle sector in this region — whereas in the industrial regions it amounts to no more than a few percent. The shares are extremely high in Sub-Saharan Africa and, especially, in South & Central Asia. However, these high shares may be overestimates — at least in South & Central Asia — in particular if one takes into account other substantial uses outside the food system. The issue of level of use of crop by-products as feed is further dealt with in the discussion section (see, particularly, the section ‘Food-system-internal uses and fates in relation to other systems’, p. 224).

Contrary to the regional pattern for the use of by-products as feed, *use for animal bedding* is larger in the industrial regions than in the non-industrial regions. Use for animal bedding is, as we can see in Figure 3.67, the largest internal use of crop by-products in the industrial regions, around 10 percent of the amount generated. We want to point out already here that the high share used for animal bedding in East Europe may not be significant, neither the zero-value for South & Central Asia. This is further discussed in the section ‘Phytomass appropriation’ (p. 215).

From Figure 3.66 we can also note that, in general, the share of by-products and residues *not specified* is somewhat larger in the industrial regions than in the non-industrial ones. This is principally an effect of the large use of crop by-products as feed in the non-industrial regions, as well as a lower manure recovery rate in these regions. How this amount ‘not specified’ may be interpreted is dealt with in the section ‘Food-system-internal uses and fates in relation to other systems’ (p. 224).

## 3.3 DISCUSSION AND CONCLUSION

The main purpose of this section is to discuss possible conclusions regarding the characteristics of the biomass metabolism of the food system, taking into consideration the accuracy and significance of the methods, data and results in this study. This part also includes comparisons with other studies.

The first section includes discussion and conclusion regarding the actual core of the work in this study. The second section deals with land use related to the phytomass appropriation of the food system.

### 3.3.1 The characteristics of the biomass metabolism of the food system

The intention of this section is to give a coherent picture of the certainties and uncertainties in the study; to point out and to structure its strengths and weaknesses. Due to the interdependent nature of the food system with substantial internal use of by-products and residues, there is no evident order for the presentation of such a picture. In addition, the step-by-step character of the estimate of the biomass flows in this study entails a tendency for individual errors to propagate through the flow estimates.

The order of the presentation below was chosen in regard to this. Animal sub-systems have the largest influence on the flows of the system why we begin with those. First, however, some comments on the quality of the FAOSTAT data used in this study.

#### Impact of revisions and accuracy of FAOSTAT data

As was mentioned in Section 3.1 (p. 57), the 1996 release of FAOSTAT, which we used in this study, was severely incomplete, since data for the former USSR were missing to a large extent. The full implications of this on the significance of the results in this study are not possible to estimate — nothing less than a complete remaking of the calculations using a latter release of FAOSTAT would do.

Having made some brief comparisons with the latest release of FAOSTAT, we believe that the differences for use of *cereals as feed* are among those with the largest implications. According to the FAOSTAT Food Balance Sheet (FBS) data in the 1996 release, global use of cereals as feed was about 530 Tg (as-is) in 1992-94 (year-average), whereas according to the *current* FBS data[136] the corresponding figure for this time period is about 640 Tg. Also the FBS data on total production of cereals have been revised upwards, from 1650 to 1770 Tg — thus, more or less equal to the increased figure for feed use. In all essentials, these differences are on account of the missing data for the former USSR in the 1996 release. By making comparisons on a country basis, we esti-

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[136] Excerpted October 15, 1999, from the FAOSTAT on-line database at http://apps.fao.org.

mate that the values for use of cereals as feed should be *increased* by at least 82 Tg (as-is) for the region East Europe in this study (from the 46 Tg value in the 1996 release), and by 9 Tg (as-is) for the region South & Central Asia (from 7.7 Tg in the 1996 release).[137]

Due to the structure of the model and the matching with FAOSTAT, we believe that the impacts on other parts of the system are not likely to be as severe as the case apparently is with cereals. However, bearing in mind the relatively large size of the former USSR of the region East Europe in this study, and the fact that the region underwent considerable social and economic changes during the chosen time period for this study, we find it advisable to assume a rather skeptical attitude toward the FAOSTAT data, as well as the results in this study, for the region East Europe in general.

Except for animal feed use, the impacts of the FAOSTAT revisions are not discussed further below. If not otherwise stated, all mentions of and references to FAOSTAT data below refer to the 1996 release.

Besides the erroneous data for East Europe and South & Central Asia, there were certainly other inaccuracies in the FAOSTAT data used in this study (see footnote 82, p. 57). However, it was beyond the scope of this study to estimate systematically the extent of such inaccuracies, or their possible influence on the results. In the text below, reference is made to possible errors in FAOSTAT only occasionally.

### Animal food systems productivity, feed use and phytomass appropriation

The animal food systems are those that dominate the phytomass appropriation of the food system. Due to the relatively large complexity as regarding the factors that determine phytomass appropriation, this section is divided into three sub-sections. The first one deals with the estimates of *specific feed energy requirements*, the second one with the estimates of *feed use*, and the last one with the resulting *phytomass appropriation* of the animal food systems.

#### *Productivity and specific feed energy requirements*

As described in Section 3.1.2 (p. 66), productivity and specific feed energy requirements for the animal sub-systems were estimated in the compilation of model input data. The specific feed energy requirements, that is, the feed energy requirements per commodity unit produced were expressed in a *feed-equivalent* conversion efficiency (Figure 3.1 and Figure 3.2, p. 75). Differences in productivity and specific feed energy requirements are, of course, also reflected in the *actual* conversion efficiency, that is, the conversion efficiency given the feed mix of the system (see, for example, Figure 3.22, p. 123).

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[137] The figure for East Europe is the sum for Russia, Ukraine, and Belarus; and the figure for South & Central Asia is the sum for Kazakhstan, Uzbekistan, Kyrgyzistan and Turkmenistan.

As far as the general differences between the animal sub-systems are concerned, the figures produced in this study are not very remarkable. It is established knowledge that ruminant systems are less productive than pig and poultry systems. It is also known that ruminant systems are less efficient in a feed energy perspective.

Among the reasons behind these differences, the most fundamental ones concern biological parameters such as reproduction rate and growth rate. Generally speaking, ruminants have much lower reproduction rate (that is, offspring produced per female parent and time unit) than pigs and poultry, which means that a larger amount of feed energy is tied up by the reproducing animal relative to the growing (or milk/egg-producing) animal. Put differently, ruminant systems have a larger 'base load' of feed energy turn-over required just for maintaining the system.

Analogously, the relative growth rate (that is, the liveweight gain rate relative to animal liveweight) is lower for ruminants compared to pigs and poultry. This means that a larger portion of the metabolizable feed energy is used for maintenance of the animal instead of liveweight gain.

For ruminant systems, these differences imply that a larger fraction of the feed consumed is transformed to non-wanted flows, such as heat and manure, and a smaller fraction to zoomass, which is shown in Figure 3.68. This figure also illustrates differences in digestive system, showing that methane produced in enteric fermentation represents a significant feed energy loss for ruminant systems. (Note that the values in Figure 3.68 refer to actual feed intake as calculated in this study. Thus, it does not give a feed-neutral illustration of the differences.)

As regards differences between regions, a striking feature for *cattle* systems is the considerably lower values on productivity and corresponding feed-equivalent efficiency in non-industrial regions as compared to industrial countries (see Table 3.10, p. 74)

There are a number of reasons to these differences, but lack of feeds of adequate quality and poorer genetic characteristics are among the most important ones. Another major factor lies in the traditional systems that still predominate in the non-industrial production. Equally important are functions as draft power, dung production and capital storage.[138] Hence, cattle are not fed to maximize growth and economic return of production. In South & Central Asia, the low productivity is in part also a result of Hindu-based attitudes towards cattle.[139]

Thus, there are several different aspects determining the management of the ruminant systems. Low efficiency in terms of feed energy conversion does not necessarily imply that the system is ineffective if considered in a socioeconomic context. The issue of

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[138] [Jarrige & Auriol 1992, Qureshi 1992]

[139] In most states of India, cattle meat consumption is prohibited or severely restricted [Jarrige & Auriol 1992].

relevant concepts of efficiency is further discussed in the section 'Efficiency and specific biomass use' (p. 231) below.

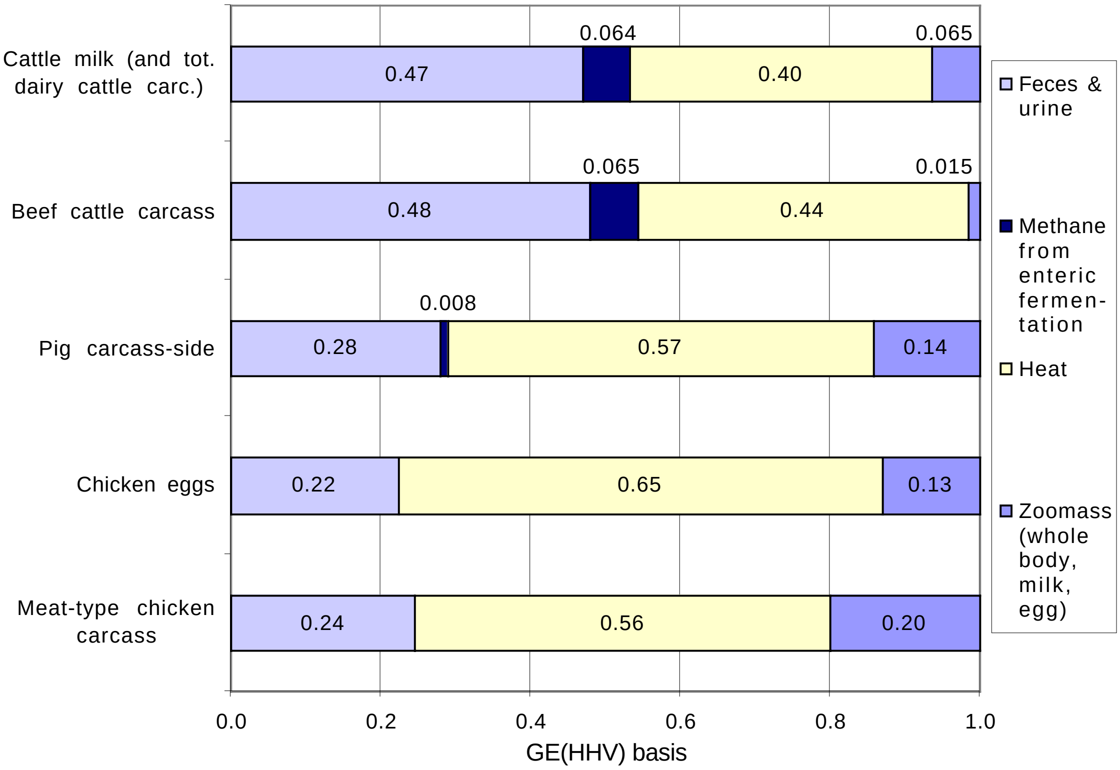

**Figure 3.68** Fates of gross energy intake in feed for separate animal sub-systems. World averages in this study. (The different components appear in the bars in the same order as in the list.)

For *pig* and *poultry* systems, the regional pattern is similar, although the relative differences between the regions are smaller than for cattle (Table 3.10). Both pig and poultry are given feeds of relatively higher quality than cattle. In addition, pig as well as poultry rearing are to a larger extent directed specifically towards production of food than is cattle rearing.

This were some brief explanatory comments on the animal food systems productivity and specific feed energy requirements estimated in this study. In the following we will discuss their reliability. The main questions here are: What is the accuracy of the methods and data used for the estimates? What is the significance of the estimates?

The following issues have been identified as the most critical ones:

- The accuracy of the model representation of the different ruminant systems
- The strength of the correlation between the parameter production-per-head and the calculated specific feed energy requirements for the animal sub-systems in the model

- The conformity between the production-per-head data in FAOSTAT and the corresponding production-per-head values in the model
- The accuracy of the assumed values on energy expenditures for grazing

*Accuracy of the model representation of the different ruminant systems*. The accuracy of the representation of the ruminants is of critical importance for the entire results of this study, due to the dominant position of the ruminants in the system (they account for 57 percent of total food phytomass appropriation). The real food system basically contains four different ruminant categories — cattle, buffalo, sheep and goats. In the FPD model, however, ruminant carcass and milk production are represented by only one of these: cattle. On a global basis, cattle systems account for about 81 percent of the ruminant carcass production and some 88 percent of the ruminant milk production, see Table 3.27. Thus, globally the cattle systems constitute a fairly large fraction of the total. However, in some regions cattle systems have a less dominant position. This applies particularly to the regions North Africa & West Asia and to South & Central Asia, where cattle accounts for no more than roughly half of the production. Still, a representation by cattle alone might give an accurate representation, given that the differences in productivity performance between the different ruminant systems are relatively small. However, there are indications that there may be quite large differences.

The strongest indication on these differences we find for the small ruminants, *sheep* and *goats*. In a study performed with a recent version of the integrated assessment model for climate change, IMAGE 2.2, sheep and goat carcass production are assumed to have lower feed conversion efficiency than cattle carcass production in nearly all regions.[140] In most regions, the difference in feed dry matter required per produced unit is a factor of two to three.

What significance would such a difference have for the results of this study? Let us assume that the specific feed requirements for sheep and goat carcass on average would be twice that of cattle. Using this figure for the 16 percent of ruminant carcass production which consists of sheep and goat, the increase in feed use would be roughly 9 to 10 EJ per year, or some 10 percent of the total amount of animal feed use in this study. The corresponding increase in phytomass appropriation would be around 15 to 20 EJ per year, or 7 to 10 percent of the entire food phytomass appropriation value in this study.

Due to these likely differences in productivity for sheep and goat carcass compared with beef cattle carcass, we find that in the regions with a relatively large share of sheep and goat carcass production, particularly North Africa & West Asia — but also South & Central Asia, East Asia and Sub-Saharan Africa — the significance of the estimated specific feed energy requirements for ruminant carcass is lower than in the other regions. We believe that it is likely that the specific feed energy requirements of the ruminant carcass systems are underestimated in these regions.

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[140] [Bouwman et al. in prep]

**Table 3.27** Productivity and relative magnitude of major ruminant systems. Year-average for 1992-1994. Compiled from FAOSTAT.

| | World | East Asia | East Europe | Latin America & Carib. | North Africa & W. Asia | North America & Oc. | South & Central Asia | Sub-Saharan Africa | West Europe |
|---|---|---|---|---|---|---|---|---|---|
| ***Carcass production*** | | | | | | | | | |
| **Cattle** | | | | | | | | | |
| Carcass production per head | 40 | 30 | 67 | 33 | 26 | 99 | 12 | 19 | 100 |
| Share of ruminant production | 81% | 65% | 90% | 97% | 47% | 94% | 44% | 74% | 89% |
| **Buffalo** | | | | | | | | | |
| Carcass production per head | 17 | 13 | - | - | 51 | - | 17 | - | - |
| Share of ruminant production | 3.8% | 8.7% | 0% | 0% | 7.5% | 0% | 25% | 0% | 0% |
| **Sheep** | | | | | | | | | |
| Carcass production per head | 6.4 | 6.6 | 7.1 | 3.2 | 7.0 | 5.4 | 6.1 | 3.6 | 10 |
| Share of ruminant production | 11% | 13% | 8.6% | 2.3% | 37% | 5.7% | 16% | 12% | 11% |
| **Goat** | | | | | | | | | |
| Carcass production per head | 5.0 | 6.9 | 5.9 | 3.4 | 4.7 | 5.2 | 5.0 | 3.9 | 5.1 |
| Share of ruminant production | 4.6% | 13% | 0.9% | 1.1% | 8.9% | 0.1% | 15% | 14% | 0.4% |
| **Cattle *and* buffalo**[a] | | | | | | | | | |
| Carcass production per head | 38 | 26 | - | - | 28 | - | 13 | - | - |
| Share of ruminant production | 84% | 74% | - | - | 52% | - | 69% | - | - |
| ***Milk production*** | | | | | | | | | |
| **Cattle** | | | | | | | | | |
| Milk production per head | 360 | 130 | 940 | 140 | 380 | 620 | 180 | 71 | 1140 |
| Share of ruminant production | 88% | 84% | 98% | 99% | 76% | 100% | 50% | 86% | 98% |
| **Buffalo** | | | | | | | | | |
| Milk production per head | 310 | 57 | - | - | 450 | - | 410 | - | - |
| Share of ruminant production | 8.7% | 11% | 0% | 0% | 7.6% | 0% | 44% | 0% | 0% |
| **Sheep** | | | | | | | | | |
| Milk production per head | 7.0 | 6.5 | 14 | - | 18 | - | 8.7 | 5.0 | 17 |
| Share of ruminant production | 1.5% | 3.8% | 1.3% | 0% | 11% | 0% | 0.9% | 5.0% | 1.3% |
| **Goat** | | | | | | | | | |
| Milk production per head | 16 | 3.2 | 80 | 9.9 | 28 | - | 42 | 8.4 | 150 |
| Share of ruminant production | 1.9% | 1.8% | 1.0% | 0.8% | 6.0% | 0% | 4.5% | 9.1% | 0.9% |
| **Cattle *and* buffalo**[a] | | | | | | | | | |
| Milk production per head | 350 | 110 | - | - | 380 | - | 240 | - | - |
| Share of ruminant production | 97% | 94% | - | - | 83% | - | 94% | - | - |

All values on annual basis. Production per head refers to production of carcass and milk (in kg as-is) per *total* number of animals-in-stock for each separate animal category. Share of ruminant production refers to share of total ruminant carcass and milk production respectively (as-is weight basis). Values are rounded to two significant digits.

[a] Refers to average for the cattle and buffalo considered as one system.

As for sheep and goat *milk*, no data were available for estimating possible inaccuracy for the current model representation. However, with regard to the limited extent of sheep and goat milk production, inaccuracies are likely to be small, except possibly in North Africa & West Asia and Sub-Saharan Africa.

As described in Section 3.1.2, the productivity of *buffalo* systems was accounted for by matching the production-per-head values of the model cattle systems against the *average* production-per-head data for cattle and buffalo in FAOSTAT. This was done for the regions East Asia and South & Central Asia. Buffalo systems are similar to cattle systems in terms of digestive system, liveweights, reproduction rates, growth rates and so on. Therefore, using the feed energy equations valid for cattle (Sections 2.3.2 and 2.3.3) *may* offer rather accurate estimates of the specific feed energy requirements of buffalo. At any rate, buffaloes make up a rather small fraction of the ruminant production, except in South & Central Asia, see Table 3.27. In total, we therefore believe that omission of separate representation of buffalo is unlikely to add considerable insignificance to the estimates of specific feed energy requirements for ruminants (with reservation for the region South & Central Asia).

Having pointed out cases where the significance of the specific feed energy requirements of the ruminant systems may be weak due to inadequate model representation, we want to emphasize that there are regions where the significance, with respect to ruminant representation, is likely to be rather high. This applies particularly to Latin America & Caribbean and North America & Oceania, where the ruminant sectors are entirely dominated by cattle, and also, but to a lesser extent, the regions East Europe and West Europe.

*Correlation between production-per-head and calculated specific feed energy requirements.* The strength of the correlation between the parameter production-per-head and the calculated specific feed energy requirements for each separate animal sub-system in the FPD model is essential for the significance of the results in this study. As described in Section 3.1.2, we used a number of different data sources for estimating the productivity of the animal sub-systems. But among the productivity data we used, the production-per-head data from FAOSTAT were the only data that in a strict sense had reference to the actual regions in this study. All other data were only related to individual countries, separate farms or were of the type “example-values” for regions or countries. Thus, the production-per-head parameter had a central position in the productivity estimate, and therefore it is essential to judge how strongly this parameter is correlated to the calculated specific feed energy requirements for each of the animal sub-systems in the FPD model.

Generally speaking, we believe that the correlation between production-per-head and specific feed energy requirements is relatively strong. This holds, however, only if the values on the base parameters (liveweight, reproduction rate, growth rate, etc) of the system are within due limits and, more importantly, that they are internally consistent. (The assumed values on these base parameters are given in Table 3.8, p. 69.) By internal consistency we mean that if, for instance, the calving rate in a beef system is assumed to be relatively low, also the growth rate of the calves in the system must be assumed to be relatively low. This is largely a matter of judgement, of course — the point is that the values of the different productivity parameters must go together reasonably well.

There are some parameters for which the correlation between production-per-head and specific feed energy requirements tends to be relatively weak. This applies particularly to liveweights for mature (non-growing) animals, mortality rates and carcass yields. Compared to other productivity parameters, changes in values of these tend to affect the values on the production-per-head and the specific feed energy requirements more unevenly.

The most critical one of these for the significance of the estimates of the specific feed energy requirements is the *mortality rate*. This parameter has a particularly large influence on the specific feed energy requirements in relation to its influence on the production-per-head value of the system. Furthermore, the data material we had available on mortality was relatively weak, especially for cattle. Since the cattle systems are very dominant in the food system, we were cautious with assuming high mortality values for cattle, and we essentially chose to assume values at the lower end. Just to give an indication of the orders of magnitude here, we can compare with the mortality rates assumed in the livestock productivity model produced in the FAO/IIASA Agro-Ecological Zones project.[141] The mortality for cattle cows in that model ranges from 3 to 6 percent, to be compared with the interval 1 to 2 percent (including all regions) in this study. For bulls & heifers younger than one year, the FAO/IIASA mortality ranges from 10 to 25 percent, whereas for older animals the values are around 5 to 10 percent. In this study, mortality for bulls & heifers range from 3 to 15 percent, all regions included. This means that the mortality rates in this study may be somewhat underestimated, especially concerning cattle.

The parameter category *liveweights*, we believe, is less critical for the significance of the specific feed energy requirements estimates. We had a relatively solid amount of data available on liveweights for the non-growing animals, that is, breeding and lactating cows, breeding sows, and breeding and egg-laying hens. In addition, our assumptions on liveweights for these animal categories were adjusted to the assumed rate of reproduction or milk/egg production of the animals: The higher rate of reproduction or production that was assumed for a particular animal category in a particular region, the higher was the liveweight assumed to be. This scheme tied the liveweight values to the productivity level of each particular system. By this, the risk for discriminatory values and inconsistencies between regional values could be kept relatively low.

Also for *carcass yields* there were a great deal of data available. Furthermore, the variation within an animal category in carcass yield is relatively small. Therefore, we do not find the values on carcass yields likely to be a critical issue for our estimates of the specific feed energy requirements, that is, they are unlikely to lower the significance of the estimates.

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[141] [Kassam et al. 1991]. The model refers to Kenya, but may be fairly representative for tropical livestock systems in general.

*Conformity between production-per-head data in FAOSTAT and corresponding production-per-head values in model.* Due to the central position of the matching of the production-per-head values, also the conformity between the production-per-head data in FAOSTAT and the (for each animal sub-system) corresponding production-per-head values in the FPD model is essential for the significance of the results. On the whole, we believe that the accordance is fairly good. Still, we see two possible sources of error which may contribute to lower the significance.

Firstly, there is the lack of specification and composition data of the commodities in FAOSTAT livestock production statistics (collection ‘Livestock Primary’). The composition of the product output from the animal systems is of interest here since the feed energy requirements of the systems are a function of the amount of gross energy deposited as liveweight gain, or milk or egg production. In the estimates of productivity and specific feed energy requirements, we reached accordance between the production-per-head data in FAOSTAT and the corresponding value in the model on an *as-is weight* basis. The issue here is to what extent that accordance holds also on a *gross energy* basis.

As stated in Section 3.1.2, we assumed different levels of quality of the animal composition in the different regions (Table 3.8, p. 69). These were mainly our own estimates, which we based on the productivity level and a judgement of the animal food sector performance in general in the region. For milk and egg, however, we used the same composition in all regions, since we had no data basis available for assuming different composition values.

*Milk* is probably the most critical case, where differences in composition actually may affect the significance of the estimates of specific feed energy requirements. In our estimates, milk is assumed to have a composition corresponding to a GE content of 3.1 MJ per kg (as-is), with a lipid content close to 4 percent (as-is) (For further composition values, see Appendix 1). In real systems, there is considerable variation in composition — we guess that lipid content may range from 3 to 5 percent. However, in most regions the milk productivity is relatively low, which means that the GE content of the milk constitutes a minor part of the energy requirements of the entire system. (For instance, at 1 000 kg milk per cow and year, GE of milk accounts for around 20 percent of the total energy requirements of the dairy cow & the replacement heifer.) Thus, it is mainly in the regions North America & Oceania and West Europe where deviations in milk composition may affect the significance. Examples of country-values on producer milk composition in those regions lie close to, or somewhat below, the assumed composition in this study.[142] For the *cattle carcass* systems, which are the most dominant animal systems, the energy requirements related to GE content of the carcass are relatively small, and possible deviations in composition are unlikely to lower the significance.

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[142] In the USDA nutrient database (available at www.nal.usda.gov/fnic), ‘producer milk’ has a composition corresponding to 3.0 MJ GE/kg as-is. About the same composition is reported for producer milk in Sweden [SLV 1997]. In Holland et al. [1991], GE content of ‘whole milk’ is about 3.1 MJ/kg as-is.

Secondly, the level of detail in FAOSTAT Livestock Primary does not correspond to the one in the FPD model. The FAOSTAT-PC version does not include data for dairy and beef cattle separately (besides dairy cow milk yield), nor for leghorn and meat-type poultry. For that reason, in the matching of production-per-head values, we had to match the model values with the FAOSTAT data for *total cattle* and *total poultry*, respectively.

For cattle we chose the approach to assume rather standardized relative differences in all regions between dairy and beef cattle (see footnote 91, p. 71). Generally speaking, these differences are relatively small. Therefore, we believe that the estimated specific feed energy requirements for *total cattle* does not lose much in significance due to this lack of detail in FAOSTAT.[143] However, it does affect the significance of specific feed energy requirements for each system considered *separately*. For example, it may be the case that the difference in specific feed energy requirements between beef cattle carcass and dairy bulls & heifers carcass is larger than in this study. On the contrary, for poultry the influence on significance is likely to be small. The reason for that is the relatively small overlap between the poultry sub-systems — only a small share of the output from the egg systems consists of poultry carcass.

*Accuracy of values on energy expenditures for grazing.* The assumed values on additional energy expenditures for grazing activity were based on relatively few data sources, and must be regarded as rather rough estimates (see p. 76). Therefore, we consider the significance of the estimates of the extra energy expenditures in themselves as rather low. However, additional energy expenditures due to grazing amount to no more than roughly 7-8 percent of the total energy requirement for the cattle systems (Table 3.25, p. 152). Thus, its effect on the significance for the total feed energy requirements of cattle should be minor.

### *End-use per capita and level of production*

The levels of feed use and phytomass appropriation of the animal food sector are, of course, directly influenced by the level of *production* of animal food *commodities*. Because of its critical importance for the estimate of feed use and phytomass appropriation, it is of interest to compare the values on production of animal food commodities in this study (that is, the values in the model calculation) with the corresponding ones in FAOSTAT. Such a comparison gives an indication of the accuracy of the model depic-

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[143] It may be noted that in the model calculation, the value on the *average* productivity for the beef and dairy cattle carcass sub-systems taken together — that is, considered as one system — may be significantly different compared with the corresponding value for cattle in FAOSTAT. This is because of the function of the sub-systems cattle milk and beef cattle carcass as representatives for the *entire* ruminant milk and ruminant carcass production, respectively, in each region. These representative functions means that, in the model calculation, the *relative* proportions in each region between production of *cattle carcass* and production of *cattle milk* may be significantly different from the proportions of these commodities as stated in FAOSTAT. This affects the *average value* in the model on carcass and milk production per head for the *total* carcass system, that is, for the beef and dairy cattle carcass sub-systems considered as *one* system.

tion of the end-use as well as the distribution chain (that is, distribution and storage losses, and trade).

