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THE GREEN, BLUE AND GREY WATER FOOTPRINT OF FARM ANIMALS AND ANIMAL PRODUCTS

VOLUME 1: MAIN REPORT

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Summary

The projected increase in the production and consumption of animal products is likely to put further pressure on the globe's freshwater resources. The size and characteristics of the water footprint vary across animal types and production systems. The current study provides a comprehensive account of the global green, blue and grey water footprints of different sorts of farm animals and animal products, distinguishing between different production systems and considering the conditions in all countries of the world separately. The following animal categories were considered: beef cattle, dairy cattle, pig, sheep, goat, broiler chicken, layer chicken and horses.

The study shows that the water footprint of meat from beef cattle (15400 m^3/ton as a global average) is much larger than the footprints of meat from sheep (10400 m^3/ton), pig (6000 m^3/ton), goat (5500 m^3/ton) or chicken (4300 m^3/ton). The global average water footprint of chicken egg is 3300 m^3/ton, while the water footprint of cow milk amounts to 1000 m^3/ton. Per ton of product, animal products generally have a larger water footprint than crop products. The same is true when we look at the water footprint per calorie. The average water footprint per calorie for beef is twenty times larger than for cereals and starchy roots. When we look at the water requirements for protein, we find that the water footprint per gram of protein for milk, eggs and chicken meat is about 1.5 times larger than for pulses. For beef, the water footprint per gram of protein is 6 times larger than for pulses. In the case of fat, we find that butter has a relatively small water footprint per gram of fat, even lower than for oil crops. All other animal products, however, have larger water footprints per gram of fat when compared to oil crops. The study shows that from a freshwater resource perspective, it is more efficient to obtain calories, protein and fat through crop products than animal products.

Global animal production requires about 2422 Gm^3 of water per year (87.2% green, 6.2% blue, 6.6% grey water). One third of this volume is for the beef cattle sector; another 19% for the dairy cattle sector. Most of the total volume of water (98%) refers to the water footprint of the feed for the animals. Drinking water for the animals, service water and feed mixing water account only for 1.1%, 0.8% and 0.03%, respectively.

The water footprints of animal products can be understood from three main factors: feed conversion efficiency of the animal, feed composition, and origin of the feed. The type of production system (grazing, mixed, industrial) is important because it influences all three factors. A first explanatory factor in the water footprints of animal products is the feed conversion efficiency. The more feed is required per unit of animal product, the more water is necessary (to produce the feed). The unfavourable feed conversion efficiency for beef cattle is largely responsible for the relatively large water footprint of beef. Sheep and goats have an unfavourable feed conversion efficiency as well, although better than cattle. A second factor is the feed composition, in particular the ratio of concentrates versus roughages and the percentage of valuable crop components versus crop residues in the concentrate. Chicken and pig have relatively large fractions of cereals and oil meal in their feed, which results in relatively large water footprints of their feed and abolishes the effect of the favourable feed conversion efficiencies. A third factor that influences the water footprint of an animal product is the origin of the feed. The water footprint of a specific animal product varies across countries due to differences in climate and agricultural practice in the regions from where the various feed components are obtained. Since sometimes a relatively large

fraction of the feed is imported while at other times feed is mostly obtained locally, not only the size but also the spatial dimension of the water footprint depends on the sourcing of the feed.

It is relevant to consider from which type of production system an animal product is obtained: from a grazing, mixed or industrial system. Animal products from industrial production systems generally have a smaller total water footprint per unit of product than products from grazing systems, with an exception for dairy products (where there is little difference). However, products from industrial systems always have a larger *blue* and *grey* water footprint per ton of product when compared to grazing systems, this time with an exception for chicken products. It is the lower *green* water footprint in industrial systems that explains the smaller total footprint. Given the fact that freshwater problems generally relate to blue water scarcity and water pollution and to a lesser extent to competition over green water, this means that grazing systems are preferable over industrial production systems from a water resources point of view. In the case of cattle, pigs, sheep and goats, the *total* water footprints per ton of product are larger for grazing systems because of the worse feed conversion efficiencies, but the fact that these systems depend more strongly on roughages (which are less irrigated and less fertilised than the feed crops contained in concentrate feed) makes that the blue and grey water footprints of products from grazing systems are smaller. This compensation through the feed composition does not occur for the case of chicken. The reason is that chicken strongly rely on concentrate feed in all production systems. Mixed production systems generally take a position in between industrial and grazing systems. Not accounted for in this study is that industrialized animal production often produces large amounts of animal waste that cannot be fully recycled in the nearby land. Such large amounts of waste produced in a concentrated place are known to pollute freshwater resources if not handled properly.

By focusing on freshwater appropriation, the study obviously excludes many other relevant issues in farm animal production, such as micro- and macro-cost of production, livelihood of smallholder farmers, animal welfare, public health and environmental issues other than freshwater.

1. Introduction

In the last few decades the world has seen a significant shift in food consumption patterns towards more animal products such as meat, milk and egg, mainly due to growing economies and rising individual incomes. In developing countries, in particular, consumption of meat, milk and dairy products has been growing the last few decades at 5-6 percent and 3.4-3.8 percent annually respectively (Bruinsma, 2003). The shift in consumption patterns coupled with high population growth and rapid urbanization in most developing countries is driving the total demand for animal products upward.

The global meat production has nearly doubled between 1980 and 2004, with the largest share of growth in developing countries (FAO, 2005). Related to the increased production there is a shift away from grazing systems. Although the traditional pastoral system plays a role, most of the increase in meat and milk production in the last three decades was achieved through production increase in the mixed and industrial production systems (Bouwman et al., 2005). The shift to more intensive production systems influences the composition of animal feed. Traditionally, animals have relied on locally available feed, such as grass, crop residues and wastes from human food. The more intensive production systems depend on concentrate feeds that are traded locally and internationally. In many countries, there is a tendency towards decreasing reliance on grazing and increasing dependence on concentrate feeds. Intensive animal production systems, in which animals are raised in confinement, currently account for 74 percent of the world’s total poultry production, 40 percent of pig meat and more than two-thirds of egg production (Seré and Steinfeld, 1996). If this trend continues in the future, its implication will be far-reaching for both land and water resources requirements.

Animal production requires large volumes of water for feed production, drinking water and servicing animals. By far the largest water demand in animal production is the water needed to produce animal feed. Because of the increasing demand for animal products and the growing sector of industrial farming, the demand for feedstuffs grows as well, including cereals, starchy roots, fodder crops, oilseeds and oil meals. Such high demand for feed in turn causes a rising demand for water. Besides, intensification of animal production systems will lead to surface and ground water pollution, both from the use of fertilizers in feed crops production and improper storage and application of manures.

The global meat trade is projected to rise by more than 50 percent over the next 25 years (Bruinsma, 2003). Also international trade in feed is growing. As a result of the increasing global trade in feed crops and animal products and the growth of meat preservation over longer periods, many consumers have no longer any idea about the natural resource use and environmental impacts associated with the products they consume. Consumers of animal products are spatially disconnected from the processes necessary to produce the products (Naylor et al., 2005; Hoekstra, 2010). The concept of ‘water footprint’ provides an appropriate framework of analysis to find the link between the consumption of animal products and the use of the global water resources. The water footprint is defined as the total volume of freshwater that is used to produce the goods and services consumed by an individual or community (Hoekstra and Chapagain, 2008).

There are a few earlier publications on water use in animal production. The first and most comprehensive assessment of the water footprint of farm animals and animal products was carried out by Chapagain and Hoekstra (2003) and later updated by the same authors in their water footprint of nation's publication (Chapagain and Hoekstra, 2004). A study by FAO has quantified the global blue water use for feed production, animal drinking and servicing (Steinfeld et al., 2006). De Fraiture et al. (2007) have estimated the global water use for animal feed production, both green and blue but not distinguishing between the two. They considered water use for two lumped categories: feed crops and grazing. Zimmer and Renault (2003) made a rough estimation of the global water consumption for producing meat and other animal products, not showing details per country, animal category or product. Galloway et al. (2007) produced a study on the water consumption for chicken and pig for four countries: the USA, Japan, Brazil and the Netherlands. Peden et al. (2007) made an estimate of the global water consumption for producing the feed for farm animals. In addition to the studies mentioned there have been a few more specific studies for the Nile River Basin (Van Breugel et al., 2010) and for the USA (Renault and Wallender, 2000; Pimentel et al., 2004).

With the exception of Chapagain and Hoekstra (2003, 2004), none of the studies have estimated the water footprint of animal products by product and country at a global level. Although Chapagain and Hoekstra (2003, 2004) were able to estimate the water footprint of farm animals and animal products per country, they have taken a very crude assumption on the composition and amount of feed consumed by the different animals. Besides, the water footprints of feed crops were estimated based on national average climatic data. We have tried to improve the estimation of feed composition and feed amount per animal category and have used better estimates for the water footprints of feed crops.

The objective of the study is to assess the water footprint of farm animals and the various derived animal products for the period 1996-2005. We consider eight animal categories: beef and dairy cattle, pig, sheep, goat, broiler and layer chicken and horses. The main differences with Chapagain and Hoekstra (2003, 2004) are:

- We have estimated the amount of feed consumed per animal category, per production system and per country based on estimates of feed conversion efficiencies and statistics on the annual production of animal products. Chapagain and Hoekstra (2003, 2004) have taken rough assumptions on the quantities of feed consumed per animal category based on incidental data.
- We reckon with the relative occurrence of the three production systems (grazing, mixed and industrial) in each country, using the studies of Seré and Steinfeld (1996) and Wint and Robinson (2007). In Chapagain and Hoekstra (2003, 2004), for each country the dominant animal production system was selected, after which further calculations for this country were based on data for that specific production system.
- We have estimated the green, blue and grey water footprints of the feed crops using a spatially explicit crop water use model able to estimate actual crop water use (Mekonnen and Hoekstra, 2010a, 2010b). In the previous studies the potential rather than the actual crop water use was used. In addition, the estimate was based on country average climatic data which could lead to errors in large countries. Furthermore the earlier studies did not explicitly distinguish between the green and blue water footprint components and did not include the grey water footprint component at all.

2. Method and data

2.1 Method

We follow the water footprint definitions and methodology as set out in Hoekstra et al. (2009). The blue water footprint refers to consumption of blue water resources (surface and groundwater) along the supply chain of a product. 'Consumption' refers to loss of water from the available ground-surface water body in a catchment area. Losses occur when water evaporates, returns to another catchment area or the sea or is incorporated into a product. The green water footprint refers to consumption of green water resources (rainwater in so far as it does not become run-off). The grey water footprint refers to pollution and is defined as the volume of freshwater that is required to assimilate the load of pollutants given natural background concentrations and existing ambient water quality standards.

We consider eight farm animal categories: beef and dairy cattle, pig, sheep, goat, broiler and layer chicken and horses. When estimating total feed amounts and total water footprints per category, we include 'buffaloes' in the category of 'beef cattle' and 'asses and mules' in the category of 'horses'.

The water footprint of a live animal consists of different components: the indirect water footprint of the feed and the direct water footprint related to the drinking water and service water consumed (Chapagain and Hoekstra, 2003, 2004). The water footprint of an animal is expressed as:

$$WF[a,c,s] = WF_{feed}[a,c,s] + WF_{drink}[a,c,s] + WF_{serv}[a,c,s] \qquad (1)$$

where $WF_{feed}[a,c,s]$, $WF_{drink}[a,c,s]$ and $WF_{serv}[a,c,s]$ represent the water footprint of an animal for animal category a in country c in production systems s related to feed, drinking water and service water consumption, respectively. Service water refers to the water used to clean the farmyard, wash the animal and carry out other services necessary to maintain the environment. The water footprint of an animal and its three components can be expressed in terms of m^3/yr/animal, or, when summed over the lifetime of the animal, in terms of m^3/animal. For beef cattle, pig, sheep, goat and broiler chicken – animals that provide their products after they have been slaughtered – it is most useful to look at the water footprint of the animal at the end of its lifetime, because it is this total that will be allocated to the various products (e.g. meat, leather). For dairy cattle and layer chicken, it is most straightforward to look at the water footprint of the animal per year (averaged over its lifetime), because one can easily relate this annual animal water footprint to its average annual production (milk, eggs).

The water footprint of an animal related to the feed consumed consists of two parts: the water footprint of the various feed ingredients and the water that is used to mix the feed:

$$WF_{feed}[a,c,s] = \frac{\sum_{p=1}^{n}\left(Feed[a,c,s,p] \times WF^{*}_{prod}[p]\right) + WF_{mixing}[a,c,s]}{Pop^{*}[a,c,s]} \qquad (2)$$

Feed[*a,c,s,p*] represents the annual amount of feed ingredient *p* consumed by animal category *a* in country *c* and production system *s* (ton/yr), $WF^{*}_{prod}[p]$ the water footprint of feed ingredient *p* (m^3/ton), $WF_{mixing}[a,c,s]$ the volume of water consumed for mixing the feed for animal category *a* in country *c* and production system *s* (m^3/yr/animal) and $Pop^{*}[a,c,s]$ the number of slaughtered animals per year or the number of milk or egg producing animals in a year for animal category *a* in country *c* and production system *s*.