The model value on the global production of *total carcass* is 198 Tg as-is per year, which is 3.1 percent higher than the corresponding value (that is the value on *total meat*) in the FAOSTAT data collection 'Livestock Primary'.[144] For *ruminant carcass*, the value in the model on global production is 69.1 Tg as-is per year (26 Tg for dairy cattle carcass and 43 Tg for beef cattle carcass), which is 6.6 percent higher than the corresponding value in Livestock Primary, that is, the value on total ruminant meat production.[145] For *pig carcass*, the model value on global production is 68.7 Tg as-is (counted as *carcass-side*), which is roughly 7 percent higher than the corresponding value in Livestock Primary.[146] For *poultry carcass*, the model value on total global production is 48.0 Tg (45 Tg for meat-type chicken carcass and 3 Tg for leghorn-type chicken carcass), which is almost equal to the corresponding value in Livestock Primary (0.4 percent higher than the value for 'poultry meat').

For the other animal commodities besides carcass, the pattern is the opposite. The value in the model global production of *milk* is 512 Tg (as-is weight) per year, which is 3.3 percent lower than the value in Livestock Primary. For *eggs*, the model value on global production is 42 Tg (as-is weight) per year, which is 0.5 percent lower than in Livestock Primary.

Another indication of the accuracy of the model calculation of the animal food production levels can be obtained by comparison of the *number of animals in stock*, that is, the number of living animals at a certain point of time. In the model calculation, the number of *cattle* in stock is about 1 890 million globally, which is 47 percent higher than the number of cattle in the FAOSTAT data collection 'Live Animals'.[147] However, in the FPD model, 'cattle' represents all ruminant systems and therefore, the *model* production levels for 'cattle' are much higher than those of the *real* cattle systems. Still, at the global level, it is possible that the *equivalent number* of cattle is overestimated with a few percent relative to the data in FAOSTAT. An indication of this is that the level of production of ruminant carcass, as mentioned above, is overestimated by 6-7 percent whereas the milk production is underestimated by only 3 percent.

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[144] In the FAOSTAT domain 'Agricultural Production'. It should be observed that Livestock Primary is a data collection separate from the data collection Food Balance Sheets (FBS). Besides data on the *use* of separate vegetable and animal food commodities, the FBS also contains data on the *production* of these commodities. However, since the FBS and the Livestock Primary are separate sets of statistics, the production numbers for equivalent commodities in these collections do not necessarily agree with each other.

[145] Refers to the global total of the production values in Livestock Primary for the meat categories 'beef & veal', 'buffalo meat', 'mutton & lamb', and 'goat meat'.

[146] We interpreted the production data for 'pig meat' in Livestock Primary as weights in *crude carcass*, as opposed to weights in *carcass-side*. In the comparison with the data in Livestock Primary, we assumed that carcass-side weight is equal to 85% of the crude carcass weight (on as-is weight basis). (For further details regarding these two carcass definitions, see Appendix 1.)

[147] In the FAOSTAT domain 'Agricultural Production'. The calculated number of animals in stock in the FPD model refers, formally, to year-average. For FAOSTAT no explicit point of time is specified.

As regards the other animal systems, the calculated number in the model of *pigs* in stock is 7.3 percent higher than the number of pigs according to FAOSTAT, and for *poultry* the calculated number of animals in stock is 1.8 percent lower than in FAOSTAT.

On the regional levels, the pattern is about the same. In most regions, the model value of ruminant carcass production exceeds the corresponding one in FAOSTAT. However, in some regions the overestimates are most considerable, for example, North America & Oceania, 22 percent, and West Europe, 10 percent (both as-is weight basis). In fact, the overestimate for North America & Oceania accounts for the greater part of the overestimate on the global level. In contrast, in two of the populous regions, East Asia and South & Central Asia, the deviations are less than 1 percent. For pig carcass, the regional pattern is similar to that of ruminant carcass. In North America & Oceania and West Europe, the overestimates are rather large, around 10 percent. In the major pig-producing region, East Asia (harbors about half of the global production), the model value of pig carcass production exceeds the value in Livestock Primary by about 6 percent. These three regions together account for nearly all of the global estimate. For the other animal food commodities, divergences were small at the regional levels.[148]

One factor which may explain the divergences for meat is the handling in this study of the FBS flow ‘animal fat, raw’, as regards its representation in the end-use. As mentioned in Section 3.1.1, the consumption of raw animal fat was *entirely* represented by pig and ruminant *carcass* end-use in the FPD model. This means that all raw animal fat was assumed to be a *product* coming from what is defined as carcass.

However, at a closer look, this representation appears to be inaccurate, at least partly. Normally — given the carcass definitions customary in many countries — at least some of the raw animal fat is a *by-product* to the carcass. For cattle, for instance, some of the fatty tissue of the whole body, such as tallow, is normally not counted as part of the carcass. (For further explanations, see the section ‘Specification and composition of carcass’ in Appendix 1.) The problem, though, is that we do not know for certain how ‘meat’ in the FBS is defined. According to the FAOSTAT explanatory notes, cattle meat and pig ‘meat’ refers to dressed carcass, excluding offals and slaughter fats. But the figures in the FBS are reported by the member states, and the carcass definitions are different in different countries. It might be the case that some of the amount registered as carcass in the production statistics (that is, in FAOSTAT Livestock Primary) includes tissue that further in the processing is separated and registered as raw animal fat in the

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[148] As described in Section 3.1.1 (p. 59), for each region, milk end-use per capita was set so that the milk production figure in the FPD model agreed with the milk production figure in FAOSTAT Livestock Primary. The fact that the global production in the model, despite this, was lower than the figure for ‘World’ in Livestock Primary (512 Tg against 530 Tg) may be due to corrupted data in FAOSTAT, and/or due to the approximation made in the compilation of the regional values from FAOSTAT (see p. 57).

consumption statistics (that is, the FBS). The practices in this respect are likely to be different in different regions.[149]

Let us assume that, in contrast to this study, raw animal fat was not represented as part of the carcass, but *entirely* as a *by-product* to it. What would the model production levels then be in comparison with FAOSTAT? The model value on *total meat* production globally would be 1.9 percent lower than the value in Livestock Primary. For total *ruminant meat* the model value would be 3.3 percent lower than in Livestock Primary. Thus, if raw animal fat was depicted as a by-product to carcass entirely, the FPD model would give an underestimate, instead of an overestimate, of the levels of production. On the whole, however, the agreement with the values in Livestock Primary would be somewhat better.

There might be other factors involved behind the discrepancies in relation to FAOSTAT production values, but the handling in this study of raw animal fat is the most likely reason. We find that the representation would be more accurate if raw animal fat were modeled as a by-product, partly or wholly.

### *Feed use*

The level of feed dry matter use is basically a function of specific feed energy requirements, production level, feed mix and feed energy value of each feedstuff in the feed mix. In this study, total feed use globally was estimated to some 5 600 Tg DM per year.

Even though the feed use in this study is of the same order of magnitude as in some other studies, it seems that it lies higher than the established opinion. As one example, we can take a recent study based on IMAGE 2.2 in which global feed use in 1990 was estimated at about 4 800 Tg DM per year, the largest differences being related to higher value in this study for grass and animal forage crops.[150]

Bearing this general difference in mind, we will discuss below the reliability of the estimate of feed dry matter use in this study. The following issues have been identified as the most critical ones:

- The accuracy of the methods and data for estimating the net energy value of feedstuffs for cattle
- The adequacy of principles for allocation between animal sub-systems of the feed categories included in the FBS, as well as the assigned by-products and residues
- The accuracy of assumed values on assignment (and actual use) of by-products and residues for use as feed

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[149] For cattle, Kempster [1992] states that there are significant differences between countries in the dressing procedures. As one important example for which there are different practices in different countries, Kempster mentions the degree of removal of fat before weighing (that is, weighing as carcass).

[150] [Bouwman et al. in prep]

- The accuracy of assumed values on feed mix shares for feed categories other than those included in the FBS and by-products & residues
- The accuracy of the model representation of feed use
- The feed use related to draft work and draft animals

Before we take a closer look at these issues, we will give some comments on the outcome of the feed balance calculation region by region. (A concise description of the main procedures in these calculations was given in the section ‘Estimates of feed use — the feed balance calculations’, p. 83.) The idea is to give a rather detailed picture of the tendencies and tradeoffs in the calculation of the feed balances, which can serve as a background to the succeeding discussion. Those who are not interested in region-specific details may continue on page 201 below, where we proceed with the discussion of the above-mentioned issues.

In this regional feed balance account below, we frequently refer to the guidelines on nutrient density of feed mix as well as the guidelines on assignment of by-products and residues as feed. These guidelines are to be found in Table 3.12 (p. 80) and Table 3.20 (p. 102), respectively. The term ‘FBS feeds’ is used to denote those of the crop categories included in the FAOSTAT Food Balance Sheets which were taken into account in this study, that is, cereals grains, starchy root tubers, sugar crops and oil crops and pulses. If not otherwise stated, values on *shares in feed mix* are on *gross energy* basis, and values on *shares of generated and distributed* feed are on *dry matter* basis.

*East Asia.* FBS feeds covered feed requirements for *poultry*, with a contribution of about 12 percent of by-products (and a significant amount of fish meal, 3 percent). For *pig*, however, FBS feeds covered only 18 percent of the feed mix, and the amount assigned to by-products covered 24 percent. Since a large amount of feed was missing, we assumed a high level of assignment of non-eaten food, 45 percent of the distributed amount. Still, this amount of non-eaten food corresponded only to 21 percent of the feed mix. This meant that as much as 37 percent of the feed mix had to be covered by the balancing feed flow ‘forage-vegetables’. For *cattle*, there was a tendency to fall short of the energy density guidelines and therefore we assumed a small share of forage crops, particularly for dairy cows and bulls & heifers, despite the fact that we had few data supporting this assumption. However, animal forage crops amounted to no more than 5 percent of the total feed mix for total cattle. The tendency to low energy densities restricted the use of fibrous crop by-products, and for this reason we lowered the use of rice straw from its guideline value. In total, assigned by-products covered 31 percent of the feed mix for cattle (of which 28 percent were crop by-products, corresponding to 26 percent of the distributed amount); the rest, 64 percent, was covered by permanent pasture.

As major data source for this region we had a study of the livestock sector in China (constituting roughly two thirds of the region in population terms) which includes detailed data on feed use for the *total* livestock sector.[151] A major weakness of that study, however, is that about 36 percent of the calculated feed energy requirements (in ME) were not covered at the feed supply side, for the reason that they could not be accounted for by published statistics or through calculations.[152] As examples on feedstuffs not accounted for are mentioned water plants and garbage, which both are common feeds for pig and poultry. Another important feed category omitted on the supply side is grazing on minor areas such as roadsides, backyards and small fields; these feed sources are reportedly important for cattle and buffalo, among others.

A comparison of the feed use in this study with Simpson et al. in part reflects this, but also shows that a reasonably good accordance could be achieved. The feed categories forage-vegetables and pasture are higher in this study, 12 and 34 percent against 10 and 28 percent in Simpson et al. (as share of total feed, ME basis). If we add the contribution of non-eaten food in this study, 5.5 percent, we obtain in total a difference of 14 percent. The explanation of this difference is likely to be the fact that, in this study, the feed use fully match the feed energy requirements and therefore, in principle, includes all feedstuffs on the supply side, including those unaccounted for in Simpson et al.

For other feed categories, the feed use in this study is close to, or somewhat lower, than in Simpson et al. For crop by-products, however, there is a major discrepancy in terms of share in feed mix in relation to share of amount produced. For cereals straw & stover, Simpson et al. report use as feed being 16 percent of amount generated (on as-is weight basis), which corresponds to 26 percent (on ME basis) of total feed use (that is, of the total feed use for which use-data were available). The corresponding values in this study are 20 percent of the amount generated and 12 percent of the total feed use (on ME basis). This discrepancy can only in part be explained by the lower total feed use in Simpson et al. due to the unaccounted feedstuffs. Possible explanations are further discussed in the Section ‘Comparisons with previous knowledge and studies’, p. 237.

*East Europe.* As mentioned in the Section ‘Impact of revisions and accuracy of FAOSTAT data’ above, the release of FAOSTAT data which we used, turned out to be heavily inaccurate for the region East Europe. In the 1998 release, use of cereals as feed is at least 82 Tg *higher* than in the 1996 release (46 Tg). We have not tried to evaluate systematically the impact of the revisions on the results for this region. The comments below, particularly those referring to FBS feeds, should be read with great caution, bearing in mind that the inaccuracies are substantial.

For the 1996 release of FAOSTAT data, FBS feeds covered feed requirements for *poultry*, with a contribution of about 15 percent of by-products. For *pig*, FBS feeds covered 46 percent of the feed mix, whereas by-products covered 26 percent. Due to the apparent deficit of feed, we assumed use of non-eaten food to a small extent, 15 percent

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[151] [Simpson et al. 1994, pp. 363-365, 460-465]. Feed requirements include those of single-purpose draft animals as well as draft work performed by food producing animals.

[152] [Ibid., pp. 370-373.]

of distributed amount; this, however, corresponded to only 8 percent of the feed mix. The rest of the feed deficit, 20 percent, was covered by the balancing feed ‘forage-vegetables’. (If we had used the revised 1998 release of FAOSTAT data instead, these two latter assumptions would certainly not have been necessary.) For *cattle*, the energy density guidelines were matched by assuming substantial shares of forage crops, resulting in a share of 47 percent of the feed mix for total cattle. (Again, this share would have been considerably lower if the 1998 release of data had been used. At a rough estimate, possibly around 40 percent of this would have been covered by cereals grains instead.) Assigned crop by-products covered 4 percent (corresponding to 13 percent of the amount distributed), and the rest, 49 percent, was covered by pasture.

As data source for this region, we had data on use of forage crops, pasture and crop by-products for some countries, including the former USSR which constitutes about half of the region in population terms.[153] The value in this study on the use of grass-legume (mainly hay) is apparently to high, 36 percent as compared to 22 percent for the former USSR and 41 percent for Poland (shares for *total ruminants*). The same applies to pasture, 45 percent against 37 percent for the former USSR (*total ruminants*). For whole-cereals and crop by-products, however, the numbers are more close, 11 and 4 percent against 8 and 3-4 percent respectively (shares for the total animal food sector).[154]

*Latin America & Caribbean.* FBS feeds covered feed requirements for *poultry*, together with a contribution of little more than 20 percent by protein supplement by-products. For *pig*, FBS feeds covered 43 percent of the feed mix, and by-products contributed 29 percent. Due to tendencies towards too high protein levels of the feed mixes for poultry and pig in relation to their productivity levels, we had to lower the use of oil crops meals from the guideline value. The rest of the requirements for pigs, 28 percent of feed mix, was covered by assuming quite a considerable amount of non-eaten food, 25 percent of the distributed amount. For *cattle*, FBS feeds contributed with a small amount, 2.4 percent (of feed mix for total cattle). There was a tendency to come short of the energy density guidelines. We therefore assumed a certain use of forage crops, particularly for bulls & heifers. For total cattle, however, forage crops amounted to no more than 5 percent of the feed mix. The amount of crop by-products assigned was relatively high, 58 percent of the distributed amount, but corresponded to only 17 percent of the feed mix. The rest was mainly covered by permanent pasture (74 percent of the feed mix).

We had very few feed use data available for this region at the time of the model calculation. Recently acquired data indicate that use of crop by-products as feed may be somewhat overestimated.[155] According to these data, in the Southern Cone, native pastures are a main component in the cattle diet and use of crop by-products is very limited due to higher cost per energy unit as compared to the pastures. On the other hand, it is

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[153] Lee [1988] includes data on feed use for a large number of European countries.

[154] Numbers in Lee [1988] are given on “grain unit” basis. Numbers for this study refer to ME basis.

[155] Quiroz et al. [1997] give an overview of ruminant feeding systems and extent of crop by-products use in Latin America & Caribbean.

also reported in the same study that in the predominantly tropical areas in the northern part of the region, crop by-products are important for maintaining production levels during drier periods. Also, in the Andean region, crop by-products are assumed to be fully utilized since the cereal harvest takes place during the period of least pasture availability. Thus, the extent of use is very different depending on the very conditions in the different areas, and it is not possible to obtain an integrated picture for the whole region from these data. But since the Southern Cone accounts for a large share of the ruminant production, we believe that it leans more towards an overestimate than an underestimate in this study of the use of crop by-products as feed.

Yet another recently acquired reference suggests that the share of oversown permanent pasture most likely is underestimated in this study. Instead of 5 percent (as share of total permanent pasture) it should probably be around 10 percent, or even more.[156]

*North Africa & West Asia*. FBS feeds covered the feed requirements for *poultry*, with a contribution of around 18 percent by protein supplement by-products. Feed requirements for *pig* were negligible since pig production is virtually non-existent in the region. For *cattle*, FBS feeds contributed with a small amount, about 5 percent (of feed mix for total cattle). According to some sources, use of forage crops for cattle is significant in the region. However, there was a tendency to exceed the energy density guidelines. To avoid that, we assumed a modest usage, 3.3 percent of the feed mix, for total cattle. The amount of crop by-products assigned was relatively high, 58 percent of the distributed amount, which corresponded to 25 percent of the feed mix. The rest was covered by permanent pasture (64 percent) and conversion by-products (3 percent).

Among data sources available for this region, we had data for some North African countries on feed use, for the *total* livestock sector, of concentrates, forage, pasture and crop by-products.[157] A comparison of the numbers shows that there is reasonable agreement, except for forage which is clearly lower in this study — but the variation between the countries is considerable: The numbers in this study for concentrates (cereals, starchy roots, oil crops), forage crops, pasture and crop by-products are 16, 3.2, 56 and 20 percent, respectively (ME basis), whereas the ranges in the study by Glenn are 13-24, 6-17, 41-72 and 5-20 percent, respectively (ME basis).

Data for a large number of countries in the region on feed use of cereals straw & stover, as share of the available amounts, show reasonable accordance with the numbers in this

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[156] Vera et al. [1994] report that the area of sown pastures has been estimated to approach 50 million ha. It is not clear whether this figure concerns the entire region or only a part of it, but presumably it refers to the northern part of the region, which accommodates the neotropical savannas. At any rate, the figure is relatively high in comparison with the current grassland area of the entire region, 590 million ha (figure from Table 3.30, p. 244).

[157] [Glenn 1992, p. 42]. Data refer to Algeria, Tunisia and Morocco in the mid 1980s. Unfortunately, it is not explicitly made clear whether the numbers actually refer to feed *use*; the term used in the study is “feed availability”, presumably referring to likely usage.

study.[158] For wheat and maize (the two major cereals in the region), reported numbers are 70 and 50 percent, respectively, which can be compared with the number in this study for total cereals straw & stover used as feed, 60 percent (as share of the distributed amount on dry weight basis).

Recently acquired data on feed use for ruminants, however, indicate that the level for pasture is overestimated in this study, while the use of forage, and possibly also crop by-products, is underestimated.[159] According to these data from Nordblom et al., feed mix average for those countries included in the region definition in this study, the numbers are 36, 14 and 50 percent for rangeland grazing, cereals & other concentrates, and crop residues & forage crops, respectively.[160] The corresponding figures in this study (for total cattle) would be 64, 8 and 28 percent, respectively (dry weight basis), if we count conversion by-products among concentrates. Thus, it seems obvious that pasture is overestimated in this study. For forage and crop by-products the picture is less certain since those are not separately accounted for. We guess, however, that it is mainly the use of forage that should be higher than what is assumed in this study.

*North America & Oceania*. FBS feeds covered feed requirements for *poultry* and *pig*, with contribution of around 27 percent of by-products (almost only protein supplement by-products). Due to tendencies to exceed the protein density guidelines, we lowered the use of protein meals by setting cotton meal assignment to zero. For *cattle*, FBS feeds contributed a large fraction, 22 percent (of feed mix for total cattle). Largely due to this considerable share of concentrates (cereals) in the cattle feed mixes, the energy density guidelines were heavily exceeded (Table 3.12, p. 80). According to statistical data, use of forage crops is substantial in the region, and we assumed a level corresponding to 19 percent as share of the feed mix for total cattle. The remaining feed elements for cattle was pasture, 54 percent (of which 39 percent permanent pasture), and by-products, 5 percent (conversion by-products and crop by-products about equal amount).

In contrast to the case in the other regions, for this region we had data available which allowed a comparison of some of the total feed use levels. Statistics for the USA show that intake of harvested roughage and pasture by cattle was 1.0 and 2.3 EJ ME per year in 1992-94.[161] The USA accounts for roughly 80 percent of the ruminant production in the region; if we take 80 percent of the corresponding numbers in this study we obtain 0.8 and 1.9 EJ ME per year, respectively. Thus, in total, the numbers in this study are

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[158] [Nordblom 1988, p. 50]. It is not stated whether the numbers refer to the share of the total generated amount, or to the share of the amount available after cutting and other harvest losses have been accounted for. We assume that the latter is the case.

[159] Nordblom et al. [1997, p. 133] report data on feed mix for ruminants for all countries in the region, plus a number of adjoining countries. The basis for the feed mix numbers is not given; we assume that it is dry matter.

[160] Nordblom et al [Ibid.] publish data for the region ‘West Asia-North Africa’, which includes a larger number of countries than in the corresponding region in this study. The numbers cited are our own compilation from the individual country values on feed mix for ruminant reported by Nordblom et al.

[161] [NASS 1997]

about 18 percent lower on ME basis; the difference is equivalent to about 14 percent of the total cattle feed use in this study.

*South & Central Asia*. As mentioned in the section ‘Impact of revisions and accuracy of FAOSTAT data’ (p. 179), the release of FAOSTAT data which we used turned out to be somewhat inaccurate for this region. In the 1998 release, use of cereals as feed is at least 9 Tg higher, or more than double the figure in the 1996 release (7.7 Tg). The comments on FBS feeds below should be read with caution, bearing in mind that the inaccuracies are substantial.

FBS feeds covered no more than about 40 percent of the feed requirements of *poultry*, the rest of the requirements was covered by by-products, mainly cereals milling by-products. For *pig*, FBS feeds covered 25 percent of the feed mix, and by-products contributed about 36 percent (mainly crop by-products). Due to tendencies towards too high protein levels of the feed mixes for poultry and pig in relation to their productivity levels, we lowered the assignment of oil crop meals and cotton meal from their guideline values. The main part of remaining requirements for pig was covered by a considerable amount of non-eaten food, 38 percent of the feed mix, equivalent, however, to merely 4 percent of the distributed amount. (If the revised 1998 release of FAOSTAT data had been use instead, the shares of by-products and residues for pig and poultry would have been less than half of those above.)

For *cattle*, we had considerable trouble in getting feed requirements and feed supply to match. (This fact would not had changed at all if we had used the revised 1998 release of FAOSTAT instead, since the revisions are almost negligible in relation to cattle feed use — the share of concentrates would have been roughly 1 percentage unit higher for total cattle feed mix.) A major indicator of the difficulties was that the calculated phytomass appropriation per unit area tended to reach unexpectedly, and as far as we could judge, questionably, high levels (Figure 3.71, p. 245). Due to this tendency we raised the assignment of most crop by-products to the maximum value, 90 percent of the distributed amount. Crop by-products thereby contributed 35 percent of the feed mix for total cattle, the use being equivalent to 89 percent of the *distributed* amount, and 71 percent of the *generated* amount. This level of use of crop by-products as feed is, however, extremely high. Recently acquired data on the use of crop by-products for system-external purposes, such as fuel, indicate that the use of crop by-products as feed is overestimated, see the section ‘Food-system-internal uses and fates in relation to other systems’, p. 224. As regards forage crops, use for cattle is substantial in the region according to some sources. Support for assuming a large share of forage in relation to pasture in the cattle diet could also be found in the relative distribution of grassland and cropland in the region (Figure 3.71). Partly with a purpose to keep the phytomass appropriation per unit area for grassland relatively low, we assumed rather high levels of forage use, corresponding to 24 percent of feed mix for total cattle. Of the remainder, conversion by-products covered 2 percent, which meant that permanent pasture had to cover 39 percent.

Among data sources available for this region, we had data on cattle diets in India (constituting about two thirds of the region in population terms).[162] According to these data, the prevailing feed mix for cattle in India is: concentrates 2-4 percent, green herbage (cultivated forage, hand-harvested leaves, weeds from cultivated fields, etc) 15-20 percent, dry roughage (straw, etc) 40-50 percent, and grazed feed 30-45 percent (values on air-dry basis). The accordance with the numbers in this study is not very good, especially if considering that 'green herbage' in our estimate consists of cultivated forage only.

A recently acquired study included estimates of feed requirements and feed availability for India, and partly, for Pakistan.[163] Interestingly, for India about 37 percent (DM basis) of the feed requirements were not covered on the feed supply side, that is, were not accounted for among available feedstuffs. Also remarkable is that Singh et al. count with 100 percent of the amount of crop by-products *generated* as available for animal feeding. Despite this clearly overestimated figure on feed availability for crop by-products, feed supply is far from tallying the requirements. Estimated *available* feed as share of total for the entire livestock sector are: concentrates 6.6 percent, cultivated fodder 12 percent, grazed forage 15 percent (of which only 3 percentage units from grassland, the rest from forest land and 'other' land) and crop by-products 66 percent (values on DM basis). For Pakistan, the corresponding figures are 8, 19, 27 and 46 percent, respectively.[164] The corresponding numbers in this study on feed *use* (as opposed to feed *availability*) are 4, 23, 37 and 36 percent respectively (DM basis).

Singh et al. also reports that the area in India under forage crops (cultivated fodder) is estimated to be 4 percent of the total cropland area, or 6.6 million ha, with yields averaging 10 Mg DM per ha & year. For Pakistan, the corresponding figure is 13 percent of the total cropland area (2.7 million ha). If we assume 10 Mg per ha as average yield for the calculated forage production in this study, we obtain a corresponding area of about 34 million ha, which is 13 percent of the total area of arable land in the region.

Thus, all comparisons point to the fact that the assumed level for forage crops is too high. At the same time, the levels for both permanent pasture as well as crop by-products seem already to be on the upper edge — that applies in particular to crop by-products which are almost certainly overestimated if we take into consideration uses outside the food system. Hence, it is possible to find signs of overestimation for all major feed categories included in this study. It seems clear, therefore, that there exist feed

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[162] [Verma & Jackson 1984, pp. 415-416]. Verma and Jackson cite a feed survey from 1965 but it seems clear that the authors mean that this feeding pattern is still valid. It may be noted that, in the original survey, the amount of grazed feed was not weighed (as were the other constituents) but merely estimated.