The water footprint of feed ingredients

The water footprints of the different crops, roughages and crop by-products ($WF^{*}_{prod}[p]$, m^3/ton) that are eaten by the various farm animals have been calculated following the methodology developed by Hoekstra and Chapagain (2008) and Hoekstra et al. (2009). The water footprints of feed crops were estimated using a crop water use model that estimates crop water footprints at a 5 by 5 arc minute spatial resolution globally (Mekonnen and Hoekstra, 2010a, 2010b). Grey water footprints were estimated by looking at leaching and runoff of nitrogen fertilisers only, following Mekonnen and Hoekstra (2010a,b). Since animal feed in a country originates from domestic production and imported products, for the calculation of the water footprint of animal feed in a country, we have taken a weighted average water footprint according to the relative volumes of domestic production and import:

$$WF^{*}_{prod}[p] = \frac{P[p] \times WF_{prod}[p] + \sum_{n_e} \left(T_i[n_e,p] \times WF_{prod}[n_e,p] \right)}{P[p] + \sum_{n_e} T_i[n_e,p]} \qquad (3)$$

in which $P[p]$ is the production quantity of feed product *p* in a country (ton/yr), $T_i[n_e,p]$ the imported quantity of feed product *p* from exporting nation n_e (ton/yr), $WF_{prod}[p]$ the water footprint of feed product *p* when produced in the nation considered (m^3/ton) and $WF_{prod}[n_e,p]$ the water footprint of feed product *p* as in the exporting nation n_e (m^3/ton). The water footprint of crop residues such as bran, straw, chaff and leaves and tops from sugar beet have already been accounted for in the main product, therefore their water footprint was set equal to zero.

Volume and composition of feed

The volume and composition of the feed consumed vary depending on the type of animal, the production system and the country. The amount of feed consumed is estimated following the approach of Hendy et al. (1995), in which the total annual feed consumption (including both concentrates and roughages) is calculated based on annual production of animal products and feed conversion efficiencies. Only for horses we have used the approach as in Chapagain and Hoekstra (2003), which means that we multiplied the estimated feed consumption per animal by the number of animals, thus arriving at an estimate of the total feed consumed by horses.

The steps followed to calculate the volumes and composition of feed are schematically shown in Figure 1. The total feed per production system for both ruminants and non-ruminants animals is calculated as follows:

$$Feed[a,c,s] = FCE[a,c,s] \times P[a,c,s] \qquad (4)$$

where *Feed*[*a*,*c*,*s*] is the total amount of feed consumed by animal category *a* (ton/yr) in country *c* and production system *s*, *FCE*[*a*,*c*,*s*] the feed conversion efficiency (kg dry mass of feed / kg of product) for animal category *a* in country *c* and production system *s*, and *P*[*a*,*c*,*s*] the total amount of product (meat, milk, or egg) produced by animal category *a* (ton/yr) in country *c* and production system *s*.

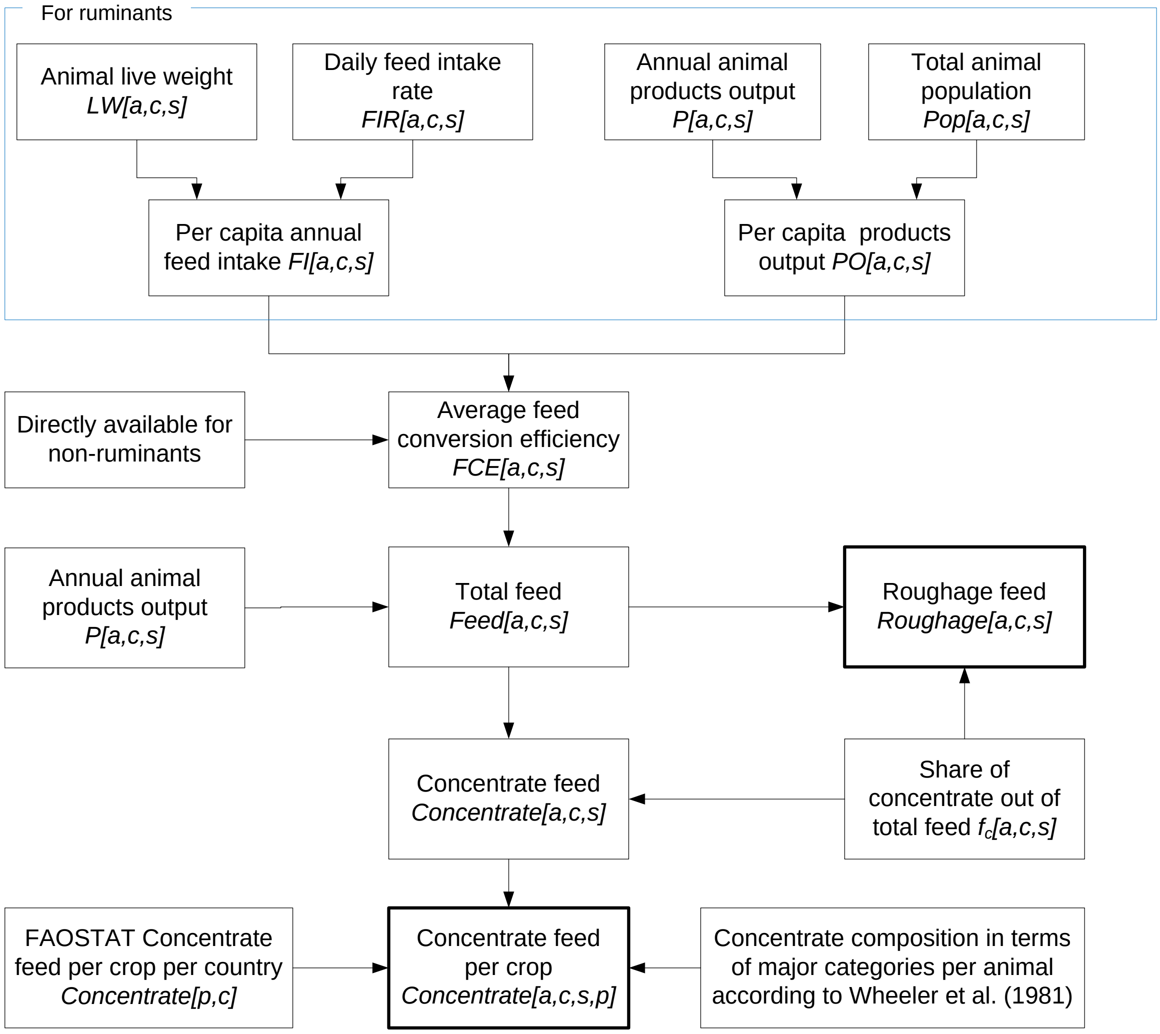

Figure 1. Steps in the calculation of feed amount per animal. For ruminants (beef cattle, dairy cattle, sheep and goat), feed conversion efficiencies are derived as indicated in the upper part of the scheme. For non-ruminants (pig, broiler and layer chicken), the feed conversion efficiencies are directly taken from the literature.

Estimating feed conversion efficiencies

Feed conversion efficiency is defined as the amount of feed consumed per unit of produced animal product (e.g. meat, milk, egg). Feed conversion efficiencies were estimated separately for each animal category (beef cattle, dairy cattle, sheep, goat, pig, broiler chicken and egg layer chicken), for each animal production system and per country. Although the term used may suggest precisely the opposite, animals that have a low 'feed conversion efficiency' are efficient users of feed. We use the term here as generally used in livestock studies. The feed conversion efficiencies (*FCE*, kg dry mass/kg product) for non-ruminants (pig and chicken) were adopted from Hendy et al. (1995). For ruminants (cattle, goat, sheep), feed conversion efficiencies were estimated through dividing feed intake per capita by annual production (of beef, milk, sheep and goat meat) per capita:

$$FCE[a,c,s] = \frac{FI[a,c,s]}{PO[a,c,s]} \qquad (5)$$

where $FI[a,c,s]$ is the feed intake per head by ruminant animal category *a* in country *c* and production system *s* (kg dry mass/yr/animal), and $PO[a,c,s]$ the product output per head for ruminant animal category *a* in country *c* and production system *s* (kg product/yr/animal). The product output (beef, milk, sheep and goat meat) per animal for ruminants is calculated as:

$$PO[a,c,s] = \frac{P[a,c,s]}{Pop[a,c,s]} \qquad (6)$$

in which $P[a,c,s]$ is the total annual production of beef, milk, sheep meat or goat meat in country *c* in production system *s* (kg/yr) and $Pop[a,c,s]$ the total population of beef cattle, dairy cattle, sheep or goat in that country and production system.

Estimating the total annual production of animal products

The annual production of animal products has been estimated as shown in Figure 2. The meat production (P_{meat}, ton/yr) per animal category *a* (beef cattle, pig, sheep and goat) in country *c* and production system *s* is estimated by multiplying the carcass yield per slaughtered animal by the annual number of animals slaughtered:

$$P_{meat}[a,c,s] = CY[a,c,s] \times SA[a,c,s] \qquad (7)$$

The carcass yield (*CY*, kg/animal) for each animal category per production system was estimated by combining country average carcass yield data from FAO (2009) with data on animal live weight per production system per economic region (Hendy et al. 1995) and data on carcass weight as percentage of live weight (FAO, 2003). The obtained carcass yields were scaled such that the total meat production per animal category equals the value provided by FAO (2009). The number of slaughtered animals per production system (*SA*, number of animal/yr) was calculated by multiplying the total animal number by the animal off-take rate per production system:

$$SA[a,c,s] = Pop[a,c,s] \times OR[a,c,s] \qquad (8)$$

where $Pop[a,c,s]$ is the population of animal category *a* in country *c* for production system *s* and $OR[a,c,s]$ the off-take rate, which is the fraction of the animal population that is taken out in a given year for slaughter (dimensionless).

Milk and egg production per production system and country were calculated as:

$$P_{milk}[a,c,s] = MY[a,c,s] \times DC[a,c,s] \qquad (9)$$

$$P_{egg}[a,c,s] = f_{egg}[a,c,s] \times P_{egg}[a,c] \qquad (10)$$

where $P_{milk}[a,c,s]$ and $P_{egg}[a,c,s]$ represent production of milk and egg in country *c* and production system *s* respectively (ton/yr), $MY[a,c,s]$ milk yield per dairy cow in country *c* and production system *s* (ton/dairy cow), $DC[a,c,s]$ the number of dairy cows in country *c* and production system *s*, $f_{egg}[a,c,s]$ the fraction of egg produced in country *c* and production system *s* and $P_{egg}[a,c]$ the total amount of egg produced in country *c* (ton/yr).