[163] [Singh et al. 1997, pp. 116-122]. Data from that reference are also to be found in Maehl [1997, p. 291].

[164] Singh et al. [Ibid., p. 121] do not specify whether the numbers for Pakistan refer to availability or to actual use; we presume it is availability. Nor is the basis for the figures stated.

categories not accounted for in this region. This issue is further dealt with under the heading ‘Accuracy of the model representation of feed use’, p. 207.

*Sub-Saharan Africa.* FBS feeds covered merely a little more than 50 percent of the feed requirements of *poultry*, the rest of the requirements was covered by by-products, mainly cereals milling by-products. For *pig*, FBS feeds covered no more than 13 percent of the feed mix, and by-products contributed about 36 percent (mainly crop by-products). The main part of the remaining requirements for pig was covered by a considerable amount of non-eaten food, 49 percent of the feed mix, equivalent to 20 percent of the distributed amount. For *cattle*, the amount of crop by-products assigned was high, 69 percent of the distributed amount, corresponding to 31 percent of the feed mix (for total cattle). The rest was covered by permanent pasture, 69 percent. We assumed no use of forage crops for cattle, since we had no sources supporting such an assumption. Neither were there, as in the case with East Asia and Latin America & Caribbean, any FBS feeds nor conversion by-products remaining after the allocation of these to poultry and pig.

Among data sources available for this region, we had data on estimated forage availability for the entire region.[165] According to these data, total forage availability was about 7.6 EJ ME per year, distributed among “cropland” 1.1, “non-agricultural land” 1.4, “permanent pasture” 4.4, and “crop residues” 0.7 EJ ME per year. Although the data refer to availability, and not actual consumption by livestock, and in addition are relatively old, they are interesting as reference points for the values of this study. For comparison, total feed use in this study was 4.0 EJ ME per year, distributed among permanent pasture 2.6, crop by-products 1.2, and FBS feeds and conversion by-products 0.2 EJ ME per year. From this comparison, we can at least conclude that the total feed use level in this study is not unrealistically high.[166]

Data on feed use of crop by-products, as share of the available amounts, show that the numbers in this study may be a little too high. One World Bank study for the region, states that most of the crop by-products are consumed by livestock.[167] In a model on crop residue use in that study, a little more than half of the amount of cereals straw and stover is assumed to be consumed by livestock. In this study, use of cereals straw & stover as share of generated was about 65 percent, but counted on all crop by-products use was 56 percent.

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[165] Fitzhugh et al. [1978] quoted in Wheeler et al. [1981, p. 35].

[166] The distribution between permanent pasture and other feedstuffs may also seem reasonable, but that depends on the interpretation of the category “cropland”. Possibly, “cropland” forage means post-harvest stubble, and “crop residues” means harvested and stored crop by-products.

[167] [McIntire et al. 1992, p. 123]

However, a recently acquired study[168] on use of crop by-products shows that the variation in the region is considerable. In Nigeria, use of crop by-products is reported to be very low — despite abundant availability and cheapness — and most of them rot or are burnt. In contrast, in the Ethiopian highlands use is most extensive and crop by-products account for 90 percent of the feed intake for ruminants. In “cereal cropping areas” of Ethiopia, use of crop by-products is reported to be 63 percent (probably as share of distributed). In semi-arid Mali, post-harvest grazing of crop by-products accounted for 41 percent of the annual feed supply for ruminants, the remainder consisted of pasture.

*West Europe*. FBS feeds covered feed requirements for *poultry* and *pig*, with contribution of around 28 percent through by-products (almost only protein supplement by-products).[169] For *cattle*, FBS feeds contributed with 12 percent (of feed mix for total cattle). Partly due to this share of concentrates (cereals) in the cattle feed mixes, the energy density guidelines were somewhat exceeded. According to statistical data, use of forage crops is most substantial in the region, and we assumed a level corresponding to 35 percent as share of the feed mix for total cattle. Remaining feed elements for cattle was pasture, 44 percent (of which 28 percent permanent pasture), and by-products, 9 percent (conversion by-products and crop by-products about equally).

Among data sources available for this region, we had a comprehensive study on feed requirements and supply in the EU (EC-10), based on statistical data.[170] A comparison of the feed intake numbers in this study with the feed *supply* numbers in that study, for the *total* animal food sector, that is, total feed, shows fairly good accordance. The largest divergences are for pasture and forage crops, for which the EC-10 numbers are 41 and 16 percent, respectively, and the numbers in this study are 28 and 25 percent, respectively (ME basis). For all other feed categories the differences are relatively small, except for cereals grains which is somewhat higher in this study, 25 against 20 percent (ME basis). In the EC-10 study, estimated feed supply exceeded calculated feed energy requirements in nearly all of the countries. As one possible source of error on the supply side it is pointed out that, in some Member States, no sufficient or reliable information is available on the quantities of roughages used. The discrepancies between supply and demand may in part explain the differences in the comparison with this study. (It should also be observed that ME basis is not necessarily an accurate basis for comparisons of feed energy value for ruminants.)

Data on the occurrence of forage crops and pasture in ruminant diets in a number of countries show that the assumed levels in this study are reasonable.[171] Use of forage

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[168] de Leeuw [1997] gives an overview of ruminant feeding systems and use of crop by-products in Sub-Saharan Africa. Some numbers for individual countries in the region are also given in an accompanying section [Maehl 1997, p. 290].

[169] The FAOSTAT figure on use of cassava as feed was interpreted as cassava meal instead of fresh tuber, that is, with a DM content of about 90% instead of 35%.

[170] [Janssens 1990]. Data included in the study refer to EC-10 in 1979-1987. The numbers referred to here are those from 1987.

[171] Lee [1988] includes data on feed use for a large number of European countries.

crops (hay and silage) in Germany, France and UK (around 1980) was 34, 41 and 24 percent respectively (shares for total ruminants), to be compared with the value in this study, 36 percent. The share of pasture in the feed mix was 26, 31 and 59 percent, respectively, and in this study 39 percent.[172]

We now proceed with the discussion of the above-listed issues important for the reliability of the feed use estimates in this study.

*Accuracy of the net energy method for cattle*. One of the most critical points for the results of feed use estimates is the accuracy of the methods and data for estimating the energy value of feedstuffs for cattle. In this study, we used the *net* energy (NE) system for calculations of energy requirements and energy value of feedstuffs (equations listed in Sections 2.3.2 and 2.3.3). Another important energy accounting system currently in use for cattle is the *metabolizable* energy (ME) system. A major advantage of the NE system is that requirements stated as net energy are independent of the diet, that is, they do not have to be adjusted for different energy densities of the diet. In the ME system, the ME density of the actual diet must be taken into account, since the efficiency of utilization of metabolizable energy for maintenance, lactation and growth depends on the energy density. The lower the ME density, the lower is the utilization efficiency of the metabolizable energy.[173]

Are there any reasons to believe that there may be inaccuracies in the NE system? One reason might be the fact that the empirical equations for calculating the NE content of feedstuffs are based on experimental diets with mainly moderate to high digestibility; 87 percent of the diets were within the range 9.8 to 13.3 MJ DE/kg DM, and only 1 percent were below 9.8 MJ DE/kg DM.[174] For comparison, the principal cattle feedstuffs globally, native permanent pasture and crop by-products, have DE densities mainly around 8 to 9.5 MJ DE/kg DM. Hence, for the main parts of the cattle feed use in this study their estimated NE contents are not empirically verified. For certain, this alone is a reason to remain somewhat skeptical towards the feed use estimates in this study.[175]

A particular reason to exercise caution in the use of the equations outside the empirically verified range might be the fact that the equations are non-linear. Figure 3.69 below shows plots of the NRC equations for $NE_m$ and $NE_g$ as well as corresponding linear estimates between 9.8 and 13.3 MJ DE/kg DM. Far outside the empirical range, the non-linear nature of the equations is obvious. However, for most low-energy-density feedstuffs — which in this study have densities around 8 to 9 MJ DE/kg DM — the dif-

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[172] Numbers in Lee [1988] are given on “French feed unit” basis. Numbers for this study refer to ME basis.

[173] [NRC 1984, p. 3]

[174] [NRC 1996, p. 4]

[175] Apart from using the equations outside their empirically verified range, NRC [1996, p. 4] also states that there are some general sources of errors. For example, the relationship between DE and ME can vary considerably as a result of differences in intake, rate of digestion and passage, and composition.

ferences between the NRC equations and the linear estimates are relatively small. The differences do not seem to really matter until values of 7.5 MJ DE/kg DM and lower. In this study, the only feedstuffs assumed to have such low energy densities were rice straw and sunflower stalks (both 7.5 MJ DE/kg DM).

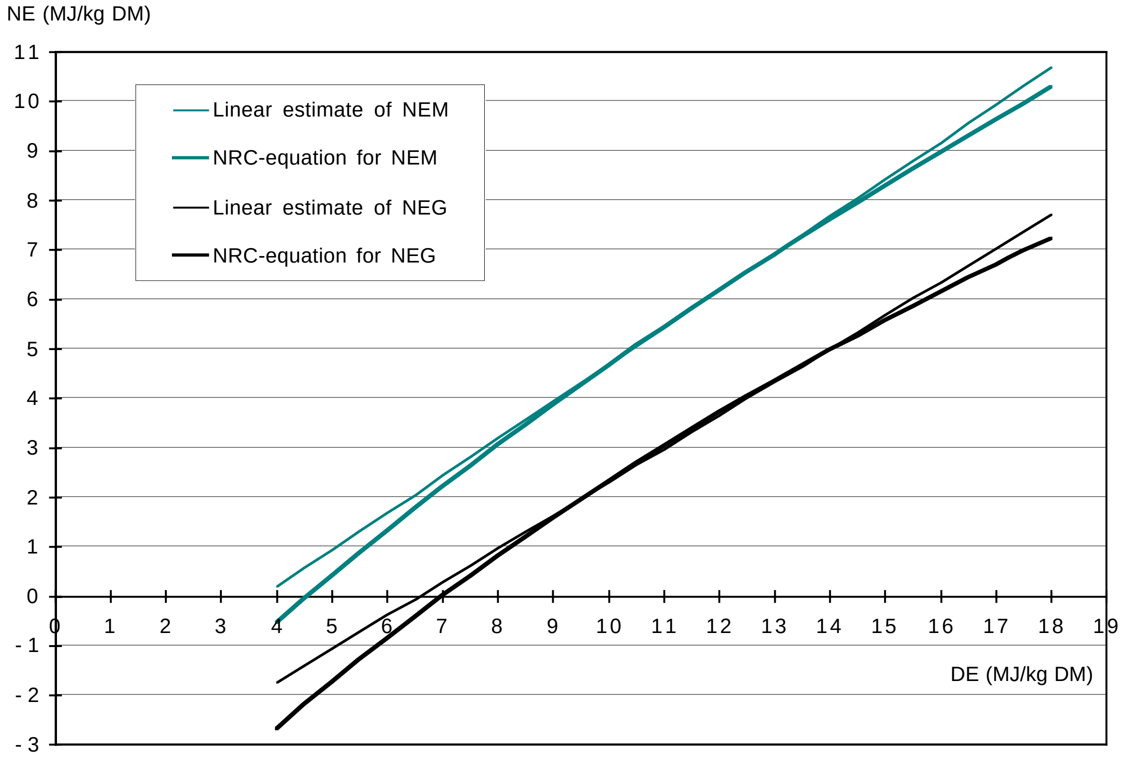

**Figure 3.69** Relations between DE and NE content of feedstuffs for cattle. NRC equations and linear estimates between 9.8 and 13.3 MJ DE/kg DM. Labels follow same order as lines. NRC equations refer to beef cattle (source: [NRC 1996]).

As for the assumed values on feed energy densities in this study, we consider those for native permanent pasture and crop by-products as the most critical ones. These are the principal feed categories for cattle globally (52 and 21 percent, respectively of total feed on GE basis), and more importantly, the variation in feed energy density within these categories are larger in relation to other feed categories. Furthermore, the generally low energy density of these feedstuffs makes the assumptions on energy content particularly difficult and subject to delicate considerations — a 10-percent reduction in DE-content from, for example, 9.0 to 8.1 MJ/kg DM means a reduction by 20 percent in net energy for maintenance ($NE_m$) and as much as 45 percent in net energy for growth ($NE_g$). Thus, so small a reduction in DE implies almost a doubling of the feed dry matter requirement for growth. On top of that, the data material we had available on feed energy densities was not very solid; that applied in particular to native permanent pasture.

With regard to this, we were cautious with assuming low DE density values, and we mainly chose to assume values at the higher end in order to avoid overestimating the feed requirements. We were also cautious with assuming large differences between the tropical and temperate pasture categories. Some examples of data on DE density for native permanent pasture were given in Section 3.1.4 (p. 97). It is clear from these examples that to a large extent, published data come short of the assumed values in this study (Table 3.19, p. 97).

From considerations of space we have not made any account of ranges of DE data for crop by-products. Generally speaking, crop by-products are characterized by digestibilities below 50 percent (corresponding to about 9 MJ DE/kg DM). As sole feeds they are even considered to be too poor to maintain adult ruminants.[176] In this study, the assumed DE values for crop by-products mainly ranges between 8 and 9 MJ DE/kg DM, with the important exceptions of rice straw (7.5) and sugar cane tops & leaves (9.5) (These values are given in Table A1.II, Appendix 1.)

It should be noted, however, that these statements are valid for the plant material as it is, that is, for untreated material. In real systems, treatment of crop by-products for nutrient enhancement purposes occur to a certain extent. For example, in China around 1990 approximately 5 percent of the total amount of cereal straw & stover used as feed were processed with ammonia.[177] However, we assumed that the extent of such treatment was not large enough to significantly affect the average DE values for crop by-products.

To sum up this part, we believe that it is unlikely that DE for native permanent pastures and crop by-products are considerably underestimated in this study. In fact, it seems more likely that DE for some of these feedstuffs is overestimated rather than underestimated, particularly for tropical native permanent pasture.

*Adequacy of principles for allocation of the FBS feeds and assigned by-products and residues.* The adequacy of the principles for allocation between animal sub-systems (described on p. 81) of FBS feeds and by-products & residues is of importance for the significance of the estimated feed mixes. For some of the animal sub-systems these principles had a determining influence on the actual shaping of the feed mix. This applied to the feed mixes for poultry in all regions, and to those for pig in most regions. (Feed mixes are shown in Figure 3.32, Figure 3.33 and Figure 3.34, pp. 142 sq.)

In some of these cases, the allocation principles implied feed mixes which from other viewpoints, such as the nutrient density of the feed mix, can be assumed to have relatively low significance. For the poultry systems in some of the regions, the principles entailed apparently too high ME densities in relation to the productivity level of the systems — this applies especially to East Asia, North Africa & West Asia, Sub-Saharan Africa, and, possibly, also Latin America & Caribbean (nutrient density values are given in Table 3.12, p. 80). For the pig systems, the corresponding may be said for the region Latin America & Caribbean. On the contrary, for the pig system in East Asia, the

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[176] [Owen & Jayasuriya 1989]

[177] [Simpson et al. 1994, pp. 308, 364]

ME density seems to be a little low in relation to the productivity level. The allocation principles also contributed to apparently too high protein densities for poultry and pig in South & Central Asia (relatively high use levels for protein-rich by-products contributed to this as well — see next point below).

Partly from these comparisons, we find that it is likely that cereals and non-fibrous by-products were allocated in somewhat too high an extent to poultry as compared to pig (that applies, for example, to East Asia). The opposite relationship probably holds for non-eaten food. In this study, non-eaten food was allocated solely to the pig systems; in real systems, however, this flow is almost certainly fed to poultry systems to some extent (though probably much less than the pig systems).

For other animal sub-systems and feed categories in the other regions, we do not see any, or only moderate, reduction of the significance of the feed mix results on account of the allocation principles. In those cases, their influence on the overall feed mix is minor.[178]

*Accuracy of values on assignment and use of by-products and residues for use as feed.* The accuracy of assumed assignment and actual use of by-products and residues as feed is, naturally, of importance for the significance of the feed use estimates (assignment and use values given in Table 3.20, p. 102). This applies in particular, to the outcome of the *mix* of the feed, but also to the *total level* of feed use.

The assignment values for *crop by-products* are by far the most critical ones since this category accounts for the largest contribution among the by-products & residues to the feed supply (globally about three quarters of all by-products and residues used as feed, or nearly 20 percent of total feed use, see Figure 3.27, p. 138). The accuracy of the crop by-products assignment levels affects the significance of mainly the *cattle* feed mixes in most of the regions. The pig feed mixes in South & Central Asia and Sub-Saharan Africa are also affected to some extent.

In the regional feed balance account above, some evidence on overestimates and underestimates of the use of crop by-products as feed was put forward. In the section ‘Food-system-internal uses and fates in relation to other systems’ (p. 224), indications are given on the accuracy of the feed use estimates with regard to use of crop by-products *outside* the food system (mainly energy). For the different regions, the outcome of these indications can be summarized as follows. Most likely overestimate: South & Central Asia; possible overestimate: Latin America & Caribbean, Sub-Saharan Africa; possible underestimate: North Africa & West Asia; and, finally, reasonably accurate estimate: East Asia. For the remaining regions — East Europe, North America & Oceania and

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[178] One likely exception from this is the pig feed mix in West Europe, which in this study has a considerable share of starchy roots (mainly cassava meal) in relation to the cereals share. In reality, some of the cassava meal is probably used also in the cattle systems which means that the share in the pig feed mix should be lower.

West Europe — the importance of crop by-products for the cattle feed mixes is small, and their significance is not appreciably affected on account of the assignment levels.

For the assignment of *conversion by-products* we had a fair amount of data to rely on. Furthermore, the magnitude of the conversion by-products is rather limited in nearly all feed mixes and regions. Therefore, we believe that, in most cases, the assumed assignment values for conversion by-products are unlikely to add considerable insignificance to the feed mixes.

Still, there are some possible exceptions concerning the protein-rich by-products, which are dominated by the oil crops meals.[179] In some cases, the use of these by-products may be overestimated. This apply to the pig feed mix in Latin America & Caribbean, and possibly also to the poultry feed mixes in this region and North Africa & West Asia, as well as the pig and poultry feed mixes in South & Central Asia. The reason for this judgement is mainly the relatively high protein densities of those feed mixes (Table 3.12, p. 80).

On the other hand, it is likely that the use of protein-rich by-products is underestimated in the industrial regions, at least in West Europe. In the real system, a significant use of protein supplements occurs in high-yielding milk production systems (of the order of 5 to 10 percent of ration, DM basis). In this study, however, use of protein-rich by-products in the milk systems in those regions was very limited. In all essentials, this limited use was an effect of inadequate model construction, which did not allow use of oil crops meals as feed for dairy cows (the only protein supplement by-product included as feed option was brewer's grains, see Table 2.3, p. 34).

As can be seen in Table 3.20, the assumed level of assignment of protein-rich by-products in the industrial regions, North America & Oceania and West Europe, was 90 percent, which would imply that there is no significant scope for higher usage. In the real system, however, there is a considerable trade of protein supplement by-products, with the predominant pattern being export from non-industrial to industrial regions.[180] In this study, no trade of by-products was assumed since that was not an option included in the FPD model. The existence of this trade pattern means that the total utilization of

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[179] As protein-rich conversion by-products we here include oil crops meals, brewer's grains, carcass fifth quarters (meat & bone meal), and cotton meal. The oil crops meals accounted for nearly 80% of the estimated total use of these as feed.

[180] According to FAOSTAT, data domain 'Agriculture & Food Trade', net-trade of 'oilseed cake meal' from 'developing countries' to 'developed countries' was roughly 18 Tg/year in 1992-94 (as-is weight). For 'Western Europe', there was a net-import of about 19 Tg/year. In contrast, for 'North America' (USA and Canada), there was a net-export of 5.4 Tg/year. For 'gluten feed and meal' — protein-rich by-products from wet milling of maize — there was a net-import to Western Europe of 5.0 Tg/year, and a net-export from North America of 6.7 Tg/year, whereas there was a net-export from 'developing countries' to 'developed countries' of roughly 0.3 Tg/year. For comparison, in this study the total generated amount of oil crops meals and cotton meal was estimated to about 120 Tg (as-is weight) per year, and use as feed in West Europe was estimated to 19 Tg/year. For cereals milling by-products, global generation was about 270 Tg/year, and use as feed in West Europe was 10 Tg/year.

oil crops meals and cotton meal is likely to be higher in the non-industrial regions than what the assignment and use-levels in Table 3.20 indicate — this applies in particular to South & Central Asia. In total, therefore, we believe that it is likely that the global use of protein-rich by-products as feed is underestimated in this study. An indication in this direction is also obtained in a comparison with a recently acquired study on the global livestock sector.[181]

To sum up this part on conversion by-products, some, or even most, of the possible inaccuracies for the levels of assignment and use of conversion by-products are due to inadequacies in the model representation of the system. Since several parts of the system are involved we find it difficult to estimate the degree of inaccuracy and its effect on the significance of individual feed mixes and regions. However, at any rate the protein-rich by-products cannot contribute more than a tiny amount of the total feed use — in this study they made up 1.8 percent of the total feed use globally (GE basis), which was about 60 percent of their total generated amount (DM basis). Thus, the resulting inaccuracies are unlikely to lower the significance of the estimated overall feed use pattern. The same more or less holds also for the other dominating flows in this feed category, the cereals milling by-products. In this study, these flows made up 1.5 percent of total feed use globally, corresponding to 47 percent of the generated amount (rice hulls excluded).

For the assumptions on the use of *non-eaten food*, we had virtually no data available. Consequently, the use levels as such for non-eaten food (Table 3.20) have relatively low significance. This fact adds insignificance to the feed mixes for the pig sub-system in some regions — particularly to Sub-Saharan Africa and South & Central Asia, and also, but to a lesser extent, East Asia and Latin America & Caribbean. Owing to East Asia’s large share of the global pig production, the significance of the global average pig feed mix is also somewhat reduced (non-eaten food accounts for 15 percent of global pig feed mix in this study).

With regard to the total feed use, the estimated use of non-eaten food makes up only a tiny share, about 1.3 percent (GE basis). However, this does not automatically mean that the total feed use estimate is not affected by the low significance of the use levels for non-eaten food. It is true that the share of total feed use is small, but so is also use as share of the amount generated — globally, estimated use as feed makes up only 16 percent of the amount generated. In this study, the pig sub-system was the sole animal sys-

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[181] de Haan et al. [1997, p. 102-103] published estimates on global utilization of ‘concentrate feeds’ in 1993. For oil meals and cakes (excluding fish meal which the authors included in this category), use was estimated to 114 Tg (weight unit not specified), which is 95% of the stated generated amount. In this study, total use of oil crops meals (incl. cotton meal) as feed was estimated to 82 Tg/year (as-is weight), which was 67% of the amount generated. Adding of the above-cited net-import to West Europe of oilseed meals (19 Tg, see footnote 180) would considerably reduce the discrepancy against the figure from de Haan et al. We do consider the utilization ratio of 95% in de Haan et al as too high, yet we believe that the global use of oil crops meals and cotton meal may be underestimated in this study by approximately 20 Tg (as-is weight).

tem with non-eaten food as feed option. Assuming that, in the real system, non-eaten food is used in other animal sub-systems as well, it is likely that the use as feed is underestimated in some regions. This applies in particular to South & Central Asia, Sub-Saharan Africa, and for certain, to North Africa & West Asia. In South & Central Asia, estimated use amounted to merely about 3 percent as share of the generated amount. Most likely, the real use as feed is higher than that. The problem however, as already pointed out, was that we had very little support for making assumptions on the use in different animal sub-systems, as well as for assumptions on nutritive value for different animal categories.

*Accuracy of assumed values on feed mix shares for feed categories*. That the accuracy of assumed values on feed mix shares for feed categories other than FBS feeds and by-products & residues (that is, animal forage crops and pasture) is crucial for the significance of the feed mix estimates goes without saying. Most of the possible inaccuracies were discussed in the regional feed balance account above. Generally speaking, we believe that the values for these feed categories have relatively high significance in the industrial regions North America & Oceania and West Europe, whereas the values for the non-industrial regions have lower significance, with East Asia probably being the region among them with the highest significance.

Among the most critical values, we consider those for grass-legume forage in South & Central Asia. Due to the large dimensions of this region's cattle feed use — it accounts for nearly 25 percent of estimated global cattle feed use (on a DM basis) — its feed mixes affect the global average cattle feed mixes considerably. Although we consider the values for the industrial regions to be reasonably accurate, there are some feed categories whose significance is lower due to weak data basis. This concerns particularly the pasture categories cropland pasture and oversown permanent pasture. The same can be said for these feed categories in all other regions wherever applicable, in particular, East Europe and Latin America & Caribbean.

*Accuracy of the model representation of feed use.* The accuracy of the model representation of the feed flows influences the significance of the feed mixes as well as the levels of total feed use. The most crucial part is likely to be the accuracy of the model *representation of the phytomass production*. We find it very difficult to formulate a coherent and concise judgement on the accuracy of the phytomass representation, and its impact on the significance of the feed use estimates. Knowledge of the use of phytomass flows as feed in the real system is poor, and consistent knowledge in particular is very limited. Yet, in the following we will illustrate some possible inaccuracies and, if possible, judge their importance on the feed use estimates.

The only relatively consistent data available are for those phytomass flows included in the FAOSTAT Food Balance Sheets (FBS).[182] In essence, these correspond to the *edi-*

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[182] Of the total feed use in the FBS, edible-type crop products account globally for roughly 97% (DM basis). The remainder consists mainly of milk and fish with about 1% each of total.

*ble-type crops products* in the phytomass vector (see Table 2.6, p. 47). For these flows we are confident that the accuracy of the model representation is fairly high. The crop products which in the model describe the feed use for this plant group constitute nearly 90 percent of the *real* feed use for the plant group as stated in the FBS (globally, DM basis). Therefore, the significance for this part of the feed use estimate is likely to be relatively high.

For the feed use of edible-type *crop by-products*, we believe that, as a whole, the model representation is fairly accurate. Almost all major crop by-products are included in the model; the crop categories with by-product description included in the model represent approximately 92 percent of the total real production in this plant group (counted on the generation of *product* as stated in the FBS, globally, DM basis). Of the 8 percent without by-product representation, there are some crops whose by-products are significant feed flows in some of the non-industrial regions. Among the most important cases are pulses straw and banana & plantain leaves.[183] On a global basis, these by-product flows are small — pulses account for roughly 2 percent of total generation of edible-type crop products, and bananas and plantains for roughly 1 percent (DM basis). In some of the regions, however, their shares are higher and might add some insignificance to the feed use estimates.

It is for the other plant groups, *animal forage crops* and *permanent pasture*, that we have the large uncertainties. For the estimated feed use in this study, these groups are made up nearly entirely of grasses and legumes (about 90 percent, GE basis). As described in Section 2.5, grasses and legumes are represented by equivalent-character flows. That means that it is essentially the accuracy of their nutrient density values that determines the accuracy of the representation of the feed use. (The same applies also to (other) forage for pigs, which is represented by the equivalent-flow forage-vegetables.) For permanent pasture, variation in energy density and accuracy of assumed values have been touched upon above (the section ‘Feed energy density of pasture’, p. 97, and discussion on the net energy method, p. 201). For the categories cropland pasture, and grass-legume hay and silage, we can just state that the variation in energy density certainly is smaller than for permanent pasture, but nevertheless considerable. Hence, in all we cannot say much more on this topic than that due to the uncertainty in the representation of these parts, considerable insignificance is added to the feed use estimates.[184]

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[183] Just to give some examples, de Leeuw [1997, p. 55] reports banana leaves to be one of four major crop by-products sources used as feed in Rwanda. Also leaves and pods of phaselous beans are reported to be substantial feed contributions. In tropical Latin America, banana leaves & pseudo-stems are counted as significant feed sources [Quiroz et al. 1997, p. 156]. In India, Singh et al. [1997, p. 117] count straw of peas and other legumes as one of several major crop by-product sources.

[184] As for individual animal forage crop flows, we could add that fodder beets & roots are among the omitted categories which, in the real system, are significant in some regions. That applies to the European regions, where fodder beets & roots account for substantial, but diminishing, fractions of the forage crops supply [Lee 1988].

Still more insignificance is added if we take into account that besides the relatively easy-identified phytomass flows which belong to the plant groups mentioned above, in the real system, there are a number of diverse phytomass flows being used as feed. For various reasons these flows do not clearly belong to one or other of the above-mentioned plant groups. Therefore, we here designate these flows as *'indefinite'*. It is outside the scope of this study to present a structured account of them, but the following categories should be among the principal ones:[185]

- Browse[186] in (predominantly) grassland areas (grazed or collected)
- Thinned-out crop phytomass (by hand)
- Weeds (from weeding by hand in cultivated fields)
- Phytomass (herbage and browse) in (predominantly) forest land and other 'non-agricultural' land (grazed or collected)
- Water plants

The extent of the use of this type of indefinite flows as feed is poorly known. In general, their contribution to the feed supply seems to be largely neglected. Some examples of the orders of magnitudes can be given: In the northern Africa, browse is estimated to make up 60 to 70 percent of rangeland production, and 40 percent of the total availability of feedstuffs.[187] Browse is more suitable for small ruminants, particularly goats, than large ruminants — in India, browse is the principal feed for goats and supplies 60 to 70 percent of their forage requirements.[188] In Gambia, which has among the highest cattle densities per land area in Africa, 'bush forage' constitutes 80 percent of dry-season feed for livestock.[189] In eastern Africa, thinning in fields is reported to yield totally 1 Mg DM per ha, and weeding may yield a further 0.5 Mg DM per ha.[190] Estimates of availability of forage for grazing in forest land, and other non-agricultural land (such as roadside grazing), range from 0.2 Mg DM per ha (Southeast Asia) to 0.75 Mg DM per ha (India).[191] In East Asia, particularly China, water plants of various kinds, such as water hyacinth and water lettuce, have traditionally been cheap substitutes for more expensive

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[185] For pig and poultry, we might also add the category scavenging for various phytomass and zoomass, such as seeds, roots, insects. However, scavenging of that kind is likely to imply only small flows.

[186] Browse refers to shoots, leaves and twigs of shrubs and woody plants, and fruits, pods, etc.

[187] [Devendra 1996]

[188] [Ibid.]

[189] [Wilson 1995, p. 46]. The remaining 20% consists of crop by-products.

[190] [de Leeuw 1997, p. 56]. Thinned-out amount is total from two thinnings of excess plants early in the season.

[191] Roxas et al. [1997, p. 108] report roughage availability for ruminants in Southeast Asia to 0.2 Mg DM/ha for forest land, 0.4 for 'unclassified' land and 0.8 for permanent pasture. Taking into account total areas, this means that forest plus unclassified land are estimated to contribute with more than 80% of grazed forage in the region. Singh et al. [1997, p. 118] estimate green fodder availability in India to 0.75 Mg DM/ha for forest land, 0.25 for 'other' land and 1.25 for permanent pasture. In total, this means that forest plus 'other' land contributes with about 80% of total grazed forage. de Leeuw [1997, p. 56] states a livestock feed production of 0.5 Mg DM/ha for 'woodlots' and 'other' land in Rwanda.

feedstuffs for pigs. Water plants are still included in feed mill rations in China, but their relative importance for the total feed energy supply is not known due to lack of data.[192]

What influence could these indefinite feedstuffs have on the estimates in this study? We take South & Central Asia as an example, because we believe that in this region these feeds are likely to be of particular importance. In Table 3.28, we have compiled an adjusted version of the feed use for the ruminants in the region; for comparison the estimated feed use in this study is also shown. In the adjusted version, we have taken into consideration the possible use of indefinite feedstuffs, but we have also taken the opportunity to adjust the use of crop by-products — which we found is very likely to have been overestimated — as well as compensate for the inaccuracies in the 1996-release of FAOSTAT. The adjustment is made on an approximate dry matter basis, which means that the adjusted feed use does not necessarily comply with the calculated feed energy requirements; however, it is likely to be accurate enough to illustrate the possible significance of the ‘indefinite’ feedstuffs.

We cannot claim that this ‘adjusted’ feed use estimate is very accurate; still, we believe it is more accurate than the original one in this study — that applies in particular to the feed use levels for forage crops and crop by-products. Also, we do find it quite evident that the contribution of indefinite feeds is likely to be considerable in this region. According to this adjusted feed use estimate, around one fifth to one fourth of the feed use for ruminants may come from thinning & weeding in crop production and grazing in forest land and ‘other’ land. It also seems quite clear that ‘garbage’, or if using the terminology of this study — non-eaten food, is unlikely to be any significant feed source for ruminants in this region. Even if we assumed a use of 50 percent of the amount generated, which almost certainly would be an overestimate, it would constitute no more than a few percent of the total feed mix for ruminants. In summary, we believe that this ‘adjusted’ feed use estimate is more accurate than the original one in this study — that applies in particular to the feed use levels for forage crops and crop by-products.

As was assumed in this example with South & Central Asia, in general we believe that the estimates of the *total* feed use do not necessarily lose very much in significance due to occurrence of the indefinite feeds. That since, in this study, the feed use fully tallies with the estimated feed energy requirements. For ruminants (cattle) the balancing feed flow is permanent pasture, which in the regions where the use of indefinite feeds is significant consists of low-energy-density native permanent pasture. Since the greater part of the indefinite feeds consumed by cattle has a low energy density, the total cattle feed matter use levels in these regions are likely to be estimated rather accurately. (A corresponding probably holds for forage-vegetables for pig feed use in East Asia.)

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[192] [Simpson et al. 1994, pp. 308, 370].

**Table 3.28** Adjusted values on feed use (actual intake) for total ruminants in South & Central Asia.

| | Values in this study | | | | | Adjusted values | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Total (Tg) | Area (Mha) | Flux (Mg/ha) | Share of gener. | Share in feed mix | Total (Tg) | Area (Mha) | Flux (Mg/ha) | Share of gener. | Share in feed mix |
| ***Total all flows*** | 1170 | | | | | 1200 | | | | |
| **Feed flows in the FPD model** | | | | | | | | | | |
| Edible-type crops products | 0.5 | - | - | 0.2% | 0.0% | 1.0 | - | - | 0.4% | 0.1% |
| Animal forage crops | 271 | 34 | 8.0[a] | 71% | 24% | 120 | 15 | 8.0[a] | (71%) | 10% |
| Permanent pasture (including browse) | 446 | 347 | 1.3 | 46% | 38% | 434 | 347 | 1.25 | (46%) | 36% |
| Crop by-products | 425 | - | - | 71% | 36% | 329 | - | - | 55% | 27% |
| Conversion by-products | 24 | - | - | 3% | 2.0% | 30 | - | - | 4% | 2.5% |
| Non-eaten food | 0 | - | - | 0% | 0% | 15 | - | - | 25% | 1.2% |
| **Other feed flows** | | | | | | | | | | |
| Herbage & browse from forest land | | | | | | 85 | 114 | 0.75 | | 7.1% |
| Herbage & browse from other land | | | | | | 74 | 295 | 0.25 | | 6.2% |
| Thinning & weeding in cropland | | | | | | 110 | 150 | 0.75 | | 9.2% |

Weights in dry matter. Shares of generated amount and shares in feed mix on dry matter basis.

For the estimate of *forage from forest land and other land* we used the same approach as Singh et al. [1997] in their estimate of feed supply in India (see footnote 191 above). It should be observed that the feed flux of 0.25 Mg/ha was adopted to the *entire* area 'other land' in this region, as did Singh et al in their estimate. (For land area numbers, see Table 3.30, p. 244.) For the estimate of *thinning & weeding* we used *half of* the flux reported by de Leeuw [1997] (see previous page), adopted to an area approximately of the size of the harvested area of cereals in the region. Use of *crop by-products* as feed was lowered to a level slightly below that for Sub-Saharan Africa (56% of generated). We believe that this level is more accurate than the previous one in this study, if taking into consideration use of crop by-products for energy and other purposes (this conclusion is elaborated in the section 'Food-system-internal uses and fates in relation to other systems', p. 224). Use of *non-eaten food* for ruminants was included in the adjusted version mainly for the purpose to illustrate its possible order of magnitude. The level 25% of the generated amount was chosen arbitrarily. (Use in this study included only use for pigs, in total corresponding to 4% of generated in the region). Use of *edible-type crop products* and *conversion by-products* was increased taking into account that some 9 Tg of cereals (as-is weight) was missing in the 1996-release of FAOSTAT (see the section 'Impact of revisions and accuracy of FAOSTAT data', p. 179). Use of *permanent pasture* was slightly adjusted so that its flux agreed with that assumed by Singh et al. [1997]. (Singh et al do not explicitly state that their figure refers not only to herbage but also to browse. However, here we consider browse from (permanent) grassland as accounted for within this category.) Finally, use of *forage crops* was adjusted so that total feed use approximately tallied with that of the original estimate. Since a large amount of forage crops is replaced with low-energy-density feedstuffs, as forage from forest land and thinned-out phytomass, we slightly increased the total feed use level.

[a] Singh et al. [1997] state that average yield in India for cultivated fodder is 10 Mg DM/ha. We use the number 8 Mg/ha, assuming that all cultivated fodder is consumed in conserved form (hay) — DM loss in haymaking is assumed to be 20 percent (see the section 'Feed processing', p. 86)

On the contrary, as for the very *mix* of feedstuffs, the significance of the cattle feed use estimates is indeed reduced on account of the indefinite feeds, which the South & Central Asia example clearly demonstrates. The fact that the cattle feed mixes in the real system are much more diversified than those in this study is very likely to apply to all non-industrial regions. This means that, in these regions the feed mix components should not be interpreted straight off, that is, as being exactly what the name suggest. This applies particularly to the feed balancing flow ‘permanent pasture’ — it should not be interpreted as consumption of actual pasture (herbage), but as consumption of pasture *plus* indefinite feed flows as browse, etc. (Again, the corresponding holds for forage-vegetables for pig feed use in East Asia.)

Of importance for the accuracy of the model representation of the feed flows is also the *scope of the feed options* for the animal sub-systems, that is, whether individual flows in the model actually are included as feed options in the different animal sub-systems. In the discussion above on assignment-levels for by-products, we identified that the scope of the feed options for some of the animal sub-systems affected the levels of use of by-products and residues as feed. In the FPD model, oil crops meals and cotton meal were not included as feed options for cattle. Similarly, non-eaten food was included for neither poultry nor cattle. These omissions lowered the significance of the feed mixes in some cases, as described above.

Above we also identified that the omission of *trade of by-products* had similar consequences. Generally speaking, omission of trade of by-products does not add appreciable insignificance to the feed mixes for the total animal food sector, since for the bulk of by-products trade is as good as non-existing. However, as described above, for oil crops meals and cotton meal trade is considerable, and hence the significance of the feed mixes are reduced in some cases.

Besides these, we also see some inaccuracies owing to *omission of conversion by-products* usable as feed. In the FPD model no processing of whole milk was included. Depending on the character of milk processing, it can give rise to substantial quantities of by-products with high nutritive value (such as whey, skimmed milk and butter milk). In most regions, use of such by-products as feed is limited, and in these cases omission of them is unlikely to add considerable insignificance to the feed mix estimates. However, in the region West Europe a considerable fraction is used as feed, although the total amount yet is comparatively small — use amounts to about 20 percent as share of supply (as-is weight basis), and corresponds to approximately 3 percent of the amount of cereals used as feed (DM basis).[193] Other omitted conversion by-products which might be significant in some cases are by-products from fruit processing, such as citrus pulp and molasses from citrus juice production.

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[193] Calculated from FAOSTAT Food Balance Sheets. Refers to the flow ‘Milk ex. butter’, year-average for 1992-94.

*Feed use related to draft work and draft animals.* The feed use for draft work and draft animals influences the significance of the feed use estimates. As already has been pointed out above, feed energy requirements for draft work performed by large ruminants (cattle) were not included in this study. Nor have we included feed use for single-purpose draft animals such as horses, asses and camels. Given that our feed use estimate is accurate, the feed use for large ruminants, as well as the entire livestock sector (that is, including draft animals), should therefore be higher in the real system than in this study. In a Winrock-study referring to 1977-78, the feed energy requirement for draft animals alone was estimated to slightly more than 10 percent of the requirements of total livestock sector (ME basis).[194] However, most likely the relative importance of draft animals has declined since then, since the animal-food related livestock production has increased.

For obvious reasons, feed use data available for large ruminants refer to the *total* feed use, that is, also to feed consumption related to performance of draft work. Feed use data that refer to the entire animal or livestock sector include, normally, not only food-producing livestock but also draft animals. In the interpretation of the feed use data in the creation of feed balances in this study, this was not taken into account. Quite obviously, this adds insignificance to the feed use estimates. For example, in the real system small amounts of FBS feeds are likely be fed to draft animals. However, more critical is the case with crop by-products. In the real system, significant amounts of crop by-products are fed to draft animals. This implies a tendency to an overestimate of the use of crop by-products as feed in this study, since it here refers to only food-producing livestock. This, in turn, implies a tendency to an underestimate of other feed components than crop by-products, particularly permanent pasture, since the total feed use still must comply with the feed energy requirements. The regions with large fractions of draft animals and where, therefore, these tendencies are stronger are North Africa & West Asia and East Asia, and Latin America & Caribbean. In the other regions the fractions of draft animals are relatively low—of interest is that this applies not least to South & Central Asia, where we assumed a particularly far-reaching use of crop by-products.

*Phytomass appropriation*

The level of *marginal* phytomass appropriation for animal food is basically a function of feed use of phytomass products, harvest index, recovery rates as well as feed processing losses for forage crops, and pasture utilization. *Net* phytomass appropriation is determined by these factors plus the use of crop by-products as feed and animal bedding. Total marginal phytomass appropriation of the animal food sub-systems was estimated to 147 EJ GE per year globally, and net appropriation to 150 EJ per year. Any benchmarking of these numbers were not feasible since no such data were found in other sources or studies. This is essentially due to the fact that these ‘phytomass appropriation’ concepts by no means are standard concepts in food-system related studies.

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[194] [Wheeler et al. 1981, p. 43]

Below we will discuss the reliability of the estimate of marginal and net phytomass appropriation in this study. The following issues have been identified as the most critical ones:

- The adequacy of the pasture utilization concept and the accuracy of its assumed values
- The accuracy of assumed values on recovery rates and feed processing losses for forage crops
- The accuracy of assumed values on harvest index for edible-type crops
- The accuracy of assumed values on specific litter use

Use of crop by-products as feed, which affects the net phytomass appropriation, and indirectly also marginal phytomass appropriation, was discussed in the section ‘Feed use’ above and will not be dealt with further here. Inaccuracies in the representation of the phytomass production was also touched upon in that section and will not further be dealt with here, apart from the influence on the estimates of native permanent pasture.

*Adequacy of the pasture utilization concept and the accuracy of its assumed values.* The pasture utilization is probably the most critical factor for the phytomass appropriation estimates since pasture has a very dominant position in the feed mix for ruminants (permanent pasture accounts for about two thirds of the marginal phytomass appropriation for the entire animal food sector — see Figure 3.25, p. 137). As we pointed out in Section 3.1.4, the data basis for the assumption on pasture utilization was weak. Moreover, in real systems pasture utilization varies very much depending on grazing and management practices. However, since the regions cover large grassland areas, variations should be counterbalanced to considerable extent. Still, on account of the weak data basis for pasture utilization, we are forced to conclude that considerable insignificance is added to the phytomass appropriation estimates for pasture in general.

As for *native* permanent pasture, however, the very accuracy of the pasture utilization is of less importance since the phytomass appropriation associated with its intake is an equivalent-value. Phytomass appropriation for native permanent pasture *is equivalent to* the level of above-ground herbage production *if assuming grazing of a pure herbage sward* (see also the description of this part of the FPD model in the section ‘Permanent pasture’, p. 51). Thus, for native permanent pasture, the pasture utilization concept does not claim to actually describe the real level of consumption of herbage in relation to the real total above-ground phytomass production. Instead, it is an equivalent-measure that reflects that, under native-species conditions, grazing typically implies extraction of no more than about half of the herbage production above ground (values are shown in Table 3.18, p. 96).

Another aspect which contributes to lower the significance of the phytomass appropriation estimates for permanent pasture, is the fact that this flow is a balancing flow for the cattle systems. This means that permanent pasture in part also represents the ‘indefinite’ feedstuffs, such as browse, weeds etc, as we described in the preceding section. If the contributions of such indefinite feedstuffs are large, the pasture utilization concept for permanent pasture is less adequate and loose in significance. Due to lack of data of the occurrence of indefinite feeds, however, we were not able to quantify this possible loss in significance, on neither global nor regional basis. (However, an indication of the orders of magnitudes for the region South & Central Asia was given in Table 3.28, p. 211.)

*Accuracy of assumed values on recovery rates and feed processing losses.* The accuracy of the assumed values on recovery and feed processing for forage crops appreciably affects the phytomass appropriation estimates since forage crops in total makes up quite a large share — nearly 15 percent of the total for the entire animal food sector (GE basis). As for the recovery rates, we had virtually no data available and our assumptions are therefore no more than guesses based on general knowledge of the production and harvesting systems. Due to the lack of data we assumed a standard value of 90 percent (of above-ground production, DM basis) for all crops in all regions (values are given in Table 3.17, p. 94). Generally speaking, we believe that this value is more likely to be an overestimate than an underestimate, particularly in areas with low yields per ha.

For the losses in feed processing (hay-making, ensiling, etc) the data basis was somewhat better, but, yet, far from solid. Again, therefore, we adopted a flat value of 20 percent dry matter loss for all feed processing losses in all regions. Some of the data sources (given in the section ‘Feed processing’, p. 86) indicate that losses in feed processing might be higher than 20 percent — this applies especially to legume-dominated forage. Therefore, we believe that it is unlikely that 20 percent represents an overestimate of the losses overall.

*Accuracy of assumed values on harvest index.* The accuracy of assumed values on harvest index for edible-type crops influences the phytomass appropriation estimates considerably — these crops represent about 20 percent of total. The strength of the data we had available for harvest index varied substantially depending on crop category — for cereals the data basis was relatively solid, for cassava, sugar cane and soybean it was reasonable, whereas for the remaining categories the data were scanty. Since cereals is the completely dominating category among edible-type crops used as feed (makes up 18 percent of the above-mentioned total of 20 percent), we believe that the accuracy of the harvest index values is fairly good. In total, therefore, considerable insignificance is not added to the phytomass appropriation estimates on account of the harvest index values.

*Accuracy of assumed values on specific litter use.* The accuracy of the values on specific litter use affects the significance of the estimates of the net phytomass appropriation. Generally speaking, for the regions North America & Oceania and West Europe, the data basis was reasonably solid, whereas for the other regions it was virtually nonexistent. For the latter regions, therefore, the significance is rather low for specific litter use values as such (values shown in Table 3.13, p. 86). However, in most of these regions the total amount of crop by-products used as litter is small in comparison with that for use as feed, which means that, despite this weak significance, the influence on the significance for the estimate of the total net phytomass appropriation is relatively small.

A major exception from this generalization is the region East Asia where use as litter amounts to some 30 percent of the use as feed, which is mainly due to the extensive occurrence of animal bedding in the pig production systems. Another exception is the region East Europe, where the assumed specific litter use values resulted in a total use which must be considered as a substantial overestimate, particularly if seen in relation to the total amount of crop by-products generated (see Figure 3.67, p. 177). Largely this is due to the high share of animal forage crops in the cattle feed mixes which became the result of the inaccuracies in the FAOSTAT data (see the regional feed balance account above). Since East Europe is such a small region, however, these inaccuracies do not appreciably affect the significance of the global numbers. The region South & Central Asia here represents a special case. As we described in the regional feed balance account, nearly all of the available crop by-products were assigned to feed use because of a seemingly restricted supply capacity of phytomass products. For that reason, we set the specific litter use for the cattle systems to zero. We guess that, in the real system, animal bedding in cattle systems do occur to some extent, but maybe with other material than crop by-products.

*Summary view*

In summary, we believe that the significance of the estimates of productivity and specific feed energy requirements is relatively high, whereas the significance is moderate for the estimates of feed use and phytomass appropriation. In general, the significance of the estimates are likely to be higher for the whole animal food sector than for the individual animal sub-systems. Also, the estimates of the *sum* of flows, as regards feed use, for example, have much higher significance than the individual flows. Likewise, the global figures should have higher significance than those for the individual regions. Overall, the significance of the estimates are likely to be higher in the industrial regions than in the non-industrial ones. East Europe has probably the lowest significance.

We believe that it is more likely that this study underestimates rather than overestimates the specific feed energy requirements. The main reason for this conclusion is the inadequate representation of the ruminant systems, which entailed an apparent underestimate of the specific feed energy requirements for the ruminant carcass production. We see no palpable factors pointing towards an overestimate in this part of the study.

Due to this underestimate, we believe that it is more likely that this study underestimates rather than overestimates the feed use, at least so far as the global level is concerned. However, the case with feed use is less clear than that for the specific feed energy requirements. More uncertainties are involved, such as the net energy method for ruminants. There are also some factors that point towards an overestimate, such as the level of production of carcass.

For the phytomass appropriation it is even more difficult to pass any overall judgements. Drawing on what applies to the feed use estimates, it does not seem unlikely that the phytomass appropriation in this study represents an underestimate. There are no strong indications of an overestimate in this part alone.

### Vegetable food systems phytomass appropriation

Animal food commodities indeed dominate the phytomass appropriation of the food system. Still, vegetable food commodities make up as much as one third of the total appropriation on a global basis, or about 74 EJ GE per year. Of this third, cereals products account for the main part, about 60 percent — hence, some 20 percent as share of total (values are given in Figure 3.16, p. 120). Comparison of these figures was not possible since no such data were found in other sources or studies.

The relationships determining the phytomass appropriation for vegetable foods are far less complicated than those for animal foods. Basically, the level of phytomass appropriation is a function of domestic end-use level, trade, distribution & storage losses, processing efficiency and harvest index. Because of the more straightforward nature of the vegetable food systems, differences between systems and regions in efficiency tend to be considerably smaller than for the animal food systems. Moreover, the end-use per capita of vegetable food varies considerably less than the end-use per capita of animal food. On a per-capita basis, therefore, the regional variations in vegetable-food-induced phytomass appropriation are small (see Figure 3.13, p. 117).

However, this apparent regional conformity is in part a consequence of this study’s relatively simplified estimates of the vegetable food systems. Below we will discuss the reliability of these estimates. The following issues have been identified as the most important ones:

- The accuracy of the model representation of the phytomass production
- The accuracy of assumed values on conversion efficiency for vegetable food processing
- The accuracy of the model representation of the food use
- The accuracy of assumed values on harvest index
- The accuracy of the assumed values on assignment of by-products for use as food

*Accuracy of the model representation of the phytomass production*. The part of the model representation of the phytomass production that applies here is, naturally enough, the plant group edible-type crops (phytomass vector is shown Table 2.6, p. 47). On the whole, we consider the accuracy of the representation of this plant group as fairly high.

The crop product flows included in the FPD model represent about 95 percent of the total *real* production in this plant group (globally, DM basis).[195]

However, there are some crop categories for which description of the associated by-products was not included in the model, the most important ones being pulses, vegetables and fruits. The effect of this omission of by-product representation is appreciable. Let us assume that those categories lacking by-product representation would have a mean harvest index of 40 percent on GE basis (the corresponding value in this study for the entire edible-type group was 47 percent). Then the total amount of by-products generated for these crop categories would be some 4.5 EJ GE per year globally, which is about 6 percent of the total estimated phytomass appropriation for vegetable foods in this study. If we refer to Figure 3.16 (p. 120), the value for the category ‘Non-converted vegetable commodities’ would be 12.1 instead of 7.6 EJ, and its share of total would be 5.4 instead of 3.4 percent. In most regions, the influence on the significance is of the this order of magnitude or lower — the exception being North Africa & West Asia where the unaccounted by-products would amount to about 10 percent of the total estimated phytomass appropriation for vegetable foods.

*Accuracy of assumed values on conversion efficiency for vegetable food processing.* The accuracy of the conversion efficiencies in the food processing is crucial, since about 85 to 90 percent of the total phytomass appropriation of the vegetable food group is related to processed commodities (efficiencies are given in Table 3.15, p. 89). For *cereals commodities*, we believe that the assumed efficiencies are fairly accurate. The model estimate of total global production of cereals grains (that is, including use as feed) agree well with the data in FAOSTAT, about 2 percent below the value in ‘Crops primary’ and about 3 percent above the value in FAOSTAT Food Balance Sheets (FBS) (both values on DM basis). However, process data for industrial countries suggest that the efficiencies may be somewhat lower than the assumed values in this study (a couple of percentage units).[196] Also, the analysis of the production data in the FBS (see Section 3.1.3, p. 89), indicates that, in some of the non-industrial regions, the efficiencies may be a couple of percentage units higher. Thus, in the real system, the differences between the industrial and non-industrial regions may be somewhat more pronounced, and the regional values in general are likely to be more diversified.

On the whole, we think that the same pattern applies also to the *sugar systems*. The model estimate of the total production of sugar crops globally agrees reasonably well with the data in FAOSTAT, but not as well as in the case of cereals. In total, the model value falls short of the FAOSTAT value by roughly 10 percent if compared with ‘Crops primary’, and by 7 percent if compared with the FBS (both DM basis). We believe that the divergences are mainly due to food-system-external uses (according to the FBS,

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[195] Estimate from production figures in FAOSTAT Food Balance Sheets for 1992-94.

[196] Matz [1991, pp. 498-502], and Pomeranz [1987, pp. 156-157, 382, 392-393].

about 4 percent of the supply globally)[197] and the fact that use of sugar crops as feed was not included as feed option in the FPD model but was modeled by cereals grains instead (according to the FBS, use of sugar crops as feed was roughly 9 Tg DM per year globally, or about 3 percent of supply). However, the analysis of the production data in the FBS indicates that the sucrose yields in the real system may be somewhat higher in the industrial regions and slightly lower in the non-industrial regions as compared with the region-uniform value assumed in this study.