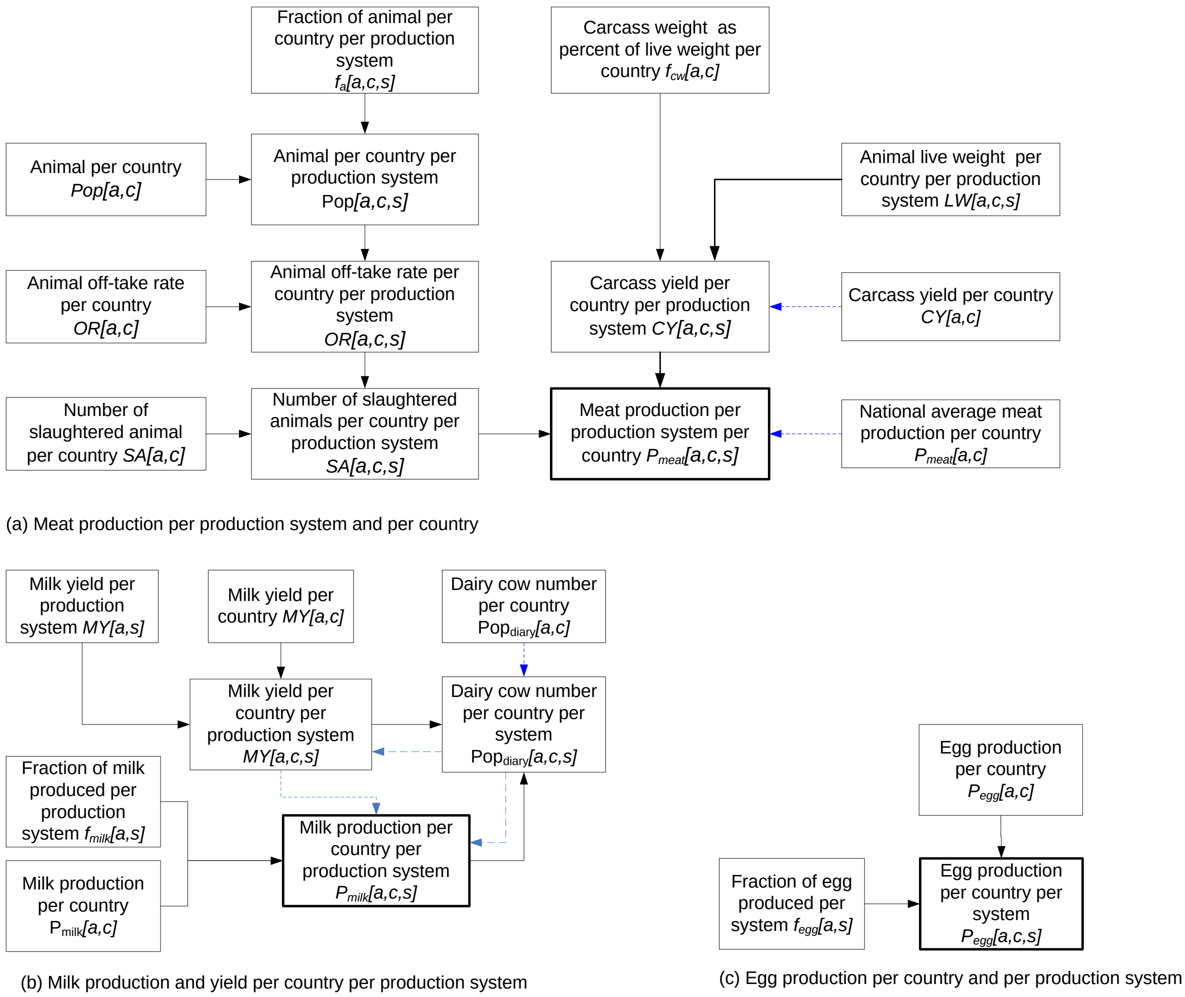

Figure 2. Steps in the calculation of: (a) annual meat production (beef cattle, pig, sheep, goat, broiler chicken); (b) annual milk production (dairy cattle); and (c) annual egg production (layer chicken). Broken arrows indicate iteration and adjustment to fit to values of FAO (2009).

Estimating the feed composition

Animal feeds are generally divided into 'concentrates' and 'roughages' (Box 2.1). The volume of concentrate feed has been estimated per animal category and per production system as:

$$Concentrate[a,c,s] = Feed[a,c,s] \times f_c[a,c,s] \quad (11)$$

where $Concentrate[a,c,s]$ is the volume of concentrate feed consumed by animal category *a* in country *c* and production system *s* (ton/yr) and $f_c[a,c,s]$ the fraction of concentrate in the total feed for animal category *a* in country *c* and production system *s*. For the latter variable, data have been obtained from Hendy et al. (1995) and Bouwman et al. (2005).

The composition of concentrate feeds varies across animal species and regions of the world. To our knowledge, there are no datasets with global coverage on the composition of feed for the different animals per country. Therefore, we have made a number of assumptions concerning the concentrate feed composition of the different animal species. According to Hendy et al. (1995), the diets of pig and poultry include, on average, 50-60% cereals, 10-20% oil meals and 15-25% 'other concentrates' (grain substitutes, milling by-products, non-conventional concentrates). Wheeler et al. (1981) provide the feed composition in terms of major crop categories for the different animal categories (Figure 3 and Figure 4). We have used these and other sources in combination with FAOSTAT country average concentrate feed values for the period 1996-2003 (FAO, 2009) to estimate the diet composition of the different animal species. In order to estimate the feed in terms of specific crops per animal, we first estimated the feed in terms of major crop categories following Wheeler et al. (1981). The feed in terms of major crop categories is further distributed to each crop proportional to the crop's share in its crops category as obtained from FAOSTAT (FAO, 2009). The roughage feed is divided into fodder, grass and crop residues using the data obtained from Bouwman et al. (2005).

Box 2.1 Definition of feed components. Source: Hendy et al. (1995) and FAO(1983).

Feeds are generally divided into 'concentrates' and 'roughages'.

- **Concentrates** are feeds which contain a high level of nutrients for a given weight of feed usually low in crude fibre content (less than 18% of dry matter content) and high in total digestible nutrients. Thus concentrates may be high in energy, as in the case of cereals and milling by-products or they may be high in protein, as are protein meals of either vegetable or animal origin. The concentrates considered in this study include all the feed material found in FAO (2009) and which are derived from crops. The concentrate feeds considered include cereals, roots and tubers, oil crops, oil meals, bran, molasses, pulses, sugar crops, fruits and vegetables.
- **Roughages** are feeds with low density of nutrients, with a crude fibre content over 18% of dry matter, include most fresh and dried forages and fodders. The main roughages are:
  - pastures: includes temporary and permanent pastures.
  - harvested roughages: include those which are sown and harvested annually for forage, fodder or silage. The principal types of harvest roughages include forage (green) cereals such as maize, oats and sweet sorghum; sugarcane, lucerne (alfalfa) and berseem (Egyptian clover); special high yielding grasses cultivated chiefly for silage (such as Thimoth grass); roots and tubers such as potatoes, beets, swedes, turnips; oilseeds such as winter rape; pulses such as field peas, beans, sweet lupins and vetches; vegetables such as pumpkins and cabbages. These feeds are sometimes processed for lower fibre content and bulk and are then usually classified as concentrate feeds (e.g. cassava chips and pellets, processed alfalfa, pea and bean meals).
  - other roughages: include a large variety of crop by-products such as straw and chaff from cereals and pulses; leaves and tops from sugar beet; fodder beets and vegetables; and other miscellaneous roughages such as acacia and ipil ipil (leucaena) leaves.

2.2 Data

A large amount of data has been collected from different sources. A major data source for animal stocks, numbers of animals slaughtered each year, annual production of animal products, and concentrate feed per country is FAOSTAT (FAO, 2009). Other important sources that have been used are: Seré and Steinfeld (1996), Hendy et al. (1995), Bouwman et al. (2005), Wint and Robinson (2007), Wheeler et al. (1981) and FAO (2003). Box 2.2 summarizes how specific data have been obtained from these different sources.

Box 2.2. Overview of data sources.

- **Animal production systems:** Seré and Steinfeld (1996) have developed a classification of animal production systems based on agro-ecology, the distinction between pastoral, mixed and landless systems and on the presence of irrigation or not. They distinguish eleven animal production systems grouped under three headings: grazing (extensive), mixed and industrial (intensive). In this study we use the schematization into these three production systems.
- **Feed conversion efficiencies:** For ruminants, the feed conversion efficiencies were estimated as explained in Section 2.1. For non-ruminants (pig, broiler and egg laying chicken), feed conversion efficiencies per animal category, per production system and per economic region were obtained from Hendy et al. (1995). For both ruminants and non-ruminants, the feed conversion efficiency data were scaled such that at the level of world regions they match the efficiencies as reported in Bouwman et al. (2005).
- **Annual production of animal products:** Data on the annual production of animal products (beef, pig meat, sheep meat, goat meat, chicken meat, milk and egg) per production system for different economic regions were obtained from Seré and Steinfeld (1996). Production data per product and country for the period 1996-2005 were obtained from FAOSTAT (FAO, 2009). The two data sources have been combined to derive production data per animal category, production system and per country for the period 1996-2005. We scaled the production data per production system such that at national level, the production aggregated over the different production systems equals the production as reported in FAO (2009) for the period 1996-2005.
- **Number of animals:** Seré and Steinfeld (1996) provide the total animal population for the different production systems for the year 1995 for a number of geographic regions in the world. Wint and Robinson (2007) provide the total animal population for the year 2005 for the different production systems for developing countries. We have combined the two sources to obtain number of animals per animal category, per production system and per country. We scaled the numbers such that at national level, the number of animals aggregated over the different production systems equal the numbers as reported in FAO (2009) for the period 1996-2005.
- **Number of slaughtered animals and animal off-take rates:** The annual number of slaughtered animals for beef cattle, pig, sheep, goat and broiler chicken per country have been taken from FAO (2009). The animal off-take rates at national level have been derived from the same source by dividing the annual number of slaughtered animals by the total population. The off-take rate for the grazing system was assumed to be 90% of the national average off-take rate for the animal category considered (Bouwman, et al., 2005). Per country, the off-take rate for the mixed and industrial production systems were scaled until the total number of slaughtered animals per animal category equalled the value provided by FAO (2009).
- **Animal live weight:** Hendy et al. (1995) provide live weight of ruminant animals (beef cattle, dairy cattle, sheep and goat) by production system and economic region. FAO (2003) give animal live weight for cattle, pig, sheep, goat and chicken. We combined these two sources, taking advantage of the fact that Hendy et al. (1995) specify data per production system (but not per country) and FAO (2003) provides data per country (but not per system).
- **Carcass weight as percentage of live weight:** FAO (2003) provides carcass weight as percentage of live weight for the different animal categories per country.
- **Ruminant animals daily feed intake rate:** Daily feed intake rate for ruminant animals (beef cattle, dairy cattle, sheep and goat) was obtained from Hendy et al. (1995).
- **Share of concentrate feed in total animal feed:** The contribution of concentrate feeds such as cereals, oil-meals, roots and other crop products in the total feed composition was obtained from Hendy et al. (1995) and Bouwman et al. (2005).
- **Composition of the concentrate feed:** The composition of concentrate feed per animal category was estimated following mainly Wheeler et al. (1981) (Figure 3-4). In addition, we used Steinfeld et al. (2006) for data on the relative composition of poultry and pig feed for major countries (Figure 5-6). The data available in Wheeler et al. (1981) and Steinfeld et al. (2006) are not sufficient to specify the feed composition at the level of specific crops or crop products. In order to come to that level of detail we use the Supply and Utilization Accounts of FAOSTAT (FAO, 2009), which provide the total concentrate feed utilization per country per crop and crop product.
- **Composition of the roughage feed:** We used Bouwman et al. (2005) to estimate the composition of the roughage feed (grass, fodder crops, crop residues).
- **Water use for drinking and animal servicing:** Data were obtained from Chapagain and Hoekstra (2003). See Appendix IV.
- **Water use for mixing feed:** Following Chapagain and Hoekstra (2003), the water use for feed mixing is assumed to be 50% of total concentrate feed intake (or 0.5 litre per kg of concentrate feed intake).

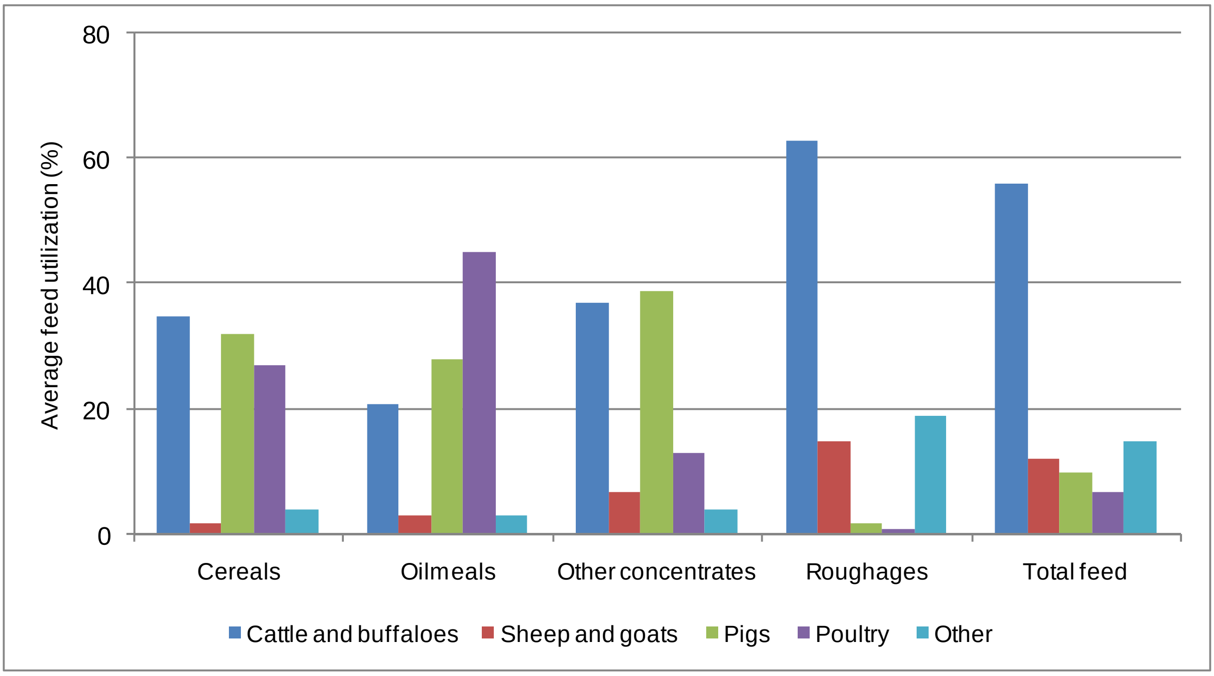

Figure 3. World average utilization of feeds by different animal species in metabolisable energy equivalents Source: Wheeler et al. (1981).