For the *vegetable oil systems*, we are less confident about the accuracy of the conversion efficiencies. The model estimate of the amount of oil crop products generated is clearly higher, but it is difficult to say by how much — possibly of the order of 10 percent or more. There are some circumstances that make an evaluation of the estimate of the oil systems particularly difficult: (1) the collection even of only the major oil crops is relatively large and diverse (such as in terms of chemical composition), (2) the group of oils is even more diverse due to the occurrence of oils as by-products from other systems (cotton, maize, etc — see further below for quantities) and (3) the food-system-external use of vegetable oils is substantial,[198] and (4) use of pulses as feed was not included as feed option but was represented by the oil crops category instead (soybean seeds).[199] We have not made any systematic analysis of these matters, but we believe that the conversion efficiencies (from crop product to oil) may be generally underestimated in this study, however, hardly by more than 5-10 percent.

*Accuracy of the model representation of food use.* Generally speaking, we believe that the accuracy of the model representation of the food use is fairly good for vegetable food. There are, however, some issues which merit discussion.

Some flows in the food use representation are *equivalent-type flows*, the largest categories being pulses, fruits and vegetables (the other ones in the vegetable foods group are tree nuts and stimulants, see food use vector in Table 2.2, p. 22). These flows are equal to the corresponding ones in the phytomass representation — hence, they remain unchanged in composition throughout the model system. For these flows, therefore, their assumed values on human ME reflect not only the ME content of the parts actually consumed, but also a number of other aspects that exist in the real system: (1) the mix, for each category, of separate crops, (2) the extent and characteristics of conversion (such

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[197] ‘Food-system-external uses’ refers to use of phytomass or converted phytomass outside the system as defined in this study, that is, use for various materials and energy purposes. The category ‘Other uses’ in the FBS corresponds fairly well to this definition.

[198] According to the FBS, on a global basis some 25% of the amount of vegetable oils supplied is attributed to the category ‘Other uses’, which probably includes purposes such as fuel, lighting, etc. This must be taken into consideration when comparing model production values with FAOSTAT production data for oil crops. (For nearly all other flow categories in the FBS, the fraction of food-system-external use is relatively low — a few percent or lower, the only significant exceptions being alcoholic beverages, ~10%, and animal fats, ~25%).

[199] According to the FBS, use of pulses as feed was roughly 9 Tg DM per year globally in 1992-94, and the modeled corresponding amount represents nearly 4% of the estimated total generation of oil crops products in this study.

as fruit juice production), and (3) the degree to which the flows actually are eaten or not (substantial quantities of fruits and vegetables are not eaten, such as peelings, pips, seeds, etc). Consequently, it is the accuracy of the assumed ME values that determines the accuracy of the level of phytomass production. In this study, we used the global average ME for each category, as stated in the FBS, for all regions. This gave an accurate model estimate of the total global generation of products for the sum of these crop categories: roughly 4 percent below the corresponding value in the FBS (DM basis).[200] However, on a regional basis, this approach with flat ME values may add appreciable insignificance, since there is considerable variation between the regions in the above-mentioned respects.

In the FPD model, *alcoholic beverages* were represented by barley beer alone. In the real system, however, barely beer accounts for only 40 percent (ME basis) of this food category globally, the remainder consisting mainly of liquor (~40 percent) and wine (~10-15 percent). Process data for grain and potato distillation indicate that their conversion efficiencies are higher than the efficiency for barley production used in this study if measured on a GE basis, whereas they are clearly lower if measured on a DM basis.[201] As for wine, we guess that the overall efficiency might be somewhat lower than for barley beer, since grape crops, presumably, have lower yield and harvest index than cereals. In total, we believe that the simple depiction with barley beer alone is unlikely to add appreciable insignificance to the phytomass appropriation estimate on a global basis, but it may do so on a regional basis.

*Accuracy of assumed values on harvest index.* The accuracy of values on harvest indices influences the phytomass appropriation estimates considerably. As was pointed out already in the animal food section above, the strength of the data we had available for harvest index varied substantially depending on crop category. For cereals, the data basis was relatively solid, whereas it was clearly deficient for white and sweet potato, sugar beet and most oil crops — for the remaining ones (cassava, sugar cane and soybean) the strength of the data was somewhere between those (values are given in Table 3.16, p. 91). Even so, on a global basis, we believe that for most crop categories, it is unlikely that considerable insignificance is added to the phytomass appropriation estimates on account of the assumed harvest index values. The major exception is the category oil crops and possibly also the starchy roots category. As for the regional values, it is likely that there is a tendency to generally lower significance, particularly for those vegetable food sub-systems related to crop categories with a poor data basis regarding harvest index.

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[200] In this comparison, the use of pulses as feed was deducted from the FBS production figure (see footnote 199 above).

[201] Boucqué & Fiems [1988, pp. 101-102] give data on typical yields for maize grain and white potato distillation. Our interpretation of the data gives conversion efficiencies slightly above 50% on GE(HHV) basis, and nearly 35% on DM basis. For comparison, assumed conversion efficiency in this study for barley beer was 43% on GE(HHV) basis, and 51% on DM basis.

*Accuracy of the assumed values on assignment of by-products for use as food.* As for the values on assignment of by-products to food use, those of interest here are the ones for the vegetable oils generated as by-products in other systems. The major ones are maize, palm kernel and cotton oil, and the minor ones rice bran and sorghum oil. In this study, 100 percent of the generated amounts of maize, sorghum, palm kernel and cotton oil were assigned to food use (see Section 3.1.6, p. 100). Clearly, this is an idealized assumption and it is very likely to be an overestimate. This standpoint is also supported by a comparison with the FBS data. In this study, the by-product oils amounted to about 15 percent of the total food use of vegetable oils globally. According to the FBS consumption data, the by-product oils (maize, rice bran and cotton oil are those stated explicitly) constitute nearly 10 percent of total. Consequently, the idealized assumption of 100 percent assignment adds a tendency to an underestimate of the production of oil crops *products*.

By-products and residues generation and importance

Most of the terrestrial phytomass production induced in the food system ends up as other flows than food ready-to-eat. In this study, the undissipated fraction of these flows (that is, excluding heat and gases) was equal to 125 EJ GE(HHV) in annual global generation, constituting about 57 percent of the estimated total phytomass appropriation of the food system. Of this, about 30 EJ was actively used within the system; active use meaning all internal fates except the categories ‘not recovered’ and ‘distribution & storage losses’ (compare Figure 3.65, p. 176). For roughly 41 EJ of the generated by-products and residues no use within the food system were stated. This amount may, therefore, be considered as a surplus of by-products and residues supplied from the food system.

Owing to the non-linear character of the by-products generation and internal use, it is difficult to perform a systematical evaluation of the accuracy of the estimates: The level of generation is determined by the overall production level in combination with subsystem-specific parameters (such as, for instance, harvest index); however, the overall production level is not entirely exogenous, but is partly also steered by the internal use of by-products as feed and food. Nevertheless, below we will evaluate some limited aspects, including comparing with some other data and studies.

In this study, the principal focus regarding the by-products and residues was to examine their use *within* the food system, with particular emphasis on to what extent such system-internal use mitigates the demand of phytomass products. It was not a *main* issue to thoroughly keep track of the down-stream course of these flows and, for instance, evaluate their actual, or potential, use in other systems. Thus, the number one priority was to estimate the levels of generation and the internal uses, whereas to estimate the system-surplus of by-products and residues was a secondary issue. This priority was reflected in the chosen system boundaries and efforts to retrieve data and is, thereby, reflected also in the varying significance of the results, as will be seen in the discussion below of the major aspects.

*Generated amounts*

*Crop by-products.* The level of generation of crop by-products is essentially a function of the level of generation of crop products and the harvest indices. In this study, the total global generation of crop by-products was estimated to 56 EJ GE(HHV) per year, or 3.5 Pg DM per year if expressed in dry weight (see Figure 3.64, p. 175 and Table 3.22, p. 129 for production values). This level is evidently in line with other estimates. A recent global estimate by Smil, referring to the mid 1990s, gave the range 3.5-4.0 Pg DM per year, with 3.75 as most likely value.[202] Our estimate of the amount of cereal straw & stover is somewhat higher than Smil's, 2.7 against 2.5 Pg DM, whereas for most other crop categories our numbers are somewhat lower. For the categories vegetables and fruits, whose by-products are not included in our figure due to omission in the model representation (see below), Smil estimated the amounts of by-products to 100 Tg DM each. Also to be observed is that Smil's global total seems to include also non-food crops such as cotton; we estimate that the amount of cotton stalk is likely to be some 90-100 Tg DM.

In general, we consider the significance of our estimates of crop by-products generation as relatively high. The significance of the values for each crop category and region depends to a large extent on the accuracy of the *assumed values on harvest indices*. As has been pointed out in the previous sections on animal and vegetable food, the strength of the underlying data for harvest indices varied substantially between the different crop categories. The most solid data available were those for cereals, whose by-products account for about 77 percent of the total in this study (see further the previous sections on p. 215 and p. 220). As for *the model representation*, we consider the accuracy from the perspective of crop by-product generation as relatively high. The major deficiency is the omission of a by-product representation for the crop categories pulses, fruits and vegetables. As we described in the vegetable food section above (see p. 217), in the real system, the total amount of by-products for these omitted categories could amount to roughly 4.5 EJ per year (equals about 270 Tg DM). The *level of generation of crop products* is calculated in the model, and its accuracy relies upon the accuracy of the entire model description from end-use up-stream to the crop production. Comparison with the data in FAOSTAT 'Crops primary' shows good accordance for cereals and starchy roots (divergence less than a few percent, DM basis). For sugar and oil crops, however, model values are below the FAOSTAT numbers by roughly 10 percent (DM basis). Largely, this is due to non-food related production, as we observed in the vegetable food section above.

*Vegetable conversion by-products*. The level of generation is basically a function of the level of generation of vegetable products and the yields of the conversion processes. In total, these flows were estimated to roughly 570 Tg DM per year globally. No sources containing coherent estimates of the corresponding category were identified. For oil crops meals, however, FAOSTAT contains data on production. For the period 1992-94,

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[202] [Smil 1999a]

the global production according to FAOSTAT was 126 Tg per year (as-is weight), to be compared with the estimated generation in this study, about 123 Tg as-is (both numbers here *include* cotton meal).[203]

For a number of separate conversion by-products, Fadel made straightforward estimates based on FAOSTAT production data and data on process characteristics.[204] Fadel estimated the total global generation of oil crop meals (including cotton meal) to roughly 110 Tg DM,[205] which is about 90 percent of the value in this study. For most other comparable flows, Fadel's numbers fall short of our estimates even to a larger extent than for the oil crops meals.

Generally speaking, we believe that the significance of our estimates of vegetable conversion by-products generation is relatively high. However, the diversity in *the model representation*, in terms of different types of commodities and processes, is much smaller than in the real system. This applies, for example, to the cereals, which involve other cereals milling processes besides those included in the model. We believe that the total values for each category do not loose considerably in significance on account of the lack of detail in the model, but for individual flows they certainly do. Other omitted processes in the model are those related to fruits and vegetables, such as juice production. However, on a global basis, the total amount of by-products from these omitted processes are unlikely to be more than 1-2 percent of the total vegetable conversion by-products. (For instance, Fadel estimated the global amount of citrus pulp to about 2 Tg DM per year.[206]) As for *the level of generation*, this study considerably underestimates the level of generation of vegetable oils, in all essentials due to non-food related production. Total global generation of vegetable oils (excluding cereals germ and bran oils) in this study was about 24 percent below the corresponding FAOSTAT figure, which is about the same as the share of vegetable oils used for non-food purposes (see footnote 198, p. 219). This adds a tendency to an underestimate the amount of conversion by-products related to those products, such as oil crop meals.

*Animal conversion by-products*. The animal conversion by-products are completely dominated by manure (feces, urine and use litter). For these, the level of generation is a

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[203] From the FAOSTAT data collection 'Crops Processed', domain 'Agricultural Production'. The FAOSTAT figure refers to the total value for 'oil cakes and meals', with the values for rice and maize cake deducted, since, in the FPD model, these flows are accounted (though, not *explicitly* modeled) for within the category 'cereals milling by-products'. (FAOSTAT sum for rice and maize cake were 5.8 Tg as-is/year.) It should be observed that both the FAOSTAT figure and the model figure referred to here *include* meal from cotton seeds and other oil-yielding *fiber crops* such as linseed and hempseed — in FAOSTAT totally 14.1 Tg as-is/year, in the FPD model 17.9 Tg as-is/year. (In the FPD model, these flows are formally considered as 'system-external inputs' — they are here added to the actual *oil crops* meals only for the sake of comparison.)

[204] [Fadel 1999]. Estimated values refer to 1993.

[205] Analogous to the numbers in FAOSTAT and in the FPD model referred to above, the figure 110 Tg include the numbers stated by Fadel for cotton meal and alike, but not those for corn germ meal and corn gluten feed and meal'.

[206] [Ibid.]

function of level of feed use and the composition of the feed. In this study, the total global amount of manure was estimated to 47 EJ GE(HHV) per year, of which about 4 EJ was used litter (compare Figure 3.59, p. 171). In rough terms, the total corresponds to about 3.1 Pg DM. Although we have not identified any recent, well-founded estimate of the global manure production, we assume that our estimate exceeds most others since our level of feed use, evidently, is higher than the established opinion (see the section ‘Feed use’, pp. 191 sq.).

The significance of the manure estimates depends, in essence, on the significance of the feed use estimates. Hence, what was said regarding the significance of the feed use (see the sub-section ‘Feed use’, p. 191) applies also here.

As for animal conversion by-products besides manure, there is particularly one aspect, regarding the accuracy of the model representation, that reduces the significance: In the model no processing of whole milk (such as, cheese production) was included. In the real system, processing of milk does occur to a considerable extent, and depending on the character of the milk processing, it can give rise to substantial quantities of by-products (such as whey, skimmed milk and butter milk). A rough estimate, based on analysis of FAOSTAT production data, indicates that the total amounts may be of the order of 20 Tg DM per year globally.[207]

*Food end-use residues*. The level of generation for non-eaten food is a function of the level of food end-use and of actual food intake, and for the human feces and urine it is a function of actual food intake and food composition. Global annual generation of non-eaten food was estimated to 410 Tg DM, and human feces and urine to 150 Tg DM. We have not found any comparable numbers in other studies for these flows, neither on global nor regional basis. Overall, the significance of the generation estimates must be considered as relatively low. This is mainly due to the low significance of the regional values on food intake per capita, which were based on very few data (see the section ‘Food intake per capita’ p. 63). For the non-eaten food estimate, also the lack of partitioned description in the model for the equivalent-type vegetable flows, especially fruits and vegetables, adds some insignificance.

### *Food-system-internal uses and fates in relation to other systems*

The intention with this section is to evaluate the estimates of the (total) use within in the food system as well as the resulting system-surplus (that is, the amount ‘not specified’) of by-products and residues, particularly taking into consideration (1) possible use in other systems than the food system, and (2) possible neglected internal fates. The main question here is: What inaccuracies and insignificance regarding the estimates of inter-

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[207] Based on production data in FAOSTAT 'Livestock Primary' and milk processing data from Miller & Boer [1988, pp. 165-166], we estimate that at least half of the global milk production is processed to cheese products and butter & ghee. At a very rough estimate, this gives rise to about 12 Tg DM of skimmed milk and buttermilk, and about 9 Tg DM of whey. It should be noted that especially the skimmed milk and buttermilk are likely to be used as human food to a considerable extent.

nal use and surplus do these aspects suggest? (The estimates of internal use *in relation to the using sub-system* have been discussed in the animal and vegetable food sections above, and will only briefly be touched upon here.)

*General*. The distribution of the by-products & residues between on one hand ‘internal’ use, meaning all internal uses and fates, and on the other ‘not specified’, implying surplus from the system, is to a great extent a matter of system boundaries. As already mentioned, in the model used in this study, the boundaries of the down-stream description for the by-products and residues was essentially chosen with regard to the main focus of the study, which was to examine the use of by-products and residues *within* the food system. This implied that the degree of detail of the model at the point of the down-stream boundary is relatively low. From the perspective of *surplus* and use of food systems by-products and residues in other systems, therefore, the model representation must be considered as clearly deficient.

This means that the estimated amounts for the category ‘not specified’ in this study should not straight out be interpreted as the amounts being available for use, or alternatively, being used, in other systems, such as the energy system. It is true that for estimated amounts ‘not specified’ in this study, no use or other system-internal fate was assumed, but in the real system, parts of these amounts are likely to be left behind or wasted, and eventually oxidized, still being within the boundaries of the food system. Some important examples of such fates which can be considered as internal, and which were not included in the model are:

- Burning of crop by-products in field (for post-harvest burning of both stubble and cut material)
- Recycling of crop by-products to crop production through composting (together with other biomass flows, such as manure, human excrements, processing by-products, etc)
- Recycling of manure (including crop by-products used for bedding) and other by-products and residues, such as human feces & urine, to crop production

As for the accuracy of the data in general, for the *recovery rates* of manure and food residues (non-eaten food and human feces & urine) the quality of the data was particularly low; we had virtually no data available. Due to the lack of data, for manure generated in confinements and for food residues, we assumed a flat rate of 90 percent of the amount generated; for manure generated at grazing, recovery was assumed to be zero. Correspondingly, the data basis was very deficient also for the *distribution & storage losses* for all by-products and residues, and the assumed values are not much more than guesses (for values, see Section 3.1.5, p. 98).

In summary, on account of inadequacies in the model representation, the significance of the distribution between ‘not recovered’, ‘losses’ and ‘not specified’ for crop by-products, manure and food residues must be considered as low. Still more insignificance is added, particularly for manure and food residues, due to the weakness of the data for recovery and losses. More specific comments on these topics follow below for crop by-products and manure.

*Crop by-products*. For crop by-products, use in other systems occurs for both energy (mainly as direct fuel) and materials purposes (major examples are straw-clay bricks and walls, roofing, and board and paper making). These uses are of considerable proportions in the non-industrial regions mainly. Burning in field of crop by-products involves both post-harvest and pre-harvest burning (sugar cane only), and occur in all regions to a varying degree.

Among the external uses, direct burning for cooking and heating, and other energy purposes are the dominating ones. In Table 3.29 below, we have put together some data on the use of crop by-products and other biomass by-products and residues for energy purposes. For facilitating comparison with this study, the estimated amount of 'not specified' is also given. Included are only those regions where use of food-related by-products for energy purposes is likely to be considerable.

As can be seen in the table, for South & Central Asia the Streets & Waldhoff estimate of use of crop by-products as fuel is more than three times higher than the amount 'not specified' in this study. This is indeed a strong indication that the food-system-internal appropriation of crop by-products is overestimated in this study. This indication becomes even stronger if we also consider other possible fates, such as use for materials purposes and burning in field. As for burning in field, however, the overall availability of biomass resources in relation to demand in this region must be regarded as relatively low, and therefore we assume that this activity is of minor extent. Irrespective of the possible level of use of crop by-products for materials purposes, we consider it evident that the real extent of use as feed is lower than estimated in this study — a level similar to the one in Sub-Saharan Africa, or somewhat lower, seems to be more accurate (see Figure 3.67, p. 177).

However, it is also possible that the assumed loss rate for crop by-products, which was set to a flat 10 percent (of supply) in all regions, constitutes an overestimate in this region (as in those regions in general which have a high degree of crop by-products utilization). If so, the availability for use as feed and fuel would be larger. On the other hand, the recovery rate of crop by-products in this regions was generally set to 90 percent (see Table 3.17, p. 94) which must be regarded as very high, and is possibly an overestimate (again, see Figure 3.67 for comparison of proportions of losses and unrecovered).

Also for the region East Asia, the Streets & Waldhoff numbers seem to point towards an overestimate of the use as feed, at least if we take into consideration other uses besides feed and fuel. At a guess, based on only a few data (see footnote 126, p. 100), total use for materials purposes in this region should at least be of the order of 5-10 percent (of the amount generated).

**Table 3.29** Some regional data on biomass use for energy and this study's estimated amount of by-products & residues not used within food system.

| | East Asia | | Latin America & Caribbean | | North Africa & West Asia | | South & Central Asia | | Sub-Saharan Africa | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Per capita | Share of gen. | Per capita | Share of gen. | Per capita | Share of gen. | Per capita | Share of gen. | Per capita | Share of gen. |
| **Others estimates of use for energy** | | | | | | | | | | |
| Crop by-products[a] | 3.7 | | | | | | 1.8 | | | |
| Manure[a] | 0.14 | | | | | | 1.5 | | | |
| All biomass types except fuelwood & charcoal[b] | 5.7 | | 1.6 | | 8.2 | | 7.1 | | 5.9 | |
| **This study: Not specified use within food system** | | | | | | | | | | |
| Crop by-products | 3.6 | 41% | 3.2 | 20% | 1.6 | 19% | 0.51 | 7.1% | 1.9 | 21% |
| Manure | 1.2 | 26% | 2.2 | 11% | 0.91 | 12% | 1.3 | 17% | 0.22 | 2.5% |
| Vegetable food processing by-products | 1.1 | 65% | 2.4 | 69% | 0.96 | 62% | 1.2 | 70% | 0.71 | 69% |
| Of which estimated bagasse energy use[c] | 0.20 | 12% | 1.1 | 33% | 0.13 | 8.3% | 0.40 | 23% | 0.16 | 16% |
| All food-system-related by-products & residues | 6.7 | 40% | 9.2 | 22% | 5.3 | 27% | 4.0 | 23% | 3.7 | 18% |

Per capita values in GJ GE/capita (HHV for numbers in this study; for others estimates unspecified). Share of generated on gross energy basis.

[a] Estimates are from Streets & Waldhoff [1998] who performed a comprehensive inventory of biofuel use — specified on the categories fuelwood, crop by-products and manure — for 23 countries in 1990 in South, Central and East Asia. Direct burning of these three categories in households was the primary component of their estimates, but the authors state that in some countries it was impossible to differentiate between fuels burned in homes and fuels burned in small-scale industrial operations. The numbers shown in the table are our compilations of their country-values following the regional structure used in this study.

[b] These numbers were compiled from Hall et al. [1994] who published estimates on a country basis on biomass energy use, as well as on fuelwood and charcoal use. We compiled the numbers shown in the table by subtracting the fuelwood & charcoal figures from the total figures. Hence, they include not only food-system related biomass, but biomass in general.

[c] Refers to bagasse used internally for process energy purposes in the cane sugar process. Estimates are based on Paturau [1989, p. 10], who reports that for typical process standards, about 80 percent of the bagasse is used for process energy.

However, as mentioned above, the loss rate of 10 percent may be an overestimate, considering the high degree of crop by-products utilization in this region. In addition, for most crops the share of unrecovered by-products was assumed to be 20 percent (Table 3.17, p. 94). It does not seem unrealistic to assume that these numbers could be somewhat lower. We consider it possible, therefore, that the availability for use (that is, the amount distributed) could be higher, allowing use for both energy at the Streets & Waldhoff level as well as for materials.

As regards burning in field, post-harvest burning of rice straw is likely to be substantial in this region.[208] We had no data pertaining to this particular region, but estimates for tropical and non-industrial regions in general indicate that burning of crop by-products is of the order of 35 to 45 percent (of generated).[209] For industrial regions, burning in field is in general much lower.[210] Even if we adopt the maximum limit of 45 percent burning suggested by Smil (which, *n.b.*, includes use as fuel), this would not outright contradict the results in this study. It is true that the amount of 'not specified' in this study is only about 40 percent (Table 3.29) and that a certain use for materials purposes has to be taken into account on top of that. However, in this study, the amount of crop by-products 'not recovered' from field is not to be interpreted only as material uncut and eventually plowed-under, but in part also as material burnt in field. Since the amount 'not recovered' in this study is estimated to 20 percent (Figure 3.67, p. 177), by such an interpretation our results would be consistent with the 45 percent value.

To sum up, for the region East Asia, we do not see any strong indications, taking uses in other systems as well as burning in field into account, that the use of crop by-products as feed has been overestimated in this study. This conclusion, however, presupposes that the availability for use should be higher than estimated, roughly of the order of 5-10 percentage units higher.

For the other regions it is difficult to pass any firm judgements. The estimate by Hall for Latin America & Caribbean is remarkably low, but to a great extent this is due to inconsistencies in the country values and the estimate appears not to be significant.[211] At any rate, it seems unlikely that the use of crop by-products as fuel in this region should be as high in the East Asia region, which is far more densely populated (a factor of four per unit of agricultural area, see Table 3.30, p. 244). Thus, we do not see any strong indications on inaccuracies and insignificance for the crop by-products use in this region due to use in other systems.

As to Sub-Saharan Africa, we assume that the mean per capita use of crop by-products as fuel should be somewhere between the Streets & Waldhoff numbers for East Asia and South & Central Asia, probably closer to the former. That would imply a tendency

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[208] Smil [1999a] reports that burning in field is common in rice-growing areas with high yields and where the straw is not needed for soil conservation, mentioning Southeast Asia as one such area.

[209] Hao & Liu [1994] estimated that in tropical America, Africa and Asia, 40% of the amount of crop by-products generated was burned in the late 1970s. This figure includes both use as fuel (assumed to be 23%, based on results from Barnard & Kristoferson [1985]) and burning in field (assumed to be 17%). Smil [1999a] estimates that the most likely interval of burning of crop by-products (either in field or as fuel) is 33-45% in low-income countries, and 15-25% in affluent countries.

[210] Drawing on data for the UK, Lee & Atkins [1994] estimated that the overall burning-in-field level for straw and stover was 20% (of generated) in Western Europe in the early 1990s. In the UK, burning in field of cereals straw and stover decreased from 38% to 11% between 1983 and 1992.

[211] For quite a few countries in this region, the Hall estimate on total biomass falls short of the estimate for fuelwood and charcoal, which means that the balance, that is, the amount of other types of biomass used as energy, is negative. This applied, for example, to the data for Brazil (-1.7 GJ per capita), which makes up one third of this region on a population basis.

to overestimation of the food-system-internal appropriation of crop by-products. What was said above for South & Central Asia regarding loss and recovery rates applies also for this region. We conclude, therefore, that the use of crop by-products in other systems is a reason to assume that use as feed may be overestimated in this region.

For North Africa & West Asia, we guess that the per capita use of crop by-products as fuel should at least be at the South & Central Asia level — presumably even higher. That would imply an indication of overestimate of the use as feed. However, the same reasoning as for East Asia regarding loss and recovery rates can be applied here. In this case, we do not find any basis even for reasonable guessing, and we have to refrain from making any conclusion.

In North America & Oceania and West Europe, we believe that the significance of the estimated fates of the generated crop by-products is reasonable. However, the value of the amount of ‘not specified’ rises some suspicion (in North America & Oceania nearly 13 GJ per capita, 48 percent of the amount generated, and in West Europe, 4.7 GJ per capita, 44 percent of the amount generated). Due to this we assume that, in the real system, the amount that never leaves the field might be larger, being either burnt or plowed-under. Also, the losses are likely to be larger — of the material in total that is removed from field, the main part probably rots rather than becomes used.

*Manure*. For manure, use for energy purposes (mainly as direct fuel, but also for methane production) occurs in the non-industrial regions mainly, in most of them to a limited extent. Recycling to crop production is standard practice in all regions.

As for use for energy, the Streets & Waldhoff estimate (Table 3.29) shows that use as fuel is considerable in South & Central Asia, whereas it is almost negligible in East Asia. (For China, Streets & Waldhoff report that use of manure as fuel nowadays is phased out except in the most remote areas of northwest parts of the country.)

The estimate for South & Central Asia suggest that the amount recovered should be higher than the estimated amount in this study, implying that a certain degree of collection of manure for use as fuel should occur. This we readily accept since our numbers are based on very basic assumptions (see the introductory part ‘General’ above, p. 225). Most likely, the corresponding applies to Sub-Saharan Africa, where, we guess, the use of manure as fuel could be of the same order as in South & Central Asia, or even higher. Use at the very same level would imply that some 15-20 percent of the manure generated on pastures is collected for use as fuel.

For the other regions, we assume that use as fuel is of the same order as in East Asia, or lower (with the possible exception of North Africa & West Asia). Even if assuming considerably higher usage than in East Asia, in none of the regions that alone would imply an indication on that the recovery of manure have been underestimated.

It should be emphasized that even if the estimated use of manure for energy does not suggest that collection from pastures do not occur, it may do occur for other purposes, such as for manuring of cropland. This applies to all non-industrial regions, including South & Central Asia and Sub-Saharan Africa.

*Vegetable conversion by-products*. Besides feed use, some of these by-products are used also for energy purposes. There are only a few flows, however, where use both as feed and for energy are of interest, the major examples being rice hulls and sugarcane bagasse. On a global basis, these make up roughly 15 and 20 percent, respectively, of the total generation of vegetable conversion by-products (GE basis).

The dominant use of bagasse is as fuel for steam and heat generation in the cane sugar process. In the FPD model, we included an explicit description of this use, which enabled rough, regional estimates (see Table 3.29 above). Globally, total use of bagasse for process energy was estimated to 1.8 EJ per year, which is nearly 30 percent of the total surplus of vegetable conversion by-products (see Figure 3.65, p. 176). Of the bagasse remaining after that the use for process energy has been taken into account, the main part, 70 percent on a global basis, was assumed to be used as feed.

As for rice hulls, on a global basis use as feed was estimated to about one third of the generated amount. This level gives considerable scope for use for energy purposes, and we do not consider this one-third as an overestimate.

### Methane generation from enteric fermentation

The level of production of enteric methane is a function of the feed intake level and the fraction of dietary energy lost as methane, which, under normal feeding conditions, in turn mainly depends on the composition of feed, such as digestibility, but also on the rumen passage rate. In this study, global production of enteric methane was estimated to 96 Tg per year, ruminants (cattle) accounting for 95 Tg and pig for 1.2 Tg. For ruminants, the global mean methane loss was 6.4 percent of the feed intake, and for pig the corresponding figure was 0.85 percent (both on GE basis).

On a global basis, the estimated level in this study must be considered as significantly higher than the established opinion. The Intergovernmental Panel on Climate Change (IPCC) assumes that global emissions of enteric methane from domestic and wild animals falls in the range of 65 to 100 Tg per year, with 85 as best estimate.[212] A compilation of recent global estimates for emissions from domestic animals obtained the level of 80 Tg per year as the best estimate for the early 1990s.[213] A comparison of these

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[212] [Houghton et al. 1995, p. 86]. The same interval, 65-100 Tg/year, was the IPCC view also in the 1990 assessment [Houghton et al. 1990, p. 20], with the only difference that the best estimate then was 80 Tg/year.

[213] [Johnson & Ward 1996]. The 80 Tg figure was mainly based on Gibbs & Johnson [1994] and Crutzen et al. [1986], with adjustment of the numbers in these studies for the livestock census in 1990 and 1994

*Notes continue on next page.*

numbers with our estimate has to take into account emissions from (1) single-purpose draft animals and (2) feed use related to draft work performed by multi-purpose ruminants, since none of these was included in this estimate. At a rough estimate, these are likely to be in the range of 4-5 Tg per year.[214] Hence, if taking into account draft work, the estimate in this study of the emissions of enteric methane from domestic animals corresponds to a total of about 100 Tg per year.

The difference in relation to the established estimates is mainly due to differences in feed intake levels. As was pointed out in the section ‘Feed use’ (p. 191), feed use in this study is higher than in other studies, at least as far as the global level is concerned. The assumed methane factors in this study seem, on the contrary, to be well in line with the established opinion, and the global average for cattle of 6.4 percent in this study is close to what is considered as the typical value.[215]

Owing to the direct dependence on the feed intake, what was said regarding the significance of the feed use estimates applies also to the methane estimate in this study (see the section ‘Feed use’, pp. 191 sq.). What concerns the assumed methane factors, overall we believe that they are relatively accurate. However, the assumed values are not much more than simple judgements based on the digestibility of the feed categories (Table 3.14, p. 88), and methane factors calculated with equations which take feed composition parameters into account are likely to improve their accuracy.[216]

Efficiency and specific biomass use

In the results section above large number of illustrations of the characteristics of the food system were given in terms of different efficiency measures (see, for instance, p. 113). The system’s biomass metabolism was also characterized by concepts measuring biomass use and appropriation per food unit output (here named ‘specific biomass use’); concepts which can be regarded as efficiency measures focusing on the resource side. The intention with this section is to briefly discuss some general conclusions that can be drawn regarding efficiency and specific biomass use.

*Adequacy of concepts*

Efficiency is a very general word, and any concept claiming to measure ‘efficiency’ should be regarded with caution since its true meaning depends fundamentally on its

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(from FAOSTAT). This compilation referred to emissions from domestic animals (including draft animals) only. As regards wild animals, in the study by Crutzen et al, emissions from wild ruminants were estimated to be in the range of 2-6 Tg/year.

[214] Gibbs & Johnson [1994] estimated global emissions from the single-purpose draft animals alone (camels, horses and mules & asses) to 2.6 Tg/year in 1990. From a rough analysis of the assumptions by Gibbs & Johnson on draft work performed by cattle and buffalo, we estimate that the emission increment on account of draft work could be about 1-2 Tg.

[215] According to Johnson & Ward [1996], “typical” methane loss is 6% of dietary energy (GE basis).

[216] Examples of such equations are given by Johnson & Ward [1996]

underlying definitions. In this study, most of the efficiency concepts used have had food in focus on the output side. As for the input side, the focus has been exclusively on terrestrial phytomass and its derivatives.

Food is indeed the main service supplied from the system in focus here, and terrestrial phytomass — as well as the land on which the phytomass is produced — is its fundamental physico-biological resource base. However, depending on the context and perspective, the food system does provide other services than food (such as draft power and dung) — and it certainly appropriates substantial amounts of other resources than biomass and land (such as energy, water and nutrient deposits). This must be born in mind especially when comparing different parts of the system as well as different countries and regions. Generally speaking, in the industrial regions the reliance on additional resources, such as energy, is much larger than in the non-industrial regions, whereas the importance of other services than food is more pronounced in the non-industrial regions than in the industrial ones. This means, for example, that the ‘overall efficiency’ measure of the food system in Figure 3.10 (p. 114) is biased in favor of the industrial regions North America & Oceania and West Europe, if seen in a wider perspective of resource use and service production. The corresponding applies to many other efficiency comparisons presented in this study, such as those involving the ruminant systems.

The nutritional composition of the food commodities are also important. In this study, the focus is on the *energy* content of the human food intake per capita and the different flows. This quantity does not reflect wider nutritive aspects of the diets. Efficiency measures referring to other nutritive aspects, such as protein, would give a different pattern as regards differences between individual food commodities than in this study.

### *Vegetable food versus animal food*

The conversion efficiencies and overall efficiencies for vegetable food are, in general, considerably higher than those for animal food. On a global basis, the overall efficiency for all vegetable food commodities, that is, for vegetable food taken as a whole group, was estimated to 22 percent (GE basis), whereas the corresponding estimate for animal food as a whole was 1.7 percent, giving a factor of 13 in difference (see Figure 3.14, p. 118). Analogously, vegetable food appropriates in general much less phytomass per food unit than does animal food; this applies even if we take into consideration only the appropriation of phytomass on cropland. The global mean for cropland-phytomass appropriation per food unit for animal food commodities, taken as whole, was estimated to nearly 5 times that for vegetable food (see Figure 3.15, p. 119).

It is essential to realize that these numbers are highly aggregated averages of figures for separate animal and vegetable food commodities as well as regions. For animal food, the variations in efficiency between different commodities and regions are enormous. The efficiency differences for vegetable food are smaller, but yet considerable (see Figure 3.19, p. 122). Hence, it is not the case that vegetable food always is much more efficient than animal food — the outcome depends more specifically on which commodities and production systems that are being compared.

As an illustration of this we can take the efficiency of the pig production in Sub-Saharan Africa. The overall efficiency was estimated to 18 percent, being of the same order of magnitude as vegetable food in that and other regions (see Figure 3.20, p. 122). The main reason for this high value is the very large share of by-products and residues (in total about 85 percent) in the estimated feed mix and, therefore, appropriates relatively small amounts of phytomass products. It is true that, as discussed above (the section ‘Feed use’, p. 203 sq.), this share may be an overestimate as far as the average of the entire region is concerned, but there are certainly individual pig herds in this region, as well as other non-industrial regions, with this far-reaching reliance on by-products and residues. In any event, this example demonstrates that animal food systems may be considered as efficient in comparison with vegetable food systems in those cases where the feed base to a large extent consists of by-products and residues.

The significance of the efficiency estimates varies considerably, depending on the significance of the underlying quantities, such as feed and feedstock use, phytomass appropriation, and so on. Thus, some of the estimated differences in efficiency may not be significant. Such a case is the obtained difference in global mean overall efficiency for vegetable oils and alcoholic beverages (Figure 3.19 p. 122). This difference is entirely due to the difference in commodities utilization efficiency (compare Figure 3.21, Figure 3.22 and Figure 3.23, p. 123 sq.). Generally speaking, theses estimated commodities utilization efficiencies have relatively low significance, mainly owing to the fact that the data basis for estimating total actual food intake — which is the major determining factor as regards commodities utilization efficiency — was weak. Even weaker was the data basis for the assumptions on differences in food intake for separate food commodities (values on the latter given in Table 3.5, see the section ‘Food intake per capita’ p. 63). (As to the significance of other efficiency measures, see relevant parts regarding feed use, etc, above.)

### *Ruminant commodities versus other animal food*

As was pointed out in the section ‘Productivity and specific feed energy requirements’ (p. 180), ruminants have comparatively low reproduction and growth rates. This is essentially why ruminant meat systems generally have much lower overall efficiency than pig and poultry meat systems. On a global basis, the average overall efficiency for the beef cattle carcass system was estimated to 0.4 percent (GE basis), whereas the corresponding estimates for the pig and chicken carcass systems were 6.3 and 3.7 percent respectively (Figure 3.19, p. 122). Even for dairy bulls & heifers the overall efficiency was no more than 0.7 percent, which is remarkable since this sub-system includes only feed for the raising of surplus dairy calves and, thus, do not include feed for the reproductive functions.

What is often perceived as a problem with animal food is that its production consumes cereals grains — grains which if consumed by humans directly instead, would be sufficient for more people, and thereby mitigate food insecurity. The main targets for this criticism are pig and poultry production, as well as cattle systems based on high-grain rations. In our opinion, this criticism misses the main point. We agree that there is an element of competition between crops for more or less direct human consumption and crops for consumption by livestock. From our point of view, however, the core of this issue is competition for *cultivable land* rather than competition for cereals — or any other specific crop being used as feed. This is due to the fact that essentially all crops for human consumption are of annual or biennial type and require cultivable land, that is, cropland, for its production. Hence, cropland is an indispensable resource for vegetable food production. From the perspective of competition between vegetable food and feed for animals (as well as for other important services from cropland), we therefore consider it essential to focus on to what extent animal food systems appropriate cropland, irrespective of the form.

A not unusual argument for justifying ruminant meat systems despite their low conversion efficiency, is that they rely on "non-competitive resources" as permanent grassland and fibrous by-products — implying, thus, that the relative appropriation by these systems of "competitive resources" is minor in comparison with other animal and vegetable food systems.[217] This notion of non-competitiveness as regards these resources is, for one thing, highly questionable. Irrespective of that, if counted per food unit produced from the system, it is quite clear that the ruminant meat system's appropriation even of cropland resources alone may be considerable, also in comparison with the pig and poultry meat systems.

In the industrial regions, West Europe and North America & Oceania, the appropriation of cropland phytomass per food unit for beef cattle carcass was estimated to be about 4 times as high as those for the pig and chicken meat systems, or 60-70 units of phytomass appropriated per unit of meat eaten (Figure 3.70 below). These high figures are mainly due to a relatively high share of the cropland-related feedstuffs in the feed mix, about 50 percent (see Figure 3.29, p. 140), in combination with the inherently low reproduction and growth rates of the beef cattle systems. These numbers are average values for the entire regions, and there are, of course, considerable variations between herds and farms as to the share of cropland phytomass in the feed mix. However, the share of cropland phytomass is likely to be generally high, particularly for economic reasons, but also because of considerable winter periods.

In most non-industrial regions, the appropriation of cropland phytomass per food unit for the cattle meat systems are lower, but yet in the same order of magnitude as the pig and chicken meat systems — except for Sub-Saharan Africa, where it is negligible (Figure 3.70). The global average of the appropriation of cropland phytomass per food unit for the cattle meat systems is therefore — despite a low share of feed mix (about 18 percent) — about 2-3 times as high as those for the pig and chicken meat systems.

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[217] For example, Fitzhugh [1998] states, in a discussion on competition between livestock and mankind for nutrients, that "The truth is that meat and milk from the world's ruminant population are produced primarily from conversion of forages, crop residues, and other noncompetitive field resources." (p. 228).

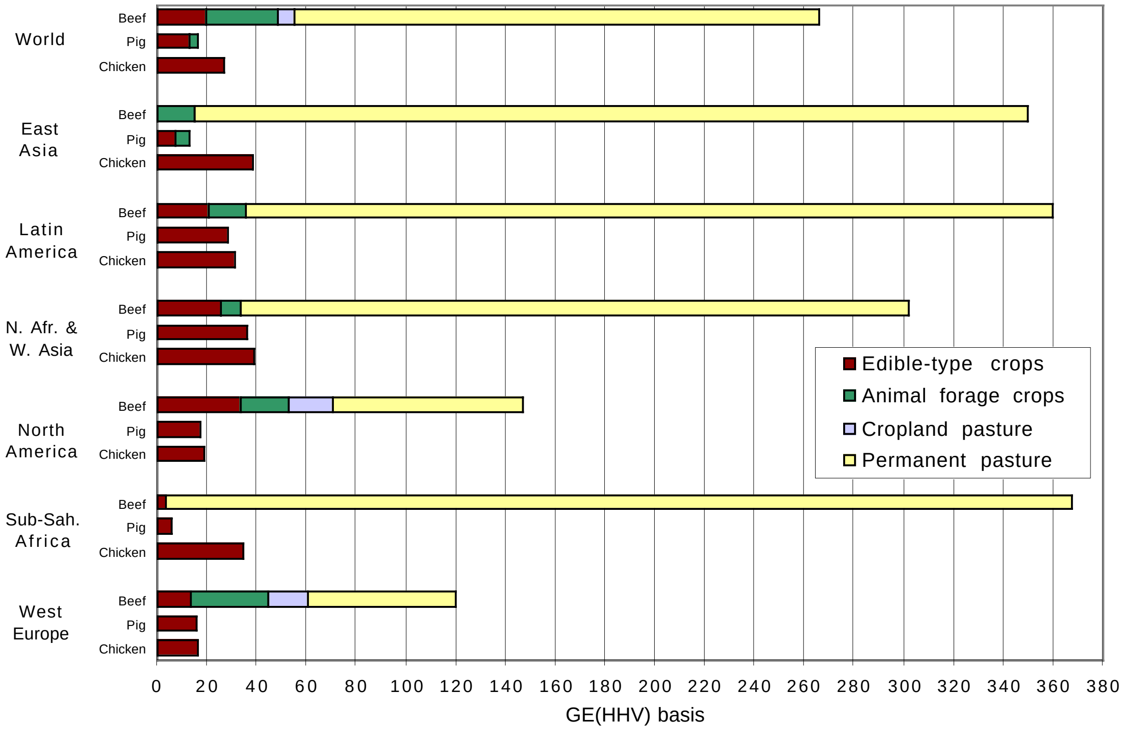

**Figure 3.70** Estimated phytomass appropriation per meat unit eaten for a selection of regions (East Europe and South & Central Asia omitted).

To conclude, for the ruminant meat systems, cropland phytomass is not a dominating component regarded *as share of* the feed mixes. That the amount of cropland phytomass *per food unit* produced, despite this, is of the same order as for the pig and poultry meat systems, or even far larger, seems to be largely neglected. Clearly, there are numerous uncertainties behind these estimates, as have been discussed above. Yet, we believe that the estimated order of magnitude on the global level holds relatively well. Particularly the values for West Europe and North America & Oceania are likely to have relatively high significance, since the data material for these regions was generally more solid than in the other ones.

## Influence of trade

The food phytomass appropriation in each region is a consequence of the food end-use within the region plus the net of exports and imports. In this study, the relative importance of these two components was estimated, taking into consideration all major trade flows. In most regions, the estimated net influence by the trade flows is minor (see Figure 3.8, p. 112). There are only two regions where the *net* of trade flows has a considerable impact on the level of the phytomass appropriation within the region: In North Africa & West Asia, where the net-import covers some 30 percent of the region's required food-induced phytomass appropriation, and in North America & Oceania, where about 27 percent of the total food phytomass appropriation within the region is due to net export of food.

To our knowledge, few comparable estimates of this kind are available. In a study performed by the Wuppertal Institute, trade of agricultural products for EU-12 in 1990 was estimated to give net-import corresponding to about 0.037 ha per cap of agricultural area, which was nearly 10 percent of total (0.40 ha per cap).[218] For the region West Europe in this study, we obtained a net-import of food phytomass corresponding to just 1 percent of total (Figure 3.8). These estimates are not entirely comparable, since the variation in yield per ha between different crops is considerable.[219] If yields were taken into account in this study, most likely the results would be closer to those of the Wuppertal study.

We consider the significance of the estimated influence of trade on the regional phytomass appropriation we consider as relatively high, with the exception of the region East Europe. In that region, FAOSTAT data on net-trade were apparently corrupted and net-import for the region was calculated as a balance of the net-import of the other regions (see Section 3.1.5, p. 98). Nevertheless, it is possible that this approach produced relatively accurate trade-values for this region, but having no verification we are forced to consider the significance as low.

Despite the approach with East Europe as balancing region, in some cases the FAOSTAT data on net-import had to be adjusted in order to avoid outright unreasonable results. Due to apparent inconsistencies between the FAOSTAT data and the model structure, negative production values were obtained for some products in East Europe, and were adjusted so that they at least exceeded zero.[220] Inversely, adjustments were also made to *reduce* obtained production values in East Europe.[221] The total influence by these adjustments is discernible only for Latin America & Caribbean — taken together, they reduced the phytomass appropriation in that region by approximately 10 Tg DM, or 0.3 percent of total. In all other regions, the effects are smaller.[222]

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[218] Spangenberg [1995, p. 54]. The estimated land balance consisted of net-import for arable land (incl. land under permanent crops), 0.039 ha/capita, and net-export for grassland, 0.0018 ha/capita. In addition to food commodities, these figures included also trade of cotton and natural rubber (in total, net-import corresponding to 0.0044 ha/capita).

[219] For example, average yields for coffee and cocoa beans are very low, around 0.5-0.6 Mg/ha — a factor of 5-10 lower than average yields for cereals grains. In the Wuppertal study, the import of coffee and cocoa commodities accounted for nearly half of the total estimated net-import balance (0.017 ha/cap).

[220] Export of cane white sugar was decreased from 8.1 to 3.6 Tg in Latin America & Caribbean. Soybean oil export from the same region was decreased from 1.6 to 1.1 Tg. Canola oil export was decreased in West Europe from 1.0 to 0.7 Tg. Groundnut oil export was increased in Latin America & Caribbean from 0.1 to 0.2 Tg. Rice export was decreased in East Asia from 8.3 to 6.2 Tg. For groundnut pods, export from East Asia was decreased to zero (from a share of 5% of supply), and export from Latin America & Caribbean decreased from 0.3 to 0.2 Tg. Pulses export was decreased in North America & Oceania from 1.3 to 0.9 Tg. (All values in DM.)

[221] Palm oil export from East Asia was increased from 2.5 to 3.2 Tg.

[222] It should also be noted that the FAOSTAT value on cassava import to West Europe was interpreted as cassava meal (DM density about 90%), and not cassava fresh tubers (DM density about 35%). By interpreting the FAOSTAT value on the cassava export from East Asia in the same way, reasonable accordance was achieved, that is, the balancing trade value in East Europe came close to zero.

Another aspect that affects the significance of the estimated influence of trade is that trade was not included for every flow for which, in the real system, trade is appreciable. Among the *products* in the system, this applied to the *cereal products* (cereal flours, etc) since trade data for these flows were not available in the FAOSTAT Food Balance Sheets (Section 3.1.5, p. 98). However, trade of cereal products between the regions in this study seems to be insignificant.[223] Trade of *live animals* occur to some extent, but is likely to be of no appreciable importance for our estimates.[224]

As regards *by-products*, no trade whatsoever was included in this study since trade of by-products was not an option in the FPD model. The relative extent of the trade flows seems to be largest for cereals milling by-products, oil crops meals, beet pulp and molasses.[225] It is mainly for cereals milling by-products and oil crops meals that the magnitudes of the trade flows are large enough to appreciably affect the significance of the estimated influence of trade on the regional phytomass appropriation. We have no specific idea of how trade of by-products should be considered in a trade-neutral evaluation, but at any rate we believe that omission of trade of by-products is unlikely to affect the estimates by more than 1 percent. The major exception is West Europe, where the effect might be of the order of 2-3 percent towards a higher trade-neutral value.

Comparisons with previous knowledge and studies

In the thematic sections above, several comparisons with other studies have been made for separate issues in the system. In this section, we will make some complementary comparisons. We will also focus more thoroughly on one of the most critical parts of the estimate, the animal feed use, and discuss possible causes behind apparent divergences from other estimates.

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[223] More comprehensive trade data than in the FBS are available in the FAOSTAT domain ‘Agriculture & Food Trade’. For ‘flour of cereals’, stated total trade flows for ‘developed countries’ and ‘developing countries’ are only around 0.1 Tg/year (average for 1992-94), which is about 0.01% of the estimated global production in this study.

[224] Total trade flows for ‘developed countries’ and ‘developing countries’ are around 1-3% of the global stocks, but in net-trade terms all values are less than 1% of total global stocks (1992-94 averages).

[225] Total trade flows for ‘gluten feed and meal’ and ‘bran + milling products’ for ‘developed countries’ were around 8 and 2 Tg/year respectively, which taken together is some 6% of the estimated global generation of cereals milling by-products in this study (rice hulls excluded). Exports and imports more or less balanced each other. For ‘oilseed cake meal’ total imports and exports for ‘developed countries’ were about 31 and 14 Tg/year respectively, giving a net-import of 17 Tg — thus, even the net-trade value is large in comparison with the total global production of oilseed meals, around 125 Tg/year including cotton meal (For gluten feed and meal, and oilseed cake meal, see also footnote 180, p. 205). For ‘beet pulp, dry’, total trade flows for ‘developed countries’ are around 2 Tg/year and the net-import about 0.7 Tg/year, being 12% and 4% respectively of estimated global production in this study. For ‘molasses’, imports and export are 6.5 and 2.2 Tg/year, giving a net-import of 4.3 Tg; which are to be compared with the estimated global production of 34 Tg/year. For brewery and distillery by-products, trade seems to be minor — for ‘developed countries’ it was about 2-3% of global estimated production (FAOSTAT flow ‘dregs from brewing + distilling’). The same seems to apply for meat and bone meal — trade for ‘developed countries’ was around 1-3% of estimated global production. (All numbers as-is weight, 1992-94 averages.)

### *Appropriation and extraction of phytomass*

The concept of ‘appropriation’ of biomass — or other natural resources and services — is rarely used in studies involving the food sector, and opportunities for comparisons are few. In a study on the total human appropriation of terrestrial as well as aquatic net primary production (NPP), terrestrial NPP appropriation attributed to the food sector was estimated to 3.0, 35 and 45 Pg DM per year (early 1980s) depending on the system boundary for the estimate.[226] The first figure refers only to direct consumption of organic material as food and feed; the corresponding value in this study is 6.5 Pg DM (0.88 and 5.6 Pg for food and feed, respectively). The second figure refers to NPP ‘co-opted’, and includes, among other things, materials being used in human-dominated ecosystems. In principle, this concept is relatively close to the concept of ‘appropriation’ used in this study, and some elements might be comparable, such as the estimated figures of NPP co-opted on cropland (15 Pg) and grassland (12 Pg). However, these figures include to a large extent production not only above-ground but also below-ground. They are, therefore, much higher than the figures on ‘phytomass appropriation’ in this study, which basically only included above-ground production: 7.3 Pg for cropland and 5.6 Pg for permanent grassland.

As regards extraction, or harvest, of phytomass, the number of studies might be larger than for appropriation. However, the number of estimates on a global and region level that involves those crops that are not included in FAOSTAT, that is, forage and fodder crops, seems to be very few. And there are certainly even fewer studies including estimates of the extraction, or grazing, of pasture.

In a recent study on global nitrogen flows in crop production, Smil estimated the global harvest of grass-legume forages in the mid 1990s to 500 Tg DM per year.[227] In this study, global harvest of grass-legume forages was about 710 Tg DM per year. Of this, the region East Europe accounted for about 160 Tg, a figure which definitely is an overestimate due to the inaccuracies in the FAOSTAT data on cereals feed use (see the section ‘Impact of revisions and accuracy of FAOSTAT data’, p. 179, and the regional feed balance account, p. 193). At a guess, it may be an overestimate of the real grass-legume harvest with some 60-70 Tg DM. Furthermore, the region South & Central Asia accounted for as much as 340 Tg of the global figure, that is, nearly half of the total. As has been discussed above, insufficient representation of the feed flows in the model implied that the level for forage crops was most likely too high in this region (see the section ‘Feed use‘, pp. 197 and 207). Adjustments taking into account this deficiency suggest that the overestimate might be of the order of 180-190 Tg DM, measured as harvested amount (see Table 3.28, p. 211).

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[226] [Vitousek et al. 1986]. The numbers are our own interpretation of which of the author’s entries that may be attributed to the food system.

[227] [Smil 1999b]. Relying on statistical data for about 20 of the world’s largest countries, Smil estimated the cropland area under grasses and legumes to 100-120 million ha in the mid 1990s, of which green manures (legumes grown for being plowed under) were estimated to account for no more than 20%. An assumption of a mean yield of 4-5 Mg DM/ha gave the total estimated harvest of about 500 Tg DM.