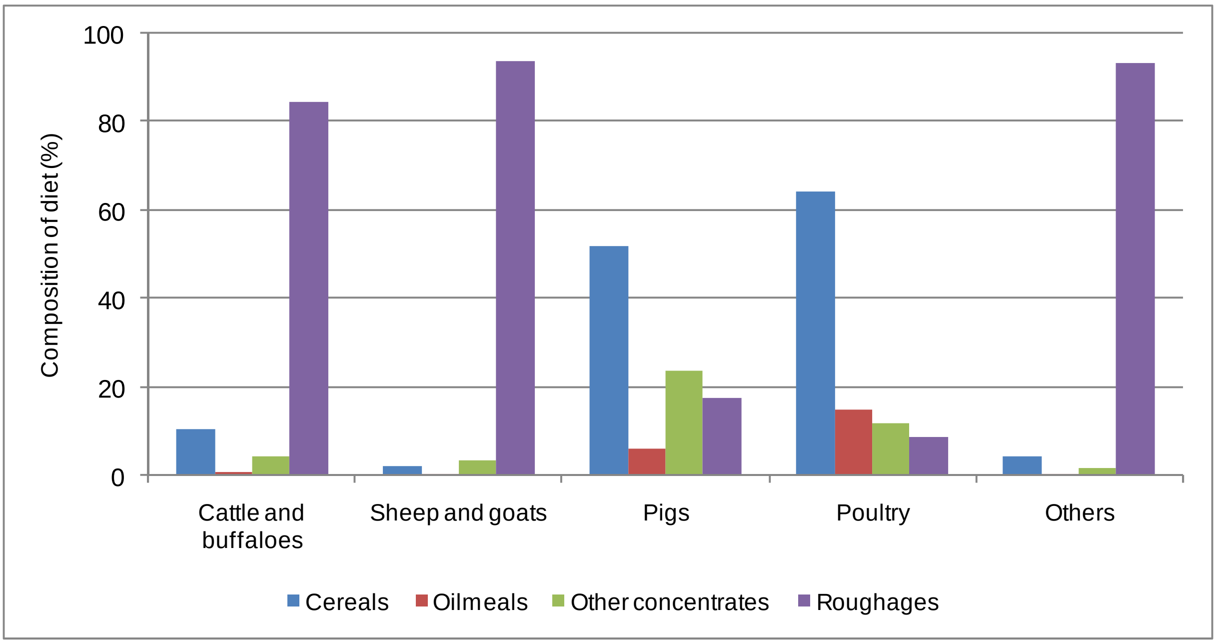

Figure 4. Aggregate world composition of diets for different species of animal in metabolisable energy equivalents Source: Wheeler et al. (1981).

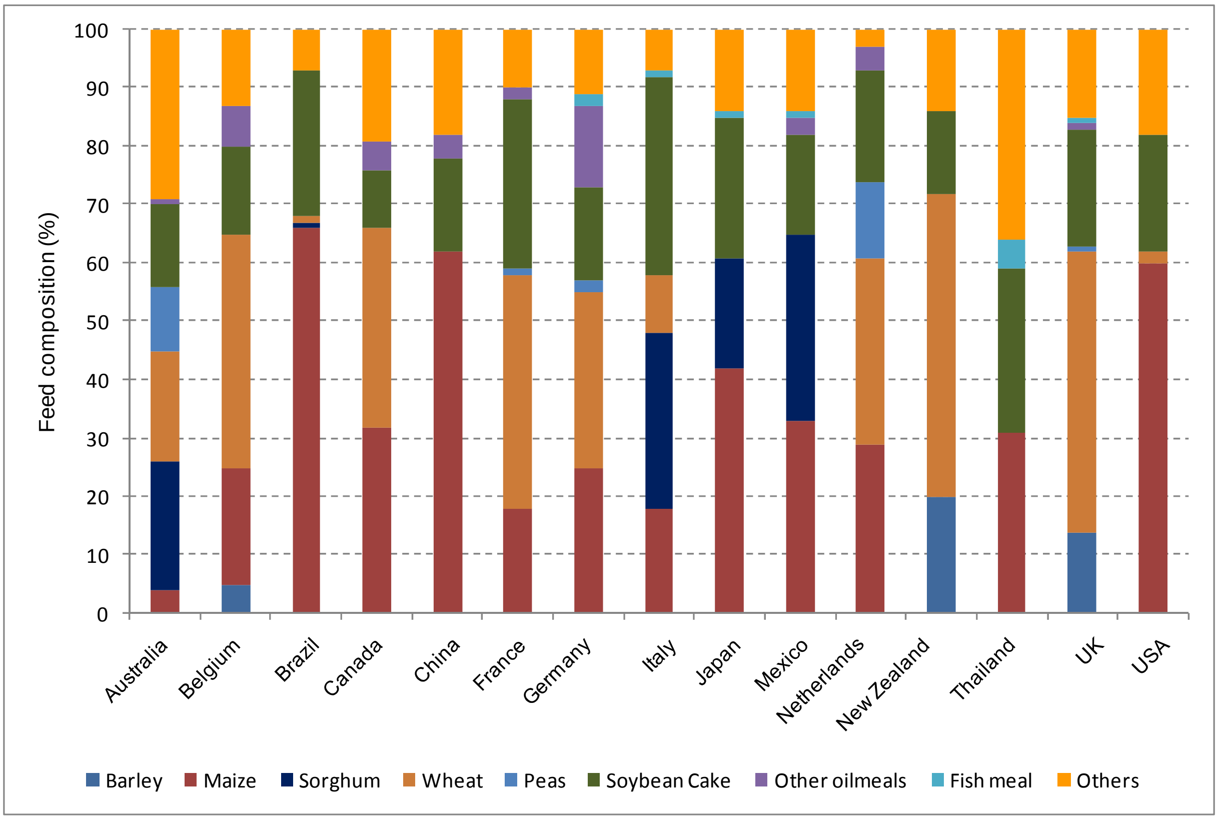

Figure 5. Relative composition of poultry feed basket in selected countries (by weight). Source: Steinfeld et al. (2006).

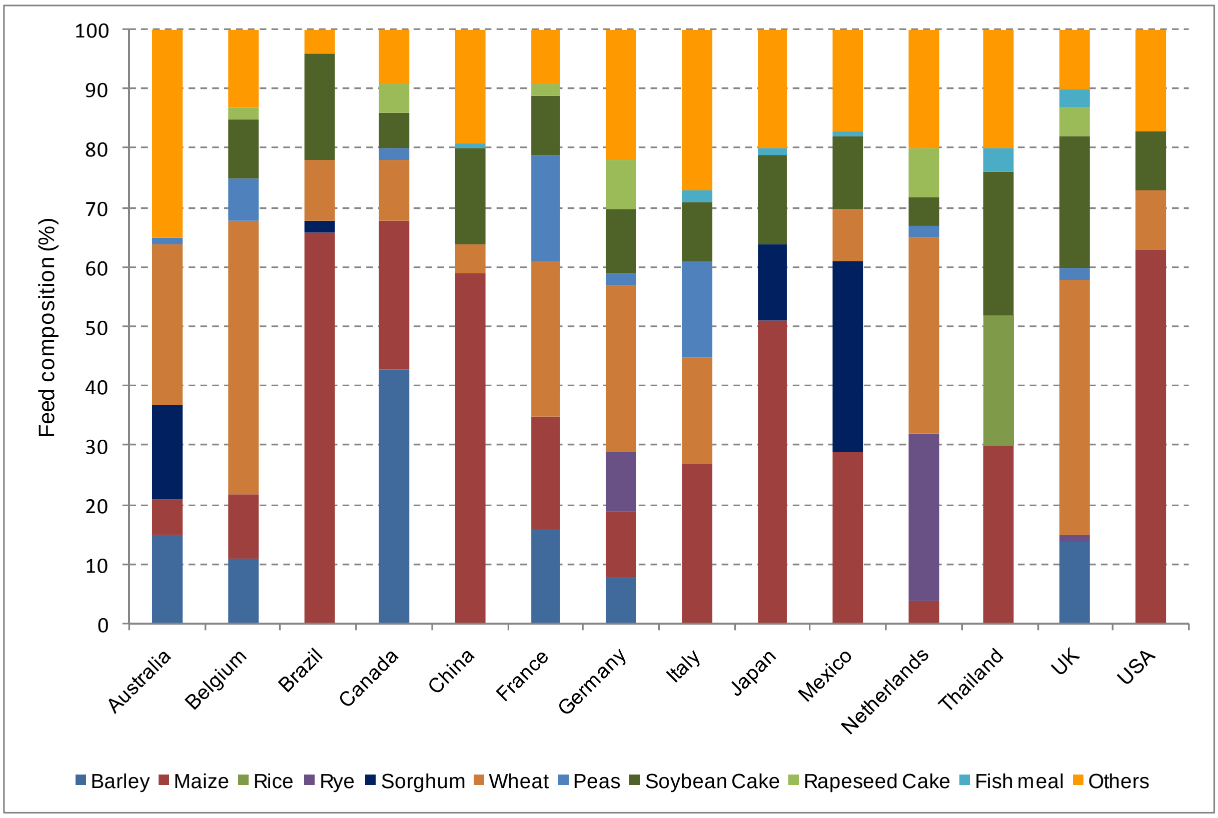

Figure 6. Relative composition of pig feed basket in selected countries (by weight). Source: Steinfeld et al. (2006).

3. Results

3.1 Quantity and composition of animal feed

Table 1 provides global average feed conversion efficiencies for different animal categories and production systems. Region-specific feed conversion efficiencies are presented in Appendix I. Ruminants (cattle, sheep, goat) are less efficient in converting feed into meat than non-ruminants (pig, chicken), amongst other due to the lower quality of feed they consume. Particularly meat production from cattle costs a lot of feed per unit of product obtained. Although ruminants need more feed, their feed largely consists of forage and other materials that humans cannot eat, while non-ruminants consume large amounts of concentrate feed that could be used for human consumption. Non-ruminants thus most obviously compete with humans for food, but in an indirect way ruminants also compete for food with humans. In some cases the roughages eaten by ruminants are produced with land and water resources that cannot alternatively be allocated to crop production for human consumption (e.g. in the case of grazing in dry or wetlands), but often the land and water resources used for roughages supply can alternatively be used for crop growth for human consumption, so that ruminants compete with humans for food also through consumption of roughages.

Table 1. Global average feed conversion efficiency per animal category and production system.

Animal category	Feed conversion efficiency (kg dry mass feed/kg output)			
	Grazing	Mixed	Industrial	Overall
Beef cattle	70.1	51.8	19.2	46.9
Dairy cattle	3.5	1.6	1.1	1.9
Broiler chicken	9.0	4.9	2.8	4.2
Layer chicken	9.3	4.4	2.3	3.1
Pig	11.3	6.5	3.9	5.8
Sheep and goat	49.6	25.8	13.3	30.2

Non-ruminants are responsible for 60% of the global consumption of concentrate feeds; ruminants account for 40%. Figure 7 shows the consumption of different concentrates by different animal categories. Chickens take the largest share in total concentrate feed consumption (30%). Three fifth of the concentrate feed consumption by chicken in the world is for broiler chicken and two fifth for layer chicken. Pig meat production takes nearly the same share (29%) in global concentrate feed consumption, while dairy cattle are responsible for 25% and beef cattle 14%. Our estimated shares of different animal categories in the total concentrate feed consumption is very close to the estimates made by Hendy et al. (1995).

Annual concentrate feed consumption averaged over the period 1996-2005 expressed in commodity fresh weight amounted to 1195 million tons per year. This value is very close to the feed data provided by FAO (2009) for the period 1996-2003 (1229 million ton/yr). The feed data analysed and presented here focus on commodities derived from crop production. Figure 8 presents a summary of the global total feed utilization of cereals, oil meals and cakes, roots and tubers, bran and others. Cereals make up the largest percentage of the total concentrate feed use (57%), followed by oil meals (15%), roots (11%) and brans (10%).

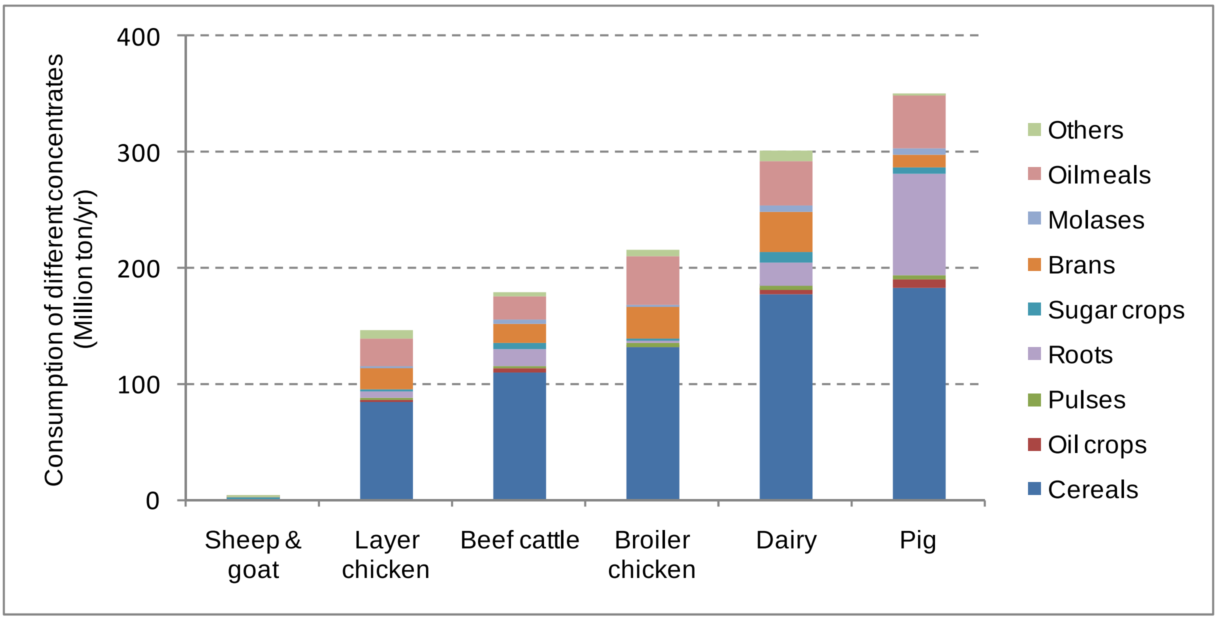

Figure 7. Consumption of different concentrates per animal category.

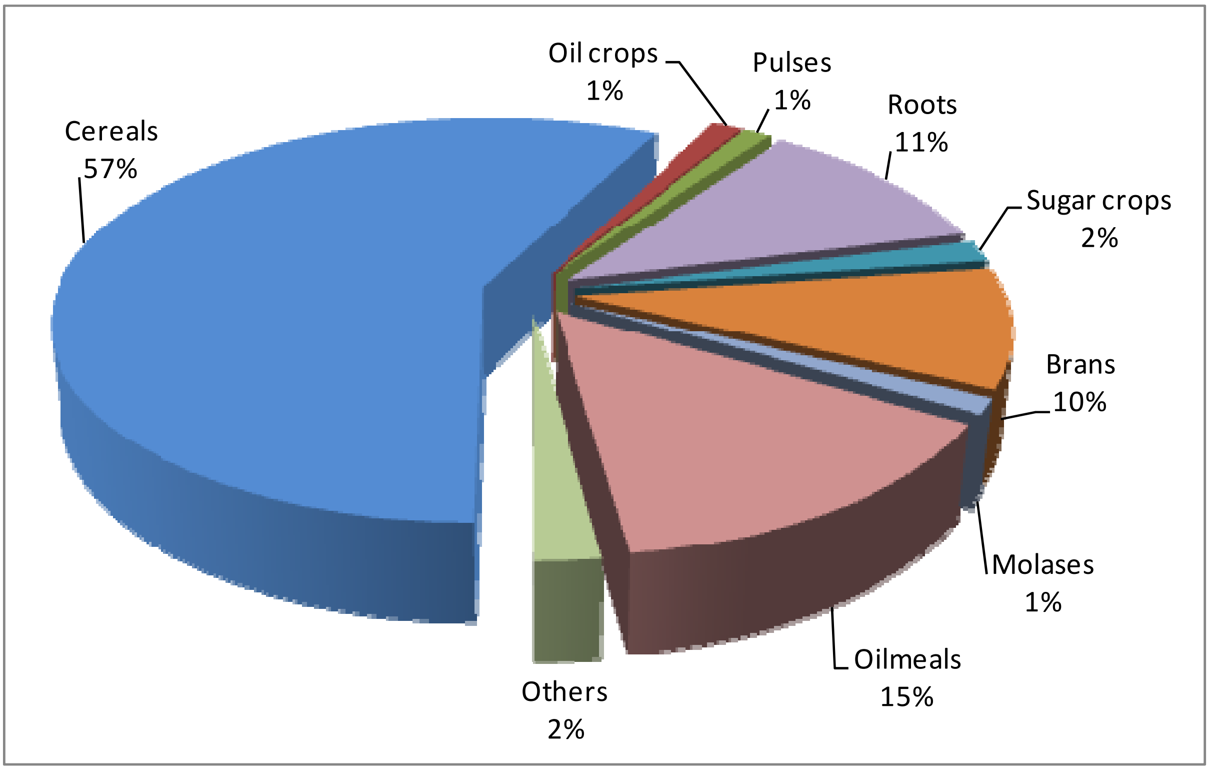

Figure 8. Contribution of different crops (on fresh weight basis) toward global total concentrate feed utilization. Period 1996-2005.

The estimated global amount of feed consumption per animal category and world region is presented in Appendix II. Feed consumption per production system is shown in Appendix III. The total feed consumption over the period 1996-2005 was 4996 million ton feed in dry matter per year, on average. Roughages account for the largest share out of this total, accounting for 80%, and feeds derived from crop production account for the remaining 20%. Considering only plant-based feed materials, our global estimate of total feed in dry matter

(4996 Mton dry mass/yr) is about 6% lower than the estimate of Wirsenius (2000) (5300 Mton dry mass/yr) and 8% more than the estimate of Bouwman et al. (2005) for 1995 (4637 Mton dry mass/yr). Our estimate of global utilization of roughages (4010 Mton dry mass/yr), which includes pasture, forages, straws, sugar crops tops and leaves, oil crops stalks and husks is 15% lower than the estimate of Wirsenius (2000) (4740 Mton dry mass/yr) and 5% larger than the estimate of Bouwman et al. (2005) for 1995 (3832 Mton dry mass/yr).

3.2 The water footprint of animal feed

The water footprint per ton of feed differs among crops and across countries. Since the most significant part of the animal water footprint comes from the feed they consume, the water footprint per unit of feed is an important factor in the determination of the water footprint of animals and their associated derived products. Table 2 shows the average water footprint of selected feed ingredients for selected countries. Crop residues and by-products such as bran, straw, chaff and leaves and tops from sugar beet have a water footprint of about zero, because the water footprint of crop growing is mainly attributed to the main crop products, not the low-value residues or by-products. As a result they provide an opportunity to reduce the water footprint of animal production. Huge reduction in the water footprint of animals can also be obtained by using crops with a relatively low water footprint per ton such as sugar beet. Therefore, careful selection of feeds that meet the nutrient requirement of the animals and at the same time have a smaller water footprint per ton could significantly reduce the indirect use of freshwater resources associated with animal production.

3.3 The water footprint of live animals at the end of their lifetime and animal products per ton

Table 3 shows, for each animal category, the average water footprint of an animal at the end of its life time and the annual water footprint of an animal. Dairy cows have the largest annual water footprint (2056 m^3/yr/animal), which is more than the average human being. Broiler chicken have the smallest footprint (26 m^3/yr/animal).

Table 4 presents the green, blue and grey water footprints of some selected animal products per production system for selected countries. Appendix V presents the full result of our analysis: green, blue and grey water footprints of all farm animals and animal products considered, per production system and per country. The water footprints of animals and animal products vary greatly across countries and production systems. When we look at global averages, however, we see that the water footprint of meat increases from chicken meat (4300 m^3/ton), goat meat (5500 m^3/ton), pig meat (6000 m^3/ton), sheep meat (10400 m^3/ton) to beef (15400 m^3/ton). The differences can be partly explained from the different feed conversion efficiencies of the animals. Beef production, for example, requires eight times more feed (in dry matter) per kilogram of meat compared to producing pig meat, and eleven times if compared to the case of chicken meat. This is not the only factor, however, that can explain the differences. Another important factor is the feed composition. Particularly the fraction of concentrate feed in the total feed is important, because concentrate feed generally has a larger water footprint than roughages. Chicken, which are efficient from a total feed point of view, are no longer that efficient when we look at the fraction of concentrates in their feed. This fraction is 73% for broiler chicken (global average), while it is only 5% for beef cattle.

Table 2. Average water footprint of selected feed components for selected countries (m^3/ton) (1996-2005).

Feed	Water footprint component	Australia	Brazil	China	Egypt	Germany	India	Mexico	USA	World Average
Wheat	Green	1994	1850	839	784	608	643	1021	1842	1277
	Blue	17	9	455	590		1162	318	88	342
	Grey	102	129	308	316	178	294	203	227	207
Barley	Green	1638	1411	847	666	499	1247	941	908	1213
	Blue		7	20	1591		780	376	204	79
	Grey	155	139	145	861	194	96	120	145	131
Maize	Green	718	1619	791	311	440	2225	1490	523	947
	Blue	521	1	74	713	20	103	62	63	81
	Grey	135	124	295	364	118	195	308	176	194
Millet	Green	2954	3344	1600	11982	2509	3719	2953	2990	4306
	Blue		164	40	26	84	76	59	61	57
	Grey	228	141	222	79	128	233	302	309	115
Cassava	Green	444	433	357	422	394	258	529	471	550
	Blue		1							
	Grey	32	17	56	31	29	24	22	22	13
Sugar beet	Green	116	39	147	14	60	63	49	67	82
	Blue	3	59		164	3		26	37	26
	Grey	63	12	82	50	21	29	14	20	25
Soybeans	Green	1714	2186	2231	1869	1533	3322	1629	1562	2037
	Blue	65	1	129	122	23	18	98	92	70
	Grey	10	15	106	43	11	92	10	10	37
Rapeseed	Green	2095	2771	1483	1556	1155	1646	2567	2743	1703
	Blue		2	7	1213	1	1467	4	3	231
	Grey	420	98	466	197	259	235	341	360	336
Sesame seed Cake	Green	1422	1813	1851	1550	1272	2756	1352	1296	1690
	Blue	54	1	107	101	19	15	81	76	58
	Grey	8	12	88	35	9	76	8	8	31
Cottonseed Cake	Green	254	648	328	154	245	1170	425	388	471
	Blue	276	52	111	670	178	341	195	169	270
	Grey	53	81	114	103	53	172	48	68	91
Fodder crops	Green	254	158	2461	232	131	412	117	244	207
	Blue	204	148					33	44	27
	Grey	15	7	105	285	30	31	11	35	20
Pasture	Green	762	307	225	225	131	407	174	372	315
	Blue									
	Grey									

Source: data for feed crops based on Mekonnen and Hoekstra (2010b); data for pasture from this study. The water footprints shown in this table refer the weighted average of domestically produced and imported feeds.

Table 3. Average annual water footprint of one animal, per animal category (1996-2005).

Animal category	Water footprint of live animal at end of life time (m^3/ton)	Average animal weight at end of life time (kg)	Average water footprint at end of life time (m^3/animal)	Average life time (yr)	Average annual water footprint of one animal (m^3/yr/animal)
Dairy cattle			20558	10	2056
Horse	40612	473	19189	12	1599
Beef cattle	7477	253	1889	3.0	630
Pig	3831	102	390	0.75	520
Sheep	4519	31.3	141	2.1	68
Layer chicken			47	1.4	33
Goat	3079	24.6	76	2.3	32
Broiler chicken	3364	1.90	6	0.25	26

Total water footprint per ton of product

For all farm animal products, except dairy products, the total water footprint per unit of product declines from the grazing to the mixed production system and then again from the mixed to the industrial production system. The reason is that, when moving from grazing to industrial production systems, feed conversion efficiencies become better. Per unit of product, about three to four times more feed is required for grazing systems when compared to industrial systems (see Table 1). More feed implies that more water is needed to produce the feed. However, the fact that feed conversion efficiencies in grazing and industrial production systems differ by a factor 3 to 4 does not mean that the water footprints of animal products are 3 to 4 times larger when derived from a grazing instead of an industrial system. This is because the feed composition of animals raised in grazing systems is generally more favourable from a water resources point of view. For all animal categories, the fraction of concentrate feed in the total feed is larger for industrial systems if compared to mixed production systems and larger for mixed systems if compared to grazing systems. The water footprint per kg of concentrate feed is generally larger than for roughages, so that this works to the disadvantage of the total water footprint of animals raised in industrial systems and to the advantage of the total water footprint of animals raised in grazing systems. This effect, however, does not fully compensate for the unfavourable feed conversion efficiencies in grazing systems. An exception is in dairy farming, where the total water footprint per unit of product is comparable in all three production systems. For dairy products, the water footprint happens to be smallest when they are derived from a mixed system and a bit larger but comparable when obtained from a grazing or industrial system.