These adjustments for East Europe and South & Central Asia would get our estimate below Smil’s figure. However, to the harvested amount grass-legume in this study we should also add the amount of grass-legume grazed directly on field — that is, cropland pasture — since this category, as far as we can tell, is included in Smil’s figure. The global above-ground production of cropland pasture was estimated to 200 Tg DM per year (in North America & Oceania and West Europe exclusively), and the amount extracted, that is, grazed, was estimated to 130 Tg DM. For this category in these regions, however, the assumption by Smil of a yield of 5 Mg DM per ha is almost certainly an underestimate — a level somewhat higher than this is probably more accurate.[228]

Smil also estimated the dry matter harvest — or rather, the *production*; at least so far as the by-products are concerned — of products and by-products for those crops included in FAOSTAT. In total, they were estimated to 2.75 and 3.75 Pg DM per year (the crop by-products estimate was already referred to in the by-products section above, see the section ‘Generated amounts’, p. 222). The corresponding numbers in this study are 2.5 and 3.5 Pg DM — to these, however, is to be added non-food crops, such as cotton, which at a rough estimate should be of the order of 150-200 Tg DM including by-products.

### *Feed use for animal food production*

On the global level, studies of animal and livestock feed use are few. Even fewer are those that are based on estimates of the total feed energy requirements and, thereby, in principle, include the *total* feed dry matter intake.

In a Winrock-study referring to the years 1977-78, global feed energy requirements for livestock excluding draft animals were estimated to about 32 EJ ME per year.[229] If the Winrock-numbers are adjusted, livestock category by category, for the increases in product output since 1977-78 the energy requirements for 1992-94 translates into about 42 EJ ME. In this study, total feed intake, expressed in sum-ME, was estimated to 47 EJ. This could be regarded as a fairly good accordance, considering the large uncertainties involved. However, not only have the production levels increased since 1977-78, but so have also the productivities of the animal food systems, which means that the adjusted Winrock-figure is an overestimate. In addition, ME is not a solid basis for comparisons since for ruminants, feed energy requirements expressed in ME have to be adjusted for the ME density of the eaten ration, which means that ME values are not directly comparable unless the rations are similar. Also, the ME content of one unit of a particular feedstuff is different for different livestock species. Thus, it is indeed questionable to add ME values for different systems and species.

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[228] For example, in Sweden — which has a relatively short growing season — typical above-ground production for cropland pasture is around 7 Mg DM/ha [SNV 1997, p. 107].

[229] [Wheeler et al. 1981, p. 43]. Requirements are specified for poultry meat, poultry eggs, sheep & goats, beef & veal (cattle & buffalo meat, we presume), cattle & buffalo milk, swine, and draft animals.

A more recent estimate is a study of livestock production and agricultural residue management performed with the integrated assessment model for climate change IMAGE.[230] In that study, global feed use was estimated to 4.8 Pg DM per year in 1990, distributed on 'grass' 2.9 Pg, 'residues' 1.0 Pg and 'crops' 0.89 Pg.[231] The feed categories are not identical to those in this study, but the following numbers may be considered as the corresponding ones: pasture plus forage crops 3.6 Pg, crop by-products 1.1 Pg, and remaining categories 0.85 Pg, giving a total of 5.6 Pg DM per year. The difference in total feed use lies almost exclusively in the ruminant sector: In the IMAGE-study, feed use by animal category was 4.0 Pg DM for ruminants, 0.51 for pigs and 0.31 for poultry ; in this study, corresponding numbers are 4.9, 0.43 and 0.29 Pg DM, respectively.

Obviously, the feed use for ruminants in this study is higher than the established level. Related to the high feed use, we see another discrepancy, regarding the pattern for crop by-products used as feed: As share of the amount of crop by-products generated, use as feed is evidently overestimated in some regions, whereas as share of feed mix, use seems to be underestimated. Below we will list possible reasons for these apparent discrepancies.

As have been discussed above, there are several possible inaccuracies in the ruminants feed use estimates in this study. Among those which are the most likely to have contributed to an *overestimate*, we believe are the following. (We should also keep in mind that there are possible inaccuracies which are likely to have contributed to an *underestimate*.)

*i)* The level of production for the ruminant systems is overestimated in this study.

In this study, the levels of production are not exogenous parameters, but are calculated in the model. In comparison with the FAOSTAT production statistics, the global modeled production of cattle meat was clearly too high in this study, whereas the milk production was somewhat too low (see the section 'End-use per capita and level of production', p. 188). In total, we consider it quite clear that, in relation to FAOSTAT, the equivalent number of cattle was overestimated by approximately 5 percent in this study.

*ii)* The net energy method for ruminants is not accurate for low-productive ruminant systems using low-energy density feedstuffs.

The equations used in this study for estimating the net energy value of feedstuffs are not empirically verified for the lower ranges of feed energy densities (around 9.0 MJ DE/kg DM or lower) which are typical for the dominant feedstuffs in the non-

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[230] [Bouwman et al. in prep].

[231] The global feed use figure is the sum for 17 regional estimates. 'Crops' includes, using the terminology in this study, edible-type crops products and vegetable conversion by-products; 'residues' are essentially crop by-products; 'grass' includes grass, whole-cereals and other roughages.

industrial regions, native permanent pasture and crop by-products (see p. 201). Even though we do not see any obvious reasons to assume that the equations are not valid in these ranges, this is a fact that leaves such a possibility open. (Another question that also may be raised here is whether the equations for estimating the net energy *requirements* (given in Chapter 2) are valid under conditions exceptional from a metabolic point of view, such as prolonged starvation periods — the latter is not uncommon in low-productive ruminant systems during the dry/cold season.)

However, in our opinion, there are also arguments in favor of this study's feed use estimates in relation to many other estimates. The feed use numbers in this study are based on some essential characteristics which are lacking for many other published feed use numbers. Hence, we believe that, in many cases, published feed use data are underestimates.

*i)* The estimates of feed energy requirements for ruminants in this study are based on detailed animal-category modeling and are matched with productivity statistics.

In this study, feed use estimates were based on relatively detailed modeling of each of the ruminant sub-systems, including descriptions on a *daily* basis, for each principal animal category[232] separately, of liveweight and liveweight gain, and the feed energy requirements corresponding to the liveweights and liveweight gains (see the section 2.3, p. 26). Together with other parameters, such as calving rate, milk production, mortality rate and carcass yield — described mainly on an annual basis — a relatively firm link was obtained in the model description for the ruminant systems between on one hand offtake and production (carcass, milk) per number of animals-in-stock, and on the other the feed energy requirements per number of animals-in-stock. By matching the offtake and production of milk and carcass per animals in the model with the corresponding region-specific figures, compiled from FAOSTAT, a direct coupling was obtained between the (productivity) statistics covering an entire region and the corresponding feed energy requirements in that region.

To our knowledge, this approach has never been used before in feed use estimates on regional and global levels. A relatively common procedure is the one of 'representative animal types'. In that approach, productivity characteristics assumed to be representative for the region in question are set, feed requirement for these characteristics calculated, and then multiplied by the number of animals in the region (the latter taken from livestock statistics).[233] Thus, that approach includes no explicit or systematical checking whether the assumed representative animal types are consistent with animal production and productivity statistics for the region in question.

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[232] Cow, replacement heifers and growing bulls & heifers.

[233] For example, this approach was used in Gibbs & Johnson [1994].

*ii)* The estimates of feed use in this study are based on complete feed balances.

In this study, feed dry matter intake for each animal category in the ruminant subsystems fully tallies with the calculated feed energy requirements for the category. Although the mix of different feedstuffs may not be accurately estimated, this approach at least gives a basis for a reasonable estimate of the *total* feed intake. This is by no means a unique feature, but on the other hand nothing that can be taken for granted as regards published feed use numbers in general. A not unusual approach is to give feed use numbers based on the estimated availability (supply capacity) for each of the feedstuffs. Hence, the estimated 'use' is based mainly on supply considerations alone, rather than considerations of requirements and supply in combination, which means that the supply does not necessarily comply with the requirements.[234]

There are certainly good reasons for this approach; however, it does entail a tendency to overlook certain types of feed use (or more exactly, types of feed supply). Among such feedstuffs are those which were designated above as 'indefinite', that is, browse, weeds, etc (see p. 209). Besides these, other feeds that tend to be neglected in such supply accounts are those from grazing on 'minor areas', such as roadsides, backyards and small fields.[235]

As regards use of crop by-products as feed, our impression is that there is an established opinion saying that crop by-products contribute approximately half of the feed ration for ruminants in the non-industrial regions.[236] This is a generalization, of course — as has been shown above in the section 'Feed use' (p. 191) there is considerable variation between different areas. Yet, in this study, the shares of crop by-products in cattle diets in the non-industrial regions were no more than roughly 30 percent (see Figure 3.30 and Figure 3.31, p. 140), which we consider being too large a deviation from the (seemingly) prevalent opinion to be left without comment. As *share of the generated amount*, use of crop by-products as feed clearly seems to be overestimated in most of these regions (the section 'Food-system-internal uses and fates in relation to other systems', p. 224).

This apparent discrepancy may to a great extent be explained by the relatively high total feed use for ruminants in this study. However, not entirely — a total feed use 20 percent lower than in this study would imply an increase of the 30-percent figure to about 37-38 percent.

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[234] For example, in Simpson et al. [1994] (China), 36% (ME basis) of the calculated feed energy requirements were not accounted for on the supply-side; in Singh et al. [1997] (India), 37% (DM basis) were not accounted for.

[235] In Simpson et al. [1994] none of the feed types listed here as 'indefinite', or grazing on minor areas or non-eaten food were included in the supply-account.

[236] As an exponent of this opinion we may take Verma & Jackson [1984] who, referring to developing countries, state that "In many parts of the world today straw makes up 60 to 90 per cent of the bovine diet. Nearly half of the world's bovines is reared and maintained on diets of 50 per cent or more of straw."

We see one major argument in favor of this study's numbers in relation to many other published figures. In this study, generation and availability (for use) of crop by-products on the one hand, and total feed requirements on the other, are endogenously calculated for each of the regions. Thus, *both* the *total availability* of crop by-products and its *proportion to the total feed requirements* are estimated *for entire regions*. In addition, both these estimates have been based on statistics (FAOSTAT) for each region. Most published figures on the use of crop by-products as feed are not based on regional-scale analysis of availability and total requirements in combination.[237] Rather, most published numbers refer to individual countries, or parts of countries, but even then they are normally not based on a coherent description of the total crop by-product availability and total feed use.

### 3.3.2 Phytomass appropriation in relation to the land use of the food system

One of the major aims of this study was to estimate the total appropriation of terrestrial phytomass induced by human food intake. A question of obvious interest is: What are the relations between the estimated appropriation of phytomass and the corresponding use of land? In this section we will briefly look into this issue.

The food system is the dominating user of cultivated land (or 'arable land') and permanent grassland (or 'permanent pasture') — for grassland, however, the dominance is far less pronounced than is the case for cultivated land. Apart from these land categories, the food system also relies on extraction of phytomass from forest land and other, miscellaneous land types (this was briefly illustrated above, see pp. 207, 211). Hence, in principle, the land appropriation of the food system extends over all major land categories. In Table 3.30, data are given on the regional extension of these major land categories.

The numbers in Table 3.30 are taken directly from FAOSTAT, and it should be observed that the data are subject to quite a high degree of uncertainty, particularly those referring to the non-industrial regions. In general, the area of cropland (arable land plus area under permanent crops) tends to be underestimated in the FAO statistics — Smil claims that the real global area of cropland almost certainly is higher than the FAO figure, at least by about 5 percent.[238]

A simplified way to illustrate the magnitude of the food phytomass appropriation per unit area of associated land use is to relate the phytomass appropriation to the total for the two principal food system land categories, cropland and permanent grassland, see Figure 3.71. This figure shows the estimated phytomass appropriation in this study, di-

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[237] For example, the data in Renard [1997], which have been widely quoted in the discussion section above, are not based on such analyses.

[238] Smil [1999b] states that "Increases of up to 5% appear to be highly plausible…", but that absence of information precludes any satisfactory correction of the FAOSTAT figures.

vided with the *total* area of cropland and permanent grassland in each region, with separate specification for cropland and grassland (land areas taken from Table 3.30). To the cropland-related phytomass is counted edible-type crops, forage crops and cropland pasture, and to grassland-related phytomass permanent pasture (for comparison, see Figures 3.3 to 3.5, pp. 108 sq.).

**Table 3.30** Land areas related to the food system.

| | Unit | World | East Asia | East Europe | Latin Am. & Carib-bean | North Africa & West Asia | North America & Oc. | *NAm excl. Aust-ralia* | South & Centr. Asia | Sub-Saharan Africa | West Europe |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Arable land & perm. crops | Total | 1 450 | 196 | 231 | 143 | 89.7 | 285 | 238 | 275 | 146 | 85.7 |
| | Cap$^{-1}$ | 0.26 | 0.11 | 0.65 | 0.31 | 0.29 | 0.91 | 0.80 | 0.21 | 0.27 | 0.23 |
| *Arable land* | Total | 1 350 | 165 | 223 | 124 | 80.4 | 281 | 234 | 267 | 131 | 75.9 |
| | Cap$^{-1}$ | 0.24 | 0.09 | 0.63 | 0.27 | 0.26 | 0.89 | 0.79 | 0.20 | 0.24 | 0.20 |
| *Permanent crops* | Total | 105 | 31.5 | 8.1 | 19.2 | 9.3 | 4.4 | 4.2 | 7.7 | 15.0 | 9.8 |
| | Cap$^{-1}$ | 0.02 | 0.02 | 0.02 | 0.04 | 0.03 | 0.01 | 0.01 | 0.01 | 0.03 | 0.03 |
| Permanent pasture | Total | 3 410 | 536 | 124 | 591 | 351 | 697 | 281 | 347 | 705 | 54.3 |
| | Cap$^{-1}$ | 0.62 | 0.29 | 0.35 | 1.3 | 1.1 | 2.2 | 0.95 | 0.26 | 1.3 | 0.15 |
| Forest & woodland | Total | 4 130 | 411 | 829 | 921 | 85.8 | 990 | 845 | 114 | 659 | 120 |
| | Cap$^{-1}$ | 0.75 | 0.22 | 2.3 | 2.0 | 0.28 | 3.1 | 2.8 | 0.09 | 1.2 | 0.32 |
| **Total agric. & forest land** | Total | 8 990 | 1 140 | 1 180 | 1 650 | 526 | 1 970 | 1 360 | 736 | 1 510 | 260 |
| | Cap$^{-1}$ | 1.6 | 0.61 | 3.3 | 3.6 | 1.7 | 6.3 | 4.6 | 0.56 | 2.8 | 0.70 |
| Other land | Total | 4 070 | 441 | 740 | 364 | 780 | 745 | 588 | 295 | 615 | 85.0 |
| | Cap$^{-1}$ | 0.73 | 0.24 | 2.1 | 0.78 | 2.5 | 2.4 | 2.0 | 0.22 | 1.1 | 0.23 |
| **Total land area** | Total | 13 060 | 1 580 | 1 920 | 2 020 | 1 310 | 2 720 | 1 950 | 1 040 | 2 130 | 345 |
| | Cap$^{-1}$ | 2.4 | 0.85 | 5.4 | 4.3 | 4.2 | 8.6 | 6.6 | 0.78 | 4.0 | 0.93 |

Total values in million ha, and per-capita values in ha per capita; averages for 1992-94. Compiled from FAOSTAT data collection 'Land use', using the same terminology as in FAOSTAT, except for the category 'Total land area' which is the sum of the categories displayed in this table. World totals may not equal sums of regional values since the latter are region-separate compilations based on FAOSTAT. A selected number of extreme-point values are high-lighted.

This is a simplified depiction of the appropriation of food phytomass per unit area of land for at least three reasons:

First, other systems than the food system use *food-type* phytomass (that is, phytomass categories of the kind included in this study), as well as permanent grassland and cropland to a significant extent. Major categories of such non-food uses are:

- Food-type crops and its derivatives used for *non-food* purposes, such as fuel, industrial feedstock and so on. This apply to oils crops and vegetable oils, and sugar crops and sugars, among others.[239]

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[239] Some examples on orders of magnitudes are given on pp. 218 sq.

- Non-food-type crops grown on cropland, such as cotton and other fiber crops, and rubber trees.
- Wood and woody phytomass extracted from permanent grassland, for use as fuel and building materials, among other things.
- Feed consumed (mainly from permanent grassland) for draft energy and single-purpose draft animals.

The occurrence of these non-food uses implies a tendency to an underestimate of the food-type phytomass appropriation per unit area.

Second, the food system appropriates also forestland and other land to significant extent, mainly through grazing livestock, but also through collection of herbage, and leaves and other browse by hand. This entails a tendency to an overestimate of the phytomass appropriation per unit area, especially in the non-industrial regions.

Third, use of thinned-out material and weeds as feed was not included in this study. In the non-industrial regions particularly, this involved an overestimate of the phytomass appropriation of especially permanent pasture (but in South & Central Asia, also forage crops). Hence, in those cases the relative distribution between cropland-related and permanent-grassland-related phytomass may be different from the one presented here.

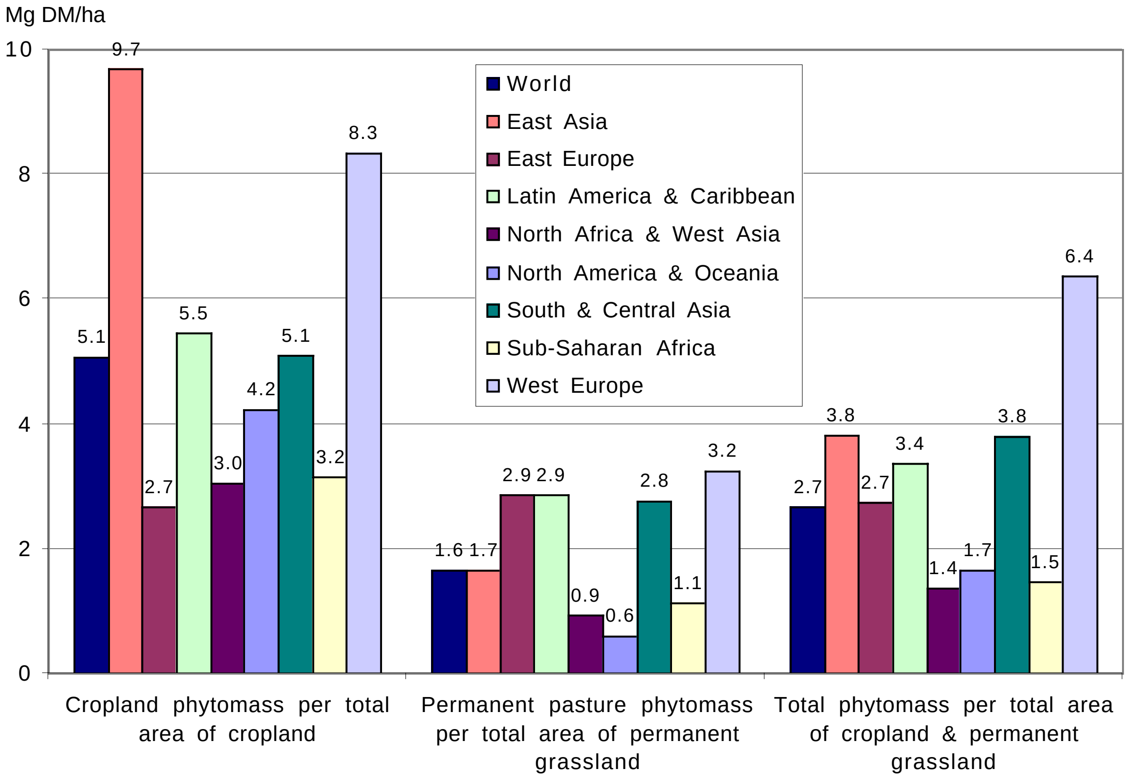

**Figure 3.71** Terrestrial food phytomass appropriation (mainly above-ground production) per approximately corresponding area of cropland and permanent grassland. (The different components appear in the bars in the same order as in the list.) See text for further explanations.

Taken together, these factors imply that the *total* food-type phytomass appropriation per unit area, all uses included, are substantially higher than the levels shown in Figure 3.71. In general, this tendency is likely to be more pronounced for permanent grassland in the non-industrial regions than in other cases. Also, the influence on the level for cropland phytomass in general is likely to be relatively small.

Even though the calculated values on appropriation per unit area of land have a simple basis, they do illustrate some relations which are likely to be fairly significant. So are, for example, the relatively high values for cropland phytomass in East Asia and West Europe (9.7 and 8.3 Mg DM/ha respectively, see Figure 3.71). In West Europe, also the grassland phytomass appropriation per unit area was high, giving a total value more than double the global average. In contrast, in the other industrial region, North America & Oceania, the estimated values on appropriation per unit area were relatively low. This is, however, largely due to the fact that Australia was included in that region. In Australia the area of permanent grassland per inhabitant is stupendously high — 24 ha per capita (mainly low-productivity grassland though) — and hence the region-average is substantially lowered despite that Australia makes up only 5 percent on a population-basis. At a very rough estimate, phytomass appropriation per unit area for this region with Australia excluded would be about 4.5 Mg DM per ha for cropland phytomass, 1.3 for grassland phytomass, and 2.8 for total food phytomass.

## 4 ACKNOWLEDGEMENTS

Thanks are due to my supervisors Sten Karlsson and Karl-Erik Eriksson. I would like to thank Sten for fruitful discussions and shrewd comments and questions, as well as useful contributions to the manuscript of the thesis. I thank Karl-Erik for thorough and valuable comments on the manuscript.

I would like to extend a special thank to my colleagues Ingrid Råde for assistance with programming in Visual Basic, and Kristian Lindgren for help with graphical design of figures. I also thank Ingrid for valuable comments on the text and precious assistance during the completion of the manuscript. Special thanks are also due to the staff at the Chalmers Library, particularly Ulla Daehli Martins, for a most helpful assistance in the procuring of references.

The financial support for this thesis by the Swedish Waste Research Council (Avfallsforskningsnämnden), the Swedish National Energy Administration (Energimyndigheten), and the Swedish Council for Planning and Coordination of Research (Forskningsrådsnämnden) is gratefully acknowledged.

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# APPENDIX 1. SPECIFICATION AND COMPOSITION OF FLOWS

## Specification and composition of carcass

*Cattle.* The whole body (liveweight) of the animal divides into ‘empty body’ and ‘ingesta’ (intestinal contents). The ‘empty body’ in turn, divides into ‘carcass’ part and ‘non-carcass’ part (also referred to as ‘fifth quarter’ in this thesis). Included in the ‘non-carcass’ part are the head, feet, tail, hide, part of the subcutaneous fat (see further below), digestive tract, red offals and blood collected. The ‘carcass’ divides into lean tissue (muscle), fatty tissue and bone.

*Pig.* Analogous to cattle, the whole body (liveweight) of the animal divides into ‘empty body’ and ‘ingesta’ (intestinal contents). The ‘empty body’ in turn, divides into ‘carcass’ part and ‘non-carcass’ part (also referred to as ‘fifth quarter’). Included in the ‘non-carcass’ part are the head, feet, skin, gristle, part of the subcutaneous fat (see further below), digestive tract, red offals and blood collected. The ‘carcass’ divides into lean tissue (muscle), fatty tissue and bone. (This means that, in this study, ‘carcass’ refers to the *carcass-side* — not to be confused with the *crude carcass*, which is another frequently used carcass definition. As ‘crude carcass’ is normally counted the empty body minus digestive tract, red offals and blood collected. ‘Carcass-side’ is the crude carcass minus head, feet, skin and gristle.)

*Chicken.* The whole body (liveweight) of the animal divides into ‘carcass’ part and ‘non-carcass’ part (also referred to as ‘fifth quarter’). Included in the ‘non-carcass’ part are the feathers, head, feet, intestines, abdominal fat, red offals, gizzard and blood. The ‘carcass’ divides into lean tissue (muscle), fatty tissue (including skin) and bone.

The depiction in the FPD model of these body constituents must be considered as relatively approximate. The main reason for this is that most data sources on body partition used in this study did not give any definitions of the separate body constituents. Important specifications, which in most cases were omitted in these sources, are, for example, (1) the cutting lines between on the one hand carcass, and on the other, head, feet and tail, (2) to what extent subcutaneous fat (fat under skin/hide), intermuscular fat, and other fat depots are considered part of the carcass, and (3) whether the carcass is weighed hot immediately after slaughter or when cold. This means, for example, that it is not clear to what extent the partition values in this study on ‘fatty tissue’ include subcutaneous fat or other fat deposits. This, in turn, means that the interpretation of the model values on carcass production in relation to the values on production in statistics is ambiguous (see the section ‘End-use per capita and level of production’ p. 188).

The assumed values on partition for each animal category and quality, as well as the corresponding chemical composition of the carcasses, are given in Table A1.I below. The values on as-is weight basis were the actual underlying data for the assumptions on partition and, therefore, these values are also shown in the table.

## Composition of other flows

Table A1.II gives the assumed values in this study on partition and composition of the flows included in the FPD model (except carcasses). In Table A1.III are given the values of the system-external flows. In general, the values on composition refer to the point of *supply* in the system. This is relevant particularly for the interpretation of the values on DM content and, thereby, the as-is weights of the flows. As a general rule, in the FPD model depiction, standard-procedure drying processes in the sub-systems — for example, the pre-storage drying of cereals grains — are carried out before the point of supply (that is, *supplied* grains are *dried* grains).