Blue and grey water footprints per ton of product

All the above is about comparing the *total* water footprints of animal products. The picture changes when we focus on the *blue* and *grey* water footprint components. With the exception of chicken products, blue and grey water footprints always increase from grazing to industrial production systems. Figure 9 illustrates this by showing the blue water footprint of a number of animal products across the three productions systems. For the grey water footprint similar pictures can be obtained. The larger blue and grey water footprints for products obtained from industrial production systems are caused by the fact that concentrate feed takes a larger share in the total feed in industrial systems when compared to grazing systems. For beef cattle in grazing systems, the global average share of concentrate feed in total feed is 2%, while in industrial systems it is 21%. Mixed systems are generally somewhere in between. Although the feed crops that are contained in the concentrate feed are often to a great extent based on green water, there is a blue water footprint component as well, and the larger the consumption of feed crops compared to roughages, the larger the total amount of blue water consumed. This explains the larger blue water footprint per ton of product in industrial production systems for beef, milk, cheese, and pig, sheep and goat meat. The application and leaching of fertilizers and other agro-chemicals in feed crop production results in the fact that the grey water footprint of animal products from industrial systems, where the dependence on feed crops is greatest, is larger than for grazing systems. Given the fact that freshwater problems generally relate to blue water scarcity and water pollution and to a lesser extent to competition over green water, this means that – from a water resources point of view – grazing systems are preferable over industrial production systems for cattle, pig, sheep and goat.

In the case of chicken products (chicken meat and egg), the industrial production system has, on average, a smaller blue and grey water footprint per ton of product compared to the other two production systems. The reason is that chicken strongly rely on concentrate feed in all production systems, intensive or extensive. Broiler chicken in extensive systems have a share of concentrate feed in total feed of 63%, while this is 81% in intensive industrial systems. There is still a difference, but the differences in feed composition for both broiler and layer chicken is less outspoken if compared to the other animal categories. As a result, the relatively unfavourable feed conversion efficiency in extensive systems is not compensated by a more favourable composition of the feed as is the case in the other animal categories.

Country differences

In general terms, one can say that the type of production system is highly relevant for the size, composition and geographic spread of the water footprint of an animal product, because the type of production system determines feed conversion efficiency, feed composition and origin of feed. Similarly we observe that the country of production influences the water footprint of animal products in general terms as well. The Netherlands, for example, shows lower total water footprints for most animal products if compared to the USA. The USA, in turn, generally shows lower total water footprints for animal products than India. These crude general differences between countries are related to existing country differences in feed conversion efficiencies, but also to the fact that water footprints of feed crops vary across countries as a function of differences in climate and agricultural practice.

Water footprint components - *example for beef*

For all animal products, the water footprint related to the animal feed takes by far the largest share in the total water footprint. Further one can say that the green water footprint is always much larger than the blue and grey water footprints. As an example, Table 5 shows in detail the components of the water footprint of producing a kilogram of beef. The water footprint is dominantly green water (94%) and the largest share comes from the feed the cattle consume (99%). Drinking and service water contribute only 1% toward the total water footprint, but 30% to the blue water footprint. The major fraction (83%) of the water footprint of a beef cow is attributed to the derived beef, but smaller fractions go to the other products: offal, leather and semen.

Table 4. The green, blue and grey water footprint of selected animal products for selected countries (m^3/ton).

Animal products	Farming system	Australia			Brazil			China			India			Netherlands			Russia			USA			Global average		
		Green	Blue	Grey	Green	Blue	Grey	Green	Blue	Grey	Green	Blue	Grey	Green	Blue	Grey	Green	Blue	Grey	Green	Blue	Grey	Green	Blue	Grey
Beef	Grazing	18056	745	55	23729	150	16	16140	0	0	25913	0	0				15182	411	200	19102	525	590	21121	465	243
	Mixed	14455	623	61	20604	187	61	13227	339	103	16192	533	144	10319	761	664	11615	451	204	12726	546	768	14803	508	401
	Industrial	4730	304	96	8421	147	244	10922	933	1234	12412	1471	866	3934	349	225	23591	1002	871	2949	356	551	8849	683	712
	Weighted average	14507	613	62	19228	178	82	12795	495	398	15537	722	288	5684	484	345	16264	585	372	12933	525	733	14414	550	451
Sheep meat	Grazing	13236	438	9	19440	372	1	9606	0	0	11441	0	0				14236	351	3	11910	312	18	15870	421	20
	Mixed	6554	427	22	10649	421	9	5337	454	14	7528	582	316	8248	422	35	7176	379	7	9842	318	74	7784	484	67
	Industrial				4747	445	12	2366	451	22	4523	593	484				3044	469	9	0	0	0	4607	800	216
	Weighted average	10151	434	15	11772	421	7	5347	452	14	7416	582	314	8248	422	35	9284	395	5	10948	315	44	9813	522	76
Goat meat	Grazing	4809	245	0	15860	328	0	5073	0	0	8081	0	0				7086	219	0				9277	285	0
	Mixed	2435	233	0	8745	349	0	2765	283	0	4544	381	9	2443	453	4	3615	247	0				4691	313	4
	Industrial				3754	406	0	1187	437	0	2046	436	30				1546	322	1				2431	413	18
	Weighted average	3733	240	0	8144	372	0	2958	312	0	4194	393	13	2443	454	4	4432	266	0				5185	330	6
Pig meat	Grazing	4299	3721	247	5482	1689	318	11134	205	738	3732	391	325	4048	479	587	7176	357	282	5118	870	890	7660	431	632
	Mixed	2056	1909	118	5109	828	316	5401	356	542	4068	893	390	3653	306	451	7212	472	289	4953	743	916	5210	435	582
	Industrial	7908	651	656	8184	215	525	3477	538	925	9236	2014	1021	3776	236	427	5165	397	207	3404	563	634	4050	487	687
	Weighted average	5284	1226	414	6080	749	379	5050	405	648	5415	1191	554	3723	268	438	6937	429	276	4102	645	761	4907	459	622
Chicken meat	Grazing	4862	276	336	6363	35	364	4695	448	1414	11993	1536	1369	2535	113	271	8854	334	321	2836	294	497	7919	734	718
	Mixed	2893	173	200	4073	32	233	3005	297	905	7676	995	876	1509	76	161	5259	210	190	1688	183	296	4065	348	574
	Industrial	2968	176	205	3723	24	213	1940	195	584	3787	496	432	1548	77	165	2976	124	108	1731	187	303	2337	210	325
	Weighted average	2962	176	205	4204	30	240	2836	281	854	6726	873	768	1545	77	165	6036	235	219	1728	187	303	3545	313	467
Egg	Grazing	2243	146	173	432	24	25	3952	375	1189	10604	1360	1176	1695	76	161				1740	183	331	6781	418	446
	Mixed	1435	99	111	257	24	15	2351	230	708	6309	815	699	1085	51	103	4617	170	168	1113	121	212	3006	312	545
	Industrial	1570	107	121	3625	28	213	2086	206	628	3611	472	400	1187	55	113	4455	164	162	1218	132	232	2298	205	369
	Weighted average	1555	106	120	2737	27	161	2211	217	666	4888	635	542	1175	55	111	4511	166	164	1206	130	230	2592	244	429
Milk	Grazing	780	74	20	1046	22	7	1580	106	128	1185	105	34	572	50	32	0	0	0	1106	69	89	1087	56	49
	Mixed	700	64	35	1254	42	36	897	147	213	863	132	65	431	40	23	1143	60	39	582	59	88	790	90	76
	Industrial	517	48	43										500	43	25	1488	76	56	444	61	100	1027	98	82
	Weighted average	704	63	33	1149	33	22	927	145	210	885	130	63	462	41	25	1273	65	45	647	60	89	863	86	72
Butter	Grazing	4246	400	107	5691	122	39	8600	577	696	6448	572	188	3111	272	176				6022	373	482	5913	305	265
	Mixed	3808	347	192	6822	230	196	4880	799	1161	4697	716	352	2345	218	123	6221	324	213	3169	321	478	4297	492	415
	Industrial	2814	261	231	0	0	0	0	0	0	0	0	0	2720	233	136	8098	415	302	2417	330	543	5591	532	448
	Weighted average	3829	344	178	6254	179	117	5044	789	1141	4819	706	341	2513	224	134	6927	355	247	3519	324	483	4695	465	393
Milk powder	Grazing	3628	342	91	4862	104	34	7348	493	595	5510	489	160	2658	232	151	0	0	0	5145	319	412	5052	261	227
	Mixed	3253	296	164	5829	197	167	4169	683	992	4013	612	301	2003	186	105	5315	277	182	2708	274	409	3671	421	354
	Industrial	2405	223	198	0	0	0	0	0	0	0	0	0	2324	199	116	6920	355	258	2065	282	464	4777	455	382
	Weighted average	3271	294	152	5344	153	100	4309	674	975	4117	603	291	2147	191	114	5919	303	211	3007	277	413	4011	398	336
Cheese	Grazing	3857	380	97	5169	126	36	7812	540	633	5857	535	171	2826	263	160				5470	355	438	5371	293	241
	Mixed	3459	331	174	6197	225	178	4432	742	1055	4267	666	320	2130	214	111	5651	310	194	2878	307	435	3903	463	377
	Industrial	2556	253	210										2471	227	124	7356	393	275	2196	315	493	5078	500	406
	Weighted average	3478	328	162	5681	178	107	4581	732	1036	4377	657	310	2283	219	121	6292	338	224	3196	310	439	4264	439	357
Leather (bovine)	Grazing	17601	801	54	22821	219	15	14300	0	0	25195	0	0				16922	529	223	21290	657	658	20905	535	240
	Mixed	14090	682	59	19815	255	59	11719	377	91	15743	593	140	11883	947	765	12946	574	228	14185	681	856	16701	644	453
	Industrial	4610	407	93	8099	217	235	9677	904	1093	12068	1505	842	4530	513	259	26295	1189	971	3287	497	614	9487	805	763
	Weighted average	14150	673	60	18445	246	79	11323	515	352	15103	777	280	6067	589	369	18093	723	414	14450	658	819	15916	679	498

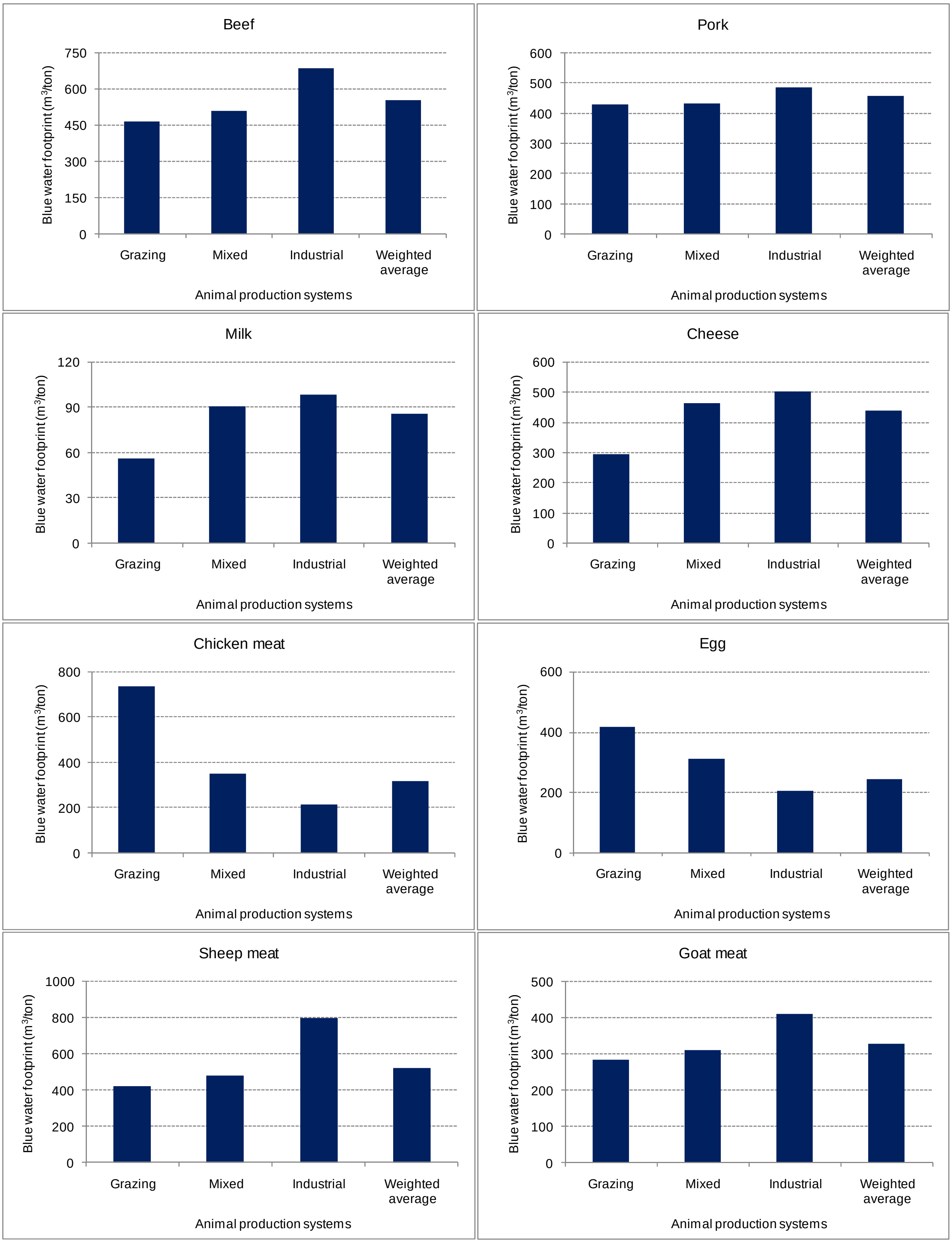

Figure 9. Global average blue water footprint per production system for selected animal products (1996-2005).

Table 5. The components of the water footprint of a beef cow and its derived products.

Feed crop*	Feed amount (kg/kg carcass)	Weighted average water footprint of feed (litre/kg)			Water footprint (litre/kg carcass)			
		Green	Blue	Grey	Green	Blue	Grey	Total
Maize	1.0102	695	111	181	702	112	182	996
Wheat	0.2441	1322	77	140	323	18.8	34.0	375
Barley	0.2657	1143	59	126	304	15.6	33.4	353
Soya bean cake	0.1858	1451	72	19	270	13.4	3.6	286
Sorghum	0.1028	1228	130	92	126	13.4	9.5	149
Oats	0.0603	1457	212	125	87.8	12.8	7.6	108
Rice, paddy	0.0754	997	259	165	75.1	19.6	12.4	107
Cassava	0.1451	498	0	12	72.3	0.0	1.8	74.1
Oilseed cakes, other	0.0275	2158	37	50	59.4	1.0	1.4	61.7
Rape and mustard cake	0.0479	977	132	151	46.8	6.3	7.2	60.4
Rye	0.0233	1573	38	109	36.7	0.9	2.5	40.1
Millet	0.0107	2718	130	172	29.0	1.4	1.8	32.2
Cereals, not specified	0.0308	874	66	41	26.9	2.0	1.3	30.2
Sunflower seed cake	0.0249	968	63	98	24.1	1.6	2.4	28.1
Pulses, not specified	0.0132	1133	307	618	15.0	4.1	8.2	27.2
Molasses	0.0597	311	110	29	18.6	6.6	1.7	26.9
Groundnut cake	0.0171	1265	121	106	21.7	2.1	1.8	25.6
Soybeans	0.0140	1744	41	24	24.5	0.6	0.3	25.4
Potatoes	0.0796	254	10	48	20.2	0.8	3.8	24.9
Cottonseed cake	0.0280	481	259	86	13.5	7.3	2.4	23.1
Cottonseed	0.0181	618	353	124	11.2	6.4	2.2	19.8
Peas, dry	0.0126	1149	21	336	14.4	0.3	4.2	18.9
Sunflower seed	0.0054	2744	144	234	14.8	0.8	1.3	16.9
Sugar cane	0.0698	171	35	16	11.9	2.5	1.1	15.5
Plantains	0.0091	1392	27	3	12.7	0.2	0.0	13.0
Beans, dry	0.0029	3270	48	575	9.4	0.1	1.6	11.1
Rapeseed	0.0049	1877	3	305	9.3	0.0	1.5	10.8
Vegetables fresh not specified	0.0369	152	49	69	5.6	1.8	2.5	10.0
Copra cake	0.0046	1567	2	10	7.2	0.0	0.0	7.2
Sweet potatoes	0.0170	285	7	57	4.8	0.1	1.0	5.9
Yams	0.0166	326	0	1	5.4	0.0	0.0	5.5
Palm kernel cake	0.0075	659	0	27	4.9	0.0	0.2	5.2
Dates	0.0009	2397	2074	97	2.1	1.8	0.1	4.0
Sesame seed cake	0.0015	2111	53	53	3.1	0.1	0.1	3.3
Sugar beet	0.0165	154	16	30	2.5	0.3	0.5	3.3
Oilseeds, not specified	0.0024	802	94	35	2.0	0.2	0.1	2.3
Other minor feed crops	0.0122	325	66	40	3.9	0.8	0.5	5.2

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Feed crop*	Feed amount (kg/kg carcass)	Weighted average water footprint of feed (litre/kg)			Water footprint (litre/kg carcass)			
		Green	Blue	Grey	Green	Blue	Grey	Total
Crop residues	21.943	0	0	0	0.0	0.0	0.0	0.0
Fodder crops	2.4632	168	29	21	415	71.8	50.7	537
Pasture (grass)	31.525	303	0	0	9556	0.0	0.0	9556
Water for feed mixing						1.5		1.5
Water footprint related to feed					12391	314	388	13107
Drinking water						110		110
Service water						29		29
Total water footprint of beef cattle (litre/kg carcass)					12391	453	388	13246
Total water footprint of a 253 kg beef cow (in litre) (assuming a total carcass weight of 143 kg)					1769000	64600	55300	1889000
… of which 83% is attributed to the 101 kg of resultant beef, so that the **water footprint of beef**** (litre/kg beef) amounts to:					14400	550	450	15400
… of which 10% is attributed to the 18 kg of resultant offal, so that the **water footprint of offal**** (litre/kg offal) amounts to:					10400	400	330	11200
… of which 5% is attributed to the 6.1 kg of resultant leather, so that the **water footprint of leather**** (litre/kg leather) amounts to:					15900	680	500	17100
… of which 2% is attributed to the 0.03 kg of resultant semen, so that the **water footprint of semen**** (litre/kg semen) amounts to:					1069000	40600	33400	1143000

* The feed amounts included here represent the global average feed intake of beef cattle. Obviously, the feed composition of individual cows will deviate based on the production system and composition of the concentrate feed applied.

** The percentage of the total water footprint of a beef cow attributed to each product refers to the 'value fraction' for that product (Appendix V). The amount of a certain product (in kg) coming from the total animal is based on the 'product fraction' for that product (Appendix V). In the blue water footprint, we added the water footprint of processing the slaughtered cow into the derived products.

3.4 Water footprint of animal versus crop products per unit of nutritional value

As a general picture we find that animal products have a larger water footprint per ton of product than crop products. As we see from Table 6, the global average water footprint per ton of crop increases from sugar crops (roughly 200 m^3/ton) and vegetables (~300 m^3/ton) to pulses (~4000 m^3/ton) and nuts (~9000 m^3/ton). For animal products, the water footprint increases from milk (~1000 m^3/ton) and egg (~3300 m^3/ton) to beef (~15400 m^3/ton). Also when viewed from a caloric standpoint, the water footprint of animal products is larger than for crop products. The average water footprint per calorie for beef is twenty times larger than for cereals and starchy roots. When we look at the water requirements for protein, we find that the water footprint per gram of protein for milk, eggs and chicken meat is about 1.5 times larger than for pulses. For beef, the water footprint per gram of protein is 6 times larger than for pulses. In the case of fat, we find that butter has a relatively small water footprint per gram of fat, even lower than for oil crops. All other animal products, however, have larger water footprints per gram of fat when compared to oil crops. The general conclusion is that from a freshwater resource perspective, it is more efficient to obtain calories, protein and fat through crop products than animal products. A note should be made here, however, that types of proteins and fats differ across the different products.

Table 6. The water footprint of some selected food products from vegetable and animal origin.

Food item	Water footprint per ton (m^3/ton)				Nutritional content			Water footprint per unit of nutritional value		
	Green	Blue	Grey	Total	Calorie (kcal/kg)	Protein (g/kg)	Fat (g/kg)	Calorie (litre/kcal)	Protein (litre/g protein)	Fat (litre/g fat)
Sugar crops	130	52	15	197	285	0.0	0.0	0.69	0.0	0.0
Vegetables	194	43	85	322	240	12	2.1	1.34	26	154
Starchy roots	327	16	43	387	827	13	1.7	0.47	31	226
Fruits	726	147	89	962	460	5.3	2.8	2.09	180	348
Cereals	1232	228	184	1644	3208	80	15	0.51	21	112
Oil crops	2023	220	121	2364	2908	146	209	0.81	16	11
Pulses	3180	141	734	4055	3412	215	23	1.19	19	180
Nuts	7016	1367	680	9063	2500	65	193	3.63	139	47
Milk	863	86	72	1020	560	33	31	1.82	31	33
Eggs	2592	244	429	3265	1425	111	100	2.29	29	33
Chicken meat	3545	313	467	4325	1440	127	100	3.00	34	43
Butter	4695	465	393	5553	7692	0.0	872	0.72	0.0	6.4
Pig meat	4907	459	622	5988	2786	105	259	2.15	57	23
Sheep/goat meat	8253	457	53	8763	2059	139	163	4.25	63	54
Bovine meat	14414	550	451	15415	1513	138	101	10.19	112	153

In order to reduce the pressure on the world's water resource associated with their consumption pattern, individuals have the option of shifting from a meat-rich to a vegetarian diet. The water footprint of an individual consumer depends to a large extent on the type of diet of the individual. Meat-based diets have a larger water footprint compared to a vegetarian diet. The average USA citizen consumes almost four times the amount of protein compared to the global average (FAO, 2009). About 63% of the daily protein intake comes from animal based products. This high level of consumption of animal-based products is directly reflected in the relative large water footprint of the average American citizen (Hoekstra and Chapagain, 2007). Replacing 50% of all animal products by an equivalent amount of high nutritious crop products such as pulses, groundnuts and potatoes will result a 30% reduction of the food-related water footprint. A vegetarian diet compared with the average current per capita food intake in the USA can reduce the water footprint of an individual by as much as 58%.

3.5 The total water footprint of animal production

During the period 1996-2005, the total water footprint for global animal production was 2422 Gm^3/yr (87.2% green, 6.2% blue and 6.6% grey water). The different components of the global water footprint of animal production are shown in Table 7. The largest water footprint for the animal production comes from the feed they consume, which accounts for 98% of the total water footprint. Drinking water, service water and feed mixing water further account only for 1.1%, 0.8% and 0.03% of the total water footprint, respectively. The estimate of drinking and service water is in line with Peden et al. (2007). Grazing accounts for the largest share (38%), followed by maize (17%) and fodder crops (8%).

The global water footprint of feed production is 2376 Gm^3/yr, of which 1463 Gm^3/yr refers to crops and the remainder to grazing (Table 8). The total water footprint of feed crops amounts to 20% of the water footprint of total crop production in the world, which is 7404 Gm^3/yr (Mekonnen and Hoekstra, 2010b). The globally aggregated *blue* water footprint of feed crop production is 105 Gm^3/yr, which is 12% of the blue water footprint of total crop production in the world (Mekonnen and Hoekstra, 2010b). This means that an estimated 12% of the global consumption of groundwater and surface water for irrigation is for feed, not for food, fibres or other crop products. Globally, the total water footprint of animal production (2422 Gm^3/yr) constitutes 29% of the water footprint of total agricultural production.

When we consider the total water footprint per animal category (Table 9), we find that beef cattle have the largest contribution (33%) to the global water footprint of farm animal production, followed by dairy cattle (19%), pig (19%) and broiler chicken (11%). The green, blue and grey water footprints per animal category and production system are shown in Table 10. Altogether, mixed production systems account for the largest share (57.4%) in the total water footprint of animal production. Grazing and industrial production systems account for 20.3% and 22.3%, respectively. In the grazing system, over 97% of the water footprint related to feed comes from grazing and fodder crops and the water footprint is dominantly (94%) green. In the mixed and industrial production systems, the green water footprint forms 87% and 82% of the total footprint, respectively. The blue water footprint in the grazing system accounts for 3.6% of the total water footprint and about 33% of this comes from the drinking and service water use. In the industrial system, the blue water footprint accounts for 8% of the total water footprint.

Table 7. Global water footprint of animal production by component.

Feed crop	Total water footprint (Mm^3/yr)				
	Green	Blue	Grey	Total	Share (%)
Grazing	912816	0.0	0.0	912816	37.7
Maize	302595	33581	74960	411136	17.0
Fodder crops	167896	9900	10903	188699	7.79
Soybean cake	168221	6559	3178	177958	7.35
Wheat	122934	8345	16214	147493	6.09
Barley	116844	6778	14410	138031	5.70
Oats	48508	10370	4753	63631	2.63
Sorghum	40781	3376	2798	46954	1.94
Rice, paddy	24699	7497	4863	37059	1.53
Oilseed cakes, other	22159	409	525	23093	0.95
Rape and mustard cake	16841	2457	3134	22432	0.93
Cassava	17630	8.6	849	18488	0.76
Cereals, not else specified	15683	881	979	17543	0.72
Sweet potatoes	12927	210	2781	15918	0.66
Rye	13628	249	1057	14934	0.62
Pulses, not else specified	7829	1242	4300	13371	0.55

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Feed crop	Total water footprint (Mm^3/yr)				
	Green	Blue	Grey	Total	Share (%)
Sunflower seed cake	11279	626	905	12809	0.53
Potatoes	9602	369	2500	12471	0.51
Millet	9617	607	458	10682	0.44
Soybeans	9786	374	212	10372	0.43
Groundnut cake	8874	658	575	10107	0.42
Peas, dry	6666	144	1736	8546	0.35
Cottonseed cake	4851	2889	775	8514	0.35
Molasses	4214	1808	410	6432	0.27
Cottonseed	3252	2480	618	6350	0.26
Vegetables fresh not else specified	3665	703	1977	6345	0.26
Beans, dry	4003	54	922	4979	0.21
Sunflower seed	4045	200	314	4560	0.19
Rapeseed	3338	11	763	4111	0.17
Copra cake	3581	3.5	23	3608	0.15
Sugar cane	2148	590	217	2955	0.12
Palm kernel Cake	2519	0.7	93	2612	0.11
Sesame seed cake	2111	53	46	2210	0.09
Plantains	2078	52	4	2134	0.09
Sugar beet	1070	70	285	1425	0.06
Oilseeds, not else specified	990	150	50	1191	0.05
Bananas	761	53	41	855	0.04
Yams	767	0.5	3.3	771	0.03
Dates	244	279	15	538	0.02
Apples	326	118	38	483	0.02
Tomatoes	102	93	39	234	0.01
Roots and tubers, not else specified	177	4.1	27	208	0.01
Fruits, other	116	25	9	150	0.01
Groundnuts	70	8	5	83	0.00
Coconuts	38	0.0	0.1	38	0.00
Cocoa beans	16	0.0	0.2	16	0.00
Onions	0.7	1.6	0.2	2.5	0.00
Sesame seed	1.8	0.3	0.2	2.2	0.00
Palm-kernels	0.8	0.0	0.0	0.8	0.00
Mixing water for feed preparation	0.0	610	0.0	610	0.03
Drinking water		27099		27099	1.12
Service water		18213		18213	0.75
Total water footprint	2112301	150660	158762	2421722	100.00

Table 8. The global water footprint of animal production compared to the global water footprint of total agricultural production for the period 1996-2005 (Gm³/yr).

	Green	Blue	Grey	Total
Water footprint of total agricultural production				
Water footprint of crop production*	5771	899	733	7404
Water footprint of grazing	913	-	-	913
Direct water footprint of livestock**	-	46	-	46
Total	6684	899	733	8317
Water footprint of animal production				
Water footprint of feed crop production	1199	105	159	1463
Water footprint of grazing	913	-	-	913
Direct water footprint of livestock**	-	46	-	46
Total	2112	151	159	2422
Water footprint of animal production as a percentage of the total water footprint in agricultural production	32%	17%	22%	29%

* Source: Mekonnen and Hoekstra (2010b).
** Water footprint of drinking, servicing and feed mixing.

A substantial part of the water footprint of an animal product produced in one country often resides outside that country. This is most in particular the case for products originating from industrial production systems, because those systems use the largest fraction of concentrate feed. Feed crops are often imported rather than produced domestically. Soybean cake, for example, which is an important feed ingredient in industrial livestock raising, is often imported. In the period 1996-2005, 49% of global soybean production was exported, either in the form of soybean or in the form of soybean cake (FAO, 2009).

Table 9. The total water footprint per animal category (1996-2005).

Animal category	Global total number of animals* (millions)	Average annual water footprint per animal** (m³/yr per animal)	Annual water footprint of animal category (Gm³/yr)	%
Beef cattle	1267	630	798	33
Dairy cattle	228	2056	469	19
Pig	880	520	458	19
Broiler chicken	9923	26	255	11
Horse	112	1599	180	7
Layer Chicken	5046	33	167	7
Sheep	1052	68	71	3
Goat	750	32	24	1
Total	19258		2422	100

* Source: FAO (2009).

** See Table 3.

Table 10. The green, blue and grey water footprints per animal category and production system (Gm^3/yr) for the period 1996-2005.

Animal category	Grazing production system			Mixed production system			Industrial production system			World total		
	Green	Blue	Grey	Green	Blue	Grey	Green	Blue	Grey	Green	Blue	Grey
Beef cattle	185	4.5	2.1	443	20	12	112	10	9.0	740	35	23
Dairy cattle	83	3.6	3.7	269	27	26	48	4.1	3.8	400	35	34
Pig	27	1.5	2.2	237	19	27	111	14	19	376	34	48
Broiler chicken	37	3.4	3.3	100	8.3	14	73	6.3	10	210	18	28
Horse	82	3.0	1.4	69	7.1	2.4	13	0.8	0.6	164	11	4
Layer chicken	4.5	0.3	0.3	52	5.4	9.4	77	6.5	12	133	12	22
Sheep	34	1.2	0.0	28	2.0	0.2	5.0	1.0	0.2	66.5	4.3	0.5
Goat	8.2	0.3	0.0	13	0.9	0.0	2.0	0.4	0.0	22.7	1.5	0.0
Total	461	17.8	13.2	1210	90	90	442	43	55	2112	151	159

4. Discussion

The result of the current study can be compared with results from earlier studies. However, only a few other studies on the water footprint per unit of animal product and the total water footprint of animal production are available. We will first compare our estimates of the water footprints per ton of animal product with two earlier studies and subsequently we will compare the total water footprint related to animal feed production with five earlier studies.

The rough estimates made by Pimentel et al. (2004) for the water footprints of beef and meat from sheep, pig and chicken are partly very close to our global estimates but partly also quite different. They report a water footprint of chicken meat of 3500 m^3/ton, which is only a bit lower than our global average estimate of 4300 m^3/ton, and even closer if we subtract the grey water footprint component from our estimate (which is not included in Pimentel's studies). They report a water footprint of pig meat of 6000 m^3/ton, which happens to coincide with our global average estimate (but our estimate includes the grey water footprint component). For sheep meat, they report a water footprint of 51000 m^3/ton and for beef 43000 m^3/ton, values that are very high when compared to our estimates (10,400 m^3/ton for sheep meat and 15400 m^3/ton for beef). We consider the values reported by Pimentel as crude first estimates, for which the underlying assumptions have not been spelled out, so that it is difficult to explain differences with our estimates.

The study of Chapagain and Hoekstra (2004) is the only publication with global estimates of the water footprint of animal products with specifications by country. At a global level, the estimated water footprints per ton of animal and animal product compare very well with the estimates from Chapagain and Hoekstra (2004), with an r^2 of 0.88 (Figure 10a). The good agreement at the global level between the two studies is probably that the global average water footprints for various feed ingredients are very close in the two studies. The trend line in Figure 10a is slightly above 1, which is caused by our higher estimates for the water footprints of sheep and goat meat. For most other animal products, the current study gives a bit lower estimates than the earlier study.

When we compare our estimates with Chapagain and Hoekstra (2004) at a country level, more differences are found (Figure 10b-f). The two studies show a relatively good agreement for pig meat, chicken meat and egg – although for egg the earlier study systematically gives higher numbers – but little agreement for beef and dairy products. In general we find that Chapagain and Hoekstra (2004) underestimated the water footprints for African countries and overestimated the water footprints for OECD countries. As already pointed out in the introductory chapter, there are three main reasons why the estimates from the current study can differ from the 2004-study and are considered more accurate. First, the current study is based on better data for the estimation of the quantity and composition of animal feed. Second, the current study reckons with the relative presence of the three production systems per country and accounts for the differences between those systems. Third, we have estimated the water footprints of the various feed ingredients more accurately by using a high-resolution grid-based crop water use model, including the effect of water deficits where they occur, making explicit distinction between the green and blue water footprint components and including the grey water footprint component.

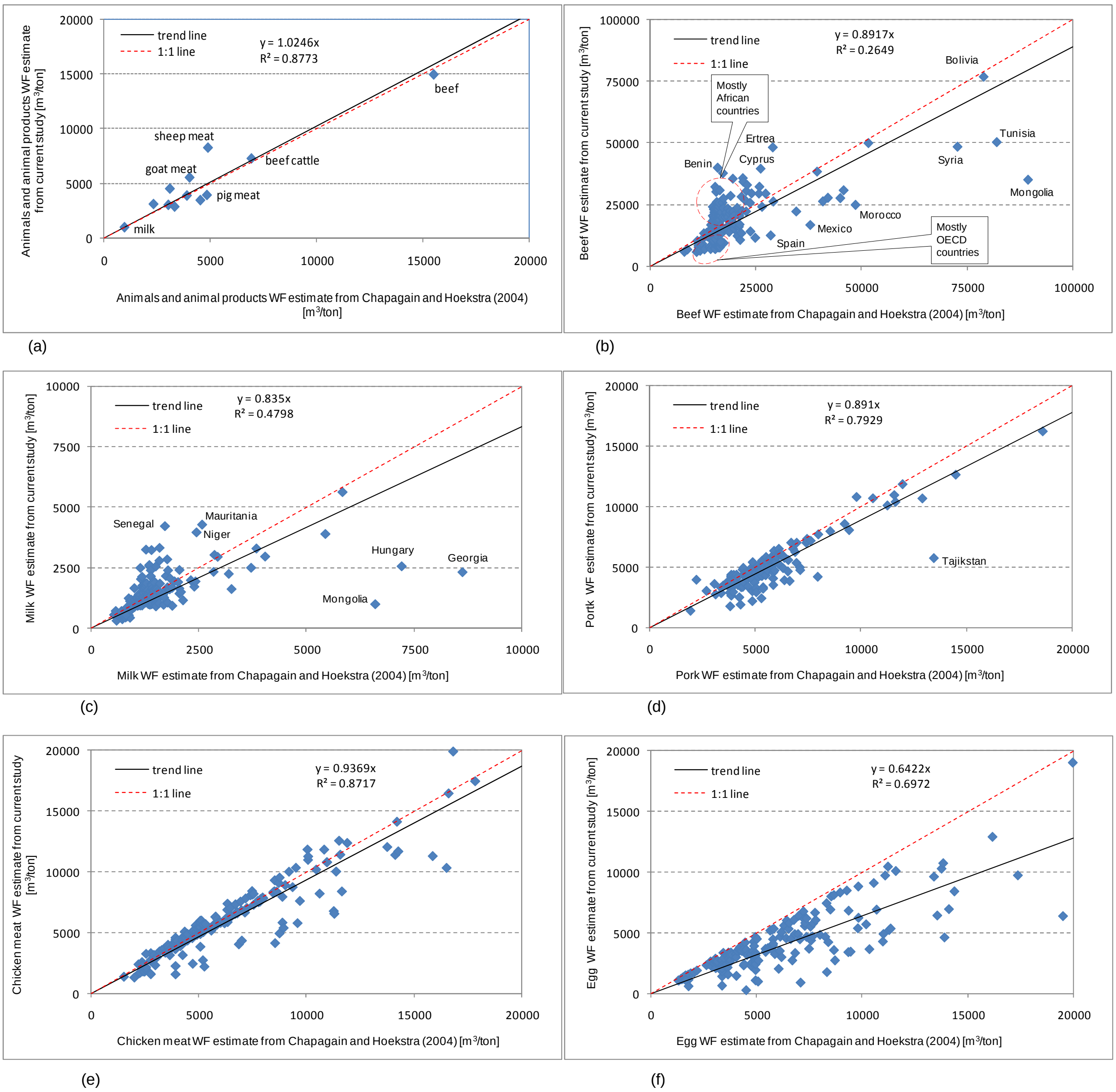

Figure 10. Comparison of average water footprint of (a) animals and animal products at global level, and (b) beef (c) milk, (d) pig meat, (e) chicken meat and (f) egg at the country level as estimated in the current study and Chapagain and Hoekstra (2004). From the current study we show here the sum of green and blue water footprints, excluding the grey water footprint, because that component was excluded in the 2004-study.

As one can see in the overview presented in Table 11, our estimate of the total evaporative water use (green plus blue water footprint) for producing animal feed (2217 Gm^3/yr) is 3% larger than the estimate by De Fraiture et al. (2007) and 5% smaller than the estimate