**Table A1.I** Assumed values on partition and composition of body and carcass in this study.

| | BODY PARTITION | | | | | | | | | | CARCASS COMPOSITION | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Carcass part* | | Lean tissue (muscle) | | Fatty tissue | | Bone | | *Non-carcass part* | | Dry matter (% as-is) | Protein (% DM) | Lipid (% DM) | Total ash (% DM) | GE (HHV) (kJ/g DM) | Human ME (kJ/g DM)[a] |
| | As-is basis | DM basis | As-is basis | DM basis | As-is basis | DM basis | As-is basis | DM basis | As-is basis | DM basis | | | | | | |
| ***Cattle***[b] | | | | | | | | | | | | | | | | |
| **Cow** | | | | | | | | | | | | | | | | |
| Low-quality | 45 | 57 | 28 | 21 | 8.1 | 18 | 10 | 19 | 55 | 43 | 44.0 | 41.7 | 42.3 | 16.0 | 26.5 | 17.9 |
| Medium-quality | 55 | 66 | 35 | 25 | 9.9 | 21 | 10 | 20 | 45 | 34 | 43.2 | 42.5 | 42.5 | 14.9 | 26.8 | 18.5 |
| **Bull** | | | | | | | | | | | | | | | | |
| Low-quality | 55 | 66 | 35 | 26 | 9.4 | 20 | 10 | 20 | 45 | 34 | 42.7 | 43.3 | 41.6 | 15.1 | 26.6 | 18.2 |
| Medium-quality | 63 | 72 | 43 | 31 | 8.8 | 19 | 11 | 22 | 37 | 28 | 40.7 | 46.2 | 38.6 | 15.2 | 26.1 | 17.6 |
| High-quality | 70 | 77 | 50 | 37 | 8.4 | 18 | 11 | 22 | 30 | 23 | 38.9 | 49.0 | 36.6 | 14.5 | 25.9 | 17.6 |
| **Heifer** | | | | | | | | | | | | | | | | |
| Low-quality | 50 | 62 | 31 | 23 | 9.5 | 20 | 10 | 20 | 50 | 38 | 43.7 | 41.8 | 43.5 | 14.7 | 26.9 | 18.7 |
| Medium-quality | 58 | 68 | 38 | 27 | 9.9 | 21 | 10 | 21 | 42 | 32 | 42.2 | 43.7 | 41.7 | 14.6 | 26.7 | 18.5 |
| ***Pigs***[c] | | | | | | | | | | | | | | | | |
| **Sow** | | | | | | | | | | | | | | | | |
| Medium-quality | 55 | 77 | 33 | 28 | 16 | 38 | 6.6 | 12 | 45 | 23 | 46.9 | 36.5 | 54.4 | 9.1 | 30.0 | 24.3 |
| **Swine** | | | | | | | | | | | | | | | | |
| Low-quality | 58 | 79 | 34 | 28 | 16 | 37 | 7.5 | 13 | 42 | 21 | 46.7 | 36.9 | 53.3 | 9.7 | 29.7 | 23.8 |
| Medium-quality | 62 | 81 | 38 | 31 | 16 | 36 | 7.4 | 13 | 38 | 19 | 45.4 | 38.6 | 51.9 | 9.5 | 29.5 | 23.6 |
| High-quality | 66 | 82 | 43 | 35 | 16 | 35 | 7.3 | 12 | 34 | 18 | 44.1 | 40.5 | 50.3 | 9.2 | 29.3 | 23.5 |
| ***Chickens***[d] | | | | | | | | | | | | | | | | |
| **Hen** | | | | | | | | | | | | | | | | |
| Medium-quality | 65 | 74 | 36 | 25 | 9.8 | 22 | 20 | 27 | 35 | 26 | 41.1 | 42.6 | 41.2 | 16.3 | 26.2 | 16.9 |
| **Broiler** | | | | | | | | | | | | | | | | |
| Low-quality | 63 | 72 | 34 | 24 | 9.5 | 21 | 20 | 27 | 37 | 28 | 41.3 | 42.2 | 41.1 | 16.6 | 26.1 | 16.7 |
| Medium-quality | 68 | 76 | 38 | 27 | 9.5 | 21 | 20 | 28 | 32 | 24 | 40.5 | 43.5 | 40.1 | 16.5 | 26.0 | 16.6 |
| High-quality | 73 | 80 | 42 | 30 | 9.5 | 21 | 21 | 29 | 27 | 20 | 39.7 | 44.8 | 38.9 | 16.3 | 25.9 | 16.5 |

All partition numbers in percent. Definitions of ‘carcass’ part and ‘non-carcass’ part for each of the animal sub-systems are given in the text above. Composition of the carcass parts (lean tissue, fatty tissue, bone) and non-carcass part (fifth quarter) are given in Table A1.II below.

[a] Refers to human ME content of edible parts (lean and fatty tissue), counted on the carcass weight.

*Notes continue on next page.*

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[b] Partition numbers given as share of *empty body*. For all cattle categories and qualities, we assumed that empty body amounts to 90% of whole body (on as-is weight basis).

[c] Partition numbers given as share of *empty body*. For all pig categories and qualities, we assumed that empty body amounts to 95% of whole body (on as-is weight basis). As described in text above, ‘carcass part’ here refers to ‘carcass-side’, which is a subset of ‘crude carcass’ — another common carcass definition. For all animal categories and qualities, we assumed that the carcass-side amounted to 85% of the crude carcass (on as-is weight basis).

[d] Partition numbers given as share of *whole body*.

**Table A1.II** Assumed values on partition and composition of flows in this study.

| | Partition (DM basis) | Dry matter (% as-is) | Protein (% DM) | Lipid (% DM) | Carbohydrate (% DM) | Sucrose (% DM) | Total ash (% DM) | GE (HHV) (kJ/g DM) | Human ME (kJ/g DM) | Beef cattle DE (kJ/g DM) | Dairy cattle DE (kJ/g DM) | Pig DE (kJ/g DM) | Pig *ME* (kJ/g DM) | Chicken ME (kJ/g DM) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Edible-type crops products*** | | | | | | | | | | | | | | |
| **Cereals grains** | | | | | | | | | | | | | | |
| Wheat grains | | 88.0 | 13.0 | | | | | 18.4 | | | | 16.3 | 15.6 | 14.7 |
| Rice grains | | 87.0 | 8.0 | | | | | 17.9 | | | | | | |
| Maize grains | | 88.0 | 10.0 | | | | | 18.8 | | 17.3 | 16.3 | 16.4 | 15.7 | 15.0 |
| Sorghum grains | | 88.0 | 10.0 | | | | | 18.7 | | 15.5 | 15.5 | 15.5 | 14.9 | 15.0 |
| Barley grains | | 88.0 | 12.0 | | | | | 18.2 | | 15.5 | 15.5 | 14.8 | 14.2 | 13.0 |
| **Starchy root tubers** | | | | | | | | | | | | | | |
| Cassava tubers | | 35.0 | 3.0 | 1.0 | 83.3 | | | 17.3 | 12.8 | 14.8 | 14.8 | 14.5 | 13.9 | |
| Flesh | 0.85 | 35.0 | 3.0 | 1.0 | 83.0 | | | 17.3 | 15.0 | | | | | |
| Skin | 0.15 | 35.0 | 3.0 | 1.0 | 85.0 | | | 17.3 | (0) | | | | | |
| Cassava meal[a] | | 88.0 | 2.6 | | | | | 17.3 | | 15.7 | | 14.7 | 14.1 | |
| White potato tubers | | 21.3 | 9.0 | 1.0 | 77.3 | | | 17.3 | 13.5 | | | | | |
| Flesh | 0.90 | 21.0 | 9.0 | 1.0 | 77.0 | | | 17.3 | 15.0 | | | | | |
| Skin | 0.10 | 25.0 | 9.0 | 1.0 | 80.0 | | | 17.3 | (0) | | | | | |
| Sweet potato tubers (raw) | | 29.4 | 5.0 | 1.0 | 81.4 | | | 17.3 | 13.5 | | | 14.0 | 13.4 | |
| Flesh | 0.90 | 29.0 | 5.0 | 1.0 | 81.0 | | | 17.3 | 15.0 | | | | | |
| Skin | 0.10 | 33.0 | 5.0 | 1.0 | 85.0 | | | 17.3 | (0) | | | | | |
| Sweet potato tubers (cooked)[a] | | 29.4 | 5.0 | | | | | 17.3 | | | | 15.0 | 14.4 | |
| **Sugar crops stems & roots** | | | | | | | | | | | | | | |
| Sugar cane stems | | 27.0 | 1.5 | | | 44.0 | | 17.0 | | | | | | |
| Sugar beet roots | | 24.0 | 3.5 | | | 67.0 | | 17.0 | | | | | | |
| **Oil crops products** | | | | | | | | | | | | | | |
| Soybean seeds (raw) | | 91.0 | 40.0 | 20.0 | 28.0 | | | 23.4 | 19.0 | | | | | |
| Soybean seeds (cooked)[a] | | 90.0 | 40.0 | | | | | 23.4 | 19.0 | | | 18.8 | 16.9 | |
| Groundnut pods | | 94.0 | 18.7 | 34.0 | | | | 25.3 | 16.8 | | | | | |
| Seed | 0.67 | 94.0 | 25.0 | 50.0 | 14.0 | | | 29.4 | 25.0 | | | | | |
| Husk | 0.33 | 94.0 | 6.0 | 1.5 | | | | 17.0 | 0 | | | | | |
| Sunflower achenes | | 93.0 | 13.5 | 23.3 | | | | 22.4 | 12.5 | | | | | |
| Kernel | 0.50 | 93.0 | 22.0 | 45.0 | 27.0 | | | 27.8 | 25.0 | | | | | |
| Husk | 0.50 | 93.0 | 5.0 | 1.5 | | | | 17.0 | 0 | | | | | |
| Canola seeds | | 92.0 | 23.0 | 45.0 | 15.0 | | | 27.8 | 20.0 | | | | | |
| Oil palm fruit bunches | | 51.1 | | 46.9 | | | | 26.7 | | | | | | |
| Clean fruit | 0.70 | 59.0 | | 67.0 | | | | 31.0 | | | | | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Non-fruit part | 0.30 | 39.0 | | (0) | | | | 16.5 | | | | | |
| **Other edible-type cultivation-products** | | | | | | | | | | | | | |
| Tree nuts | | 90.0 | 9.3 | | | | | 22.0 | 11.8 | | | | |
| Pulses | | 90.0 | 23.9 | | | | | 19.0 | 15.9 | | | | |
| Vegetables | | 10.0 | 14.0 | | | | | 17.0 | 10.0 | | | | |
| Fruits | | 20.0 | 2.5 | | | | | 17.0 | 9.0 | | | | |
| Stimulants | | 90.0 | 18.0 | | | | | 18.0 | 3.9 | | | | |
| ***Animal forage crops*** | | | | | | | | | | | | | |
| **Grass-legume** | | | | | | | | | | | | | |
| Grass-legume, temp. spp. (fresh) | | 25.0 | 15.0 | | | | | 17.5 | | | | | |
| Grass-legume, trop. spp. (fresh) | | 25.0 | 15.0 | | | | | 17.5 | | | | | |
| Grass-legume hay, temp. spp. | | 90.0 | 12.5 | | | | | 17.5 | | 10.5 | 10.5 | | |
| Grass-legume hay, trop. spp. | | 90.0 | 10.0 | | | | | 17.0 | | 9.5 | 9.5 | | |
| Grass-legume silage, temp. spp. | | 30.0 | 12.5 | | | | | 17.5 | | 11.0 | 11.0 | | |
| Grass-legume silage, trop. spp. | | 30.0 | 10.0 | | | | | 17.0 | | 10.0 | 10.0 | | |
| **Whole-cereals** | | | | | | | | | | | | | |
| Whole-maize, medium eared (fresh) | | 25.0 | 8.5 | | | | | 17.5 | | | | | |
| Whole-maize silage, medium eared | | 30.0 | 8.5 | | | | | 17.5 | | 12.5 | 12.5 | | |
| **Other animal forage crops** | | | | | | | | | | | | | |
| Forage-vegetables | | 15.0 | 17.5 | | | | | 17.0 | | | | 13.0 | 12.5 |
| ***Pasture*** | | | | | | | | | | | | | |
| **Cropland pasture** | | | | | | | | | | | | | |
| Grass-legume, temp. spp. | | 25.0 | 15.0 | | | | | 17.5 | | 12.0 | 12.0 | | |
| Grass-legume, trop. spp. | | 25.0 | 15.0 | | | | | 17.5 | | 11.0 | 11.0 | | |
| **Permanent pasture** | | | | | | | | | | | | | |
| Native grass-legume, temperate spp. | | 25.0 | 7.5 | | | | | 17.0 | | 9.3 | 9.3 | | |
| Native grass-legume, tropical spp. | | 25.0 | 10.0 | | | | | 17.5 | | 11.0 | 11.0 | | |
| Oversown grass-legume, temperate spp. | | 25.0 | 7.5 | | | | | 16.5 | | 8.5 | 8.5 | | |
| Oversown grass-legume, tropical spp. | | 25.0 | 10.0 | | | | | 17.0 | | 10.0 | 10.0 | | |

*Table continues on next page.*

**Table A1.II** (continued)

| | Partition (DM basis) | Dry matter (% as-is) | Protein (% DM) | Lipid (% DM) | Carbohydrate (% DM) | Sucrose (% DM) | Total ash (% DM) | GE (HHV) (kJ/g DM) | Human ME (kJ/g DM) | Beef cattle DE (kJ/g DM) | Dairy cattle DE (kJ/g DM) | Pig DE (kJ/g DM) | Pig *ME* (kJ/g DM) | Chicken ME (kJ/g DM) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Edible-type crops by-products*** | | | | | | | | | | | | | | |
| **Cereals straw & stover** | | | | | | | | | | | | | | |
| Wheat straw | | 90.0 | 3.6 | | | | | 16.7 | | 8.0 | 8.0 | | | |
| Rice straw | | 90.0 | 3.5 | | | | | 15.0 | | 7.5 | 7.5 | | | |
| Maize stover | | 85.0 | 5.5 | | | | | 16.5 | | 8.5 | 8.5 | | | |
| Sorghum stover | | 85.0 | 5.0 | | | | | 16.5 | | 9.0 | 9.0 | | | |
| Barley straw | | 90.0 | 4.3 | | | | | 16.9 | | 8.0 | 8.0 | | | |
| **Starchy roots tops** | | | | | | | | | | | | | | |
| Cassava tops | | | | | | | | | | | | | | |
| Attached leaves | 0.10 | 25.0 | 25.0 | | | | | 16.5 | | 11.5 | 11.5 | | | |
| Top excl. leaves | 0.90 | 25.0 | - | | | | | 16.5 | | | | | | |
| White potato tops | | 20.0 | 10.0 | | | | | 16.5 | | | | 9.0 | 8.5 | |
| Sweet potato tops | | 15.0 | 17.5 | | | | | 16.0 | | | | 9.0 | 8.5 | |
| **Sugar crops tops & leaves** | | | | | | | | | | | | | | |
| Sugar cane tops & leaves | | 28.0 | 5.0 | | | | | 17.0 | | 9.5 | 9.5 | | | |
| Sugar beet tops (fresh) | | 20.0 | 11.0 | | | | | 13.0 | | | | | | |
| Sugar beet tops (ensiled)[a] | | 20.0 | 11.0 | | | | | 13.0 | | 10.5 | 10.5 | | | |
| **Oil crops by-products** | | | | | | | | | | | | | | |
| Soybean stalks & husks | | 90.0 | 5.0 | | | | | 16.5 | | 8.0 | 8.0 | | | |
| Groundnut stalks | | 90.0 | 14.0 | | | | | 16.5 | | 9.0 | 9.0 | | | |
| Sunflower stalks & thr. heads | | 90.0 | 5.0 | | | | | 16.5 | | 7.5 | 7.5 | | | |
| Canola stalks & husks | | 90.0 | 5.0 | | | | | 16.5 | | 8.0 | 8.0 | | | |
| Oil palm leaves | | 90.0 | | | | | | 15.0 | | | | | | |
| Oil palm trunks | | 90.0 | | | | | | 15.0 | | | | | | |
| ***Vegetable conversion-products*** | | | | | | | | | | | | | | |
| **Cereals products** | | | | | | | | | | | | | | |
| Wheat straight flour | | 86.0 | 11.5 | 2.0 | 78.0 | | | 18.3 | 16.0 | | | | | |
| White rice | | 88.0 | 8.2 | 0.5 | 89.0 | | | 18.0 | 16.7 | | | | | |
| Maize grits, meal & flour | | 87.0 | 8.7 | 8.7 | 83.0 | | | 18.1 | 16.0 | | | | | |
| Sorghum grits, meal & flour | | 87.0 | 8.7 | 8.7 | 83.0 | | | 18.1 | 16.0 | | | | | |
| **Sweeteners** | | | | | | | | | | | | | | |
| Cane white sugar | | 100 | 0 | 0 | 99.5 | | | 17.5 | 16.2 | | | | | |
| Beet white sugar | | 100 | 0 | 0 | 99.5 | | | 17.5 | 16.2 | | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Vegetable oils** | | | | | | | | | |
| Soybean oil | | 100 | 0 | 100 | 0 | | | 39.3 | 37.0 |
| Groundnut oil | | 100 | 0 | 100 | 0 | | | 39.3 | 37.0 |
| Sunflower oil | | 100 | 0 | 100 | 0 | | | 39.3 | 37.0 |
| Canola oil | | 100 | 0 | 100 | 0 | | | 39.3 | 37.0 |
| Palm oil | | 100 | 0 | 100 | 0 | | | 39.3 | 37.0 |
| **Other vegetable products** | | | | | | | | | |
| Barley beer[b] | | 9.0 | 3.3 | 0 | 25.0 | | | 15.1 | 14.7 |
| ***Animal conversion-products*** | | | | | | | | | |
| **Carcass**[c] | | | | | | | | | |
| Dairy and beef cattle | | | | | | | | | |
| Lean tissue | | 26.0 | 78.1 | 17.7 | | | 4.2 | 25.4 | 19.8 |
| Fatty tissue | | 76.0 | 11.6 | 88.0 | | | 0.4 | 37.3 | 34.5 |
| Bone | | 69.0 | 30.4 | 26.1 | | | 43.5 | 17.4 | |
| Pig | | | | | | | | | |
| Lean tissue | | 28.5 | 75.0 | 20.0 | | | 5.0 | 25.6 | 20.1 |
| Fatty tissue | | 78.9 | 8.6 | 90.5 | | | 0.9 | 37.6 | 35.0 |
| Bone | | 60.0 | 35.0 | 20.0 | | | 45.0 | 16.1 | |
| Leghorn-type and meat-type chicken | | | | | | | | | |
| Lean tissue | | 25.6 | 80.1 | 16.8 | | | 3.1 | 25.6 | 19.8 |
| Fatty tissue | | 80.0 | 8.0 | 90.0 | | | 2.0 | 37.3 | 34.7 |
| Bone | | 50.0 | 35.0 | 25.0 | | | 40.0 | 18.1 | |
| **Other animal products** | | | | | | | | | |
| Cattle milk | | 12.2 | 26.5 | 31.5 | 38.0 | | 4.0 | | |
| Chicken egg | | 32.3 | 35.0 | 29.1 | 3.4 | | 32.5 | 20.3 | 17.2 |
| Yolk and white | 0.70 | 25.0 | 50.0 | 41.5 | 4.9 | | 3.6 | 29.0 | 24.6 |
| Shell | 0.30 | 100 | 0 | 0 | 0 | | 100 | 0 | 0 |

*Table continues on next page.*

**Table A1.II** (continued)

| | Partition (DM basis) | Dry matter (% as-is) | Protein (% DM) | Lipid (% DM) | Carbohydrate (% DM) | Sucrose (% DM) | Total ash (% DM) | GE (HHV) (kJ/g DM) | Human ME (kJ/g DM) | Beef cattle DE (kJ/g DM) | Dairy cattle DE (kJ/g DM) | Pig DE (kJ/g DM) | Pig *ME* (kJ/g DM) | Chicken ME (kJ/g DM) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Vegetable conversion-by-products*** | | | | | | | | | | | | | | |
| **Cereals milling by-products** | | | | | | | | | | | | | | |
| Wheat mill run | | 89.0 | 18.3 | | | | | 18.8 | | 14.5 | 14.5 | 13.0 | 12.5 | 9.5 |
| Rice bran | | 92.0 | 14.5 | | | | | 19.4 | | 12.9 | 12.9 | 12.0 | 11.5 | 11.5 |
| Rice hulls | | 91.0 | 4.4 | | | | | 16.9 | | 8.0 | 8.0 | | | |
| Maize hominy feed | | 90.0 | 15.6 | | | | | 20.5 | | 17.4 | 16.4 | 16.2 | 15.4 | 13.4 |
| Maize oil | | 100 | 0 | 100 | 0 | | | 39.3 | 37.0 | | | | | |
| Sorghum hominy feed | | 90.0 | 15.6 | | | | | 20.5 | | 17.4 | 16.4 | 16.2 | 15.4 | 13.4 |
| Sorghum oil | | 100 | 0 | 100 | 0 | | | 39.3 | 37.0 | | | | | |
| **Sugar crops conversion by-products** | | | | | | | | | | | | | | |
| Cane bagasse | | 50.0 | 1.5 | | | | | 17.0 | | 8.5 | 8.5 | | | |
| Cane molasses | | 75.0 | 8.0 | | | | | 16.0 | | 13.0 | 13.0 | 12.6 | 11.4 | |
| Cane filter cake | | 25.0 | 5.5 | | | | | 24.6 | | | | | | |
| Beet molasses | | 75.0 | 8.5 | | | | | 16.1 | | 14.6 | 13.9 | 13.5 | 12.8 | |
| Beet pulp (dried) | | 90.0 | 10.0 | | | | | 17.5 | | 13.7 | 14.4 | | | |
| Beet scums | | 50.0 | 4.9 | | | | | 22.2 | | | | | | |
| **Oilseed conversion by-products** | | | | | | | | | | | | | | |
| Soybean meal | | 89.0 | 49.4 | | | | | 19.7 | | | | 16.2 | 15.0 | 11.0 |
| Groundnut meal | | 92.0 | 45.5 | | | | | 21.3 | | | | 14.2 | 13.1 | 11.0 |
| Groundnut husks | | 94.0 | 6.0 | | | | | 17.0 | | | | | | |
| Sunflower meal | | 92.0 | 37.0 | | | | | 20.0 | | | | 13.8 | 11.9 | 10.4 |
| Sunflower husks | | 93.0 | 5.0 | | | | | 17.0 | | | | | | |
| Canola meal | | 89.0 | 40.2 | | | | | 19.2 | | | | 13.1 | 12.2 | 8.4 |
| Oil palm kernel oil | | 100 | 0 | 100 | 0 | | | 39.3 | 37.0 | | | | | |
| Oil palm kernel meal | | 90.0 | | | | | | 16.5 | | | | | | |
| Oil palm fruit bunch refuse | | 39.0 | | | | | | 16.5 | | | | | | |
| Oil palm press cake fiber | | 60.0 | | | | | | 16.5 | | | | | | |
| Oil palm nut shells | | 30.0 | | | | | | 16.5 | | | | | | |
| **Other vegetable by-products** | | | | | | | | | | | | | | |
| Brewer’s grains | | 20.0 | 30.0 | | | | | 20.0 | | 11.0 | 11.0 | 9.6 | 8.7 | 9.5 |
| Malt sprouts & hulls | | 90.0 | | | | | | 16.5 | | | | | | |
| Brewers yeast | | 90.0 | | | | | | 16.5 | | | | | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spent hops | | 90.0 | | | | | | 16.5 | | | | | |
| ***Animal conversion-by-products*** | | | | | | | | | | | | | |
| **Carcass by-products** | | | | | | | | | | | | | |
| Dairy and beef cattle fifth quarter | | 27.0 | 60.0 | 35.0 | | | 5.0 | 27.9 | 20.0 | | | | |
| Pig fifth quarter | | 20.0 | 75.0 | 20.0 | | | 5.0 | 25.6 | 20.0 | | | | |
| Leghorn and meat-type chicken fifth quarter | | 27.0 | 75.0 | 22.0 | | | 3.0 | 24.6 | 20.0 | | | | |
| Cattle and pig Ingesta (intestinal contents) | | 10.0 | 15.0 | | | | | 16.0 | | | | | |
| Meat and bone meal[d] | | 90.0 | 60.0 | | | | | 17.5 | | | | 11.3 | 10.2 |
| **Feces, urine and used litter** | | | | | | | | | | | | | |
| Dairy and beef cattle feces | | 15.0 | | | | | | 16.0 | | | | | |
| Dairy and beef cattle urine | | 5.0 | | | | | | 10.6 | | | | | |
| Pig feces | | 25.0 | | | | | | 16.0 | | | | | |
| Pig urine | | 5.0 | | | | | | 10.6 | | | | | |
| Leghorn and meat-type chicken feces and urine | | 25.0 | | | | | | 13.5 | | | | | |
| Used litter[e] | | 70.0 | | | | | | 15-17[f] | | | | | |
| **Methane** | | | | | | | | 55.7 | | | | | |
| ***End-use residues*** | | | | | | | | | | | | | |
| Non-eaten food | | 30.0 | 10-15[g] | | | | | 18-19[d] | | | | 11.5 | 10.5 |
| Human feces & urine | | 6.0 | | | | | | 13.0 | | | | | |

Blanks indicate that no value was included in the model description; thus, it should not necessarily be interpreted as inapplicability of the particular parameter.

[a] Processed for use as animal feed.

[b] Alcohol content is 34.4 percent (DM basis).

[c] This table presents the composition of carcass *parts* only — for partition and composition of entire carcasses, see previous table (Table A1.I).

[d] Processed from fifth quarters, that is, the non-carcass part of whole body; values refer to meat & bone meal originating from any of the animal sub-systems.

[e] Refers to used litter in all animal sub-systems.

[f] In the FPD model, the GE density for this flow is not prefixed, but is determined by the relative proportions in each region of the different flows which represent cereals straw and stover.

[g] In the FPD model, the protein density for this flow is not prefixed, but is calculated as a protein balance over the food use process. This means that the value depends on, among others, the relative proportions in the food end-use of individual commodities.

**Table A1.III** Assumed values on composition of system-external related flows.

| | Partition (DM basis) | Dry matter (% as-is) | Protein (% DM) | Lipid (% DM) | GE (HHV) (kJ/g DM) | Human ME (kJ/g DM) | Beef cattle DE (kJ/g DM) | Dairy cattle DE (kJ/g DM) | Pig DE (kJ/g DM) | Pig *ME* (kJ/g DM) | Chicken ME (kJ/g DM) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Aquatic-related*** | | | | | | | | | | | |
| Fish (as-is) | | 26.0 | 55.0 | 15.0 | 20.0 | 12.0 | | | | | |
| Fish meal | | 90.0 | 55.0 | | 20.0 | | | | 15.5 | 13.0 | 13.5 |
| ***Materials-related*** | | | | | | | | | | | |
| **Cotton** | | | | | | | | | | | |
| Seed cotton | | 91.2 | 15.0 | 12.0 | 20.6 | | | | | | |
| Lint | 0.35 | 90.0 | | | 17.0 | | | | | | |
| Seed | 0.60 | 92.0 | 25.0 | 20.0 | 23.0 | | | | | | |
| Other (ginning waste) | 0.05 | 90.0 | | | 17.0 | | | | | | |
| Cotton stalks | | 85.0 | 5.0 | | 16.5 | | | | | | |
| Cotton yarn | | 90.0 | | | 17.0 | | | | | | |
| Cotton oil | | 100 | 0 | 100 | 39.3 | 37.0 | | | | | |
| Cotton meal | | 90.0 | 45.0 | 8.5 | 19.5 | | | | 12.0 | 11.5 | 10.5 |
| Spinning waste, and hulls, linters & other waste | | 90.0 | | | 17.0 | | | | | | |

# APPENDIX 2. ABBREVIATIONS

<u>Concepts and units</u>

| | |
|---|---|
| DE | Digestible energy |
| DM | Dry matter |
| GE | Gross energy |
| GNP | Gross national product |
| LHV | Lower heating value |
| HHV | Higher heating value |
| NE | Net energy |
| $NE_g$ | Net energy for growth |
| $NE_l$ | Net energy for lactation |
| $NE_m$ | Net energy for maintenance |
| NPP | Net primary production |
| ME | Metabolizable energy |

| | |
|---|---|
| SPP | Species |

<u>Other</u>

| | |
|---|---|
| CAB | Commonwealth Agricultural Bureau |
| FAO | Food and Agriculture Organization of the United Nations |
| FAOSTAT | FAO Statistical Databases |
| FBS | Food Balance Sheets (data domain in FAOSTAT) |
| IGBP | International Geosphere-Biosphere Programme |
| IIASA | International Institute for Applied Systems Analysis |
| IPCC | Intergovernmental Panel on Climate Change |
| ISCU | International Council of Scientific Unions |
| NRC | National Research Council (U.S.) |
| SEI | Stockholm Environment Institute |
| UNEP | United Nations Environment Programme |
| WMO | World Meteorological Organization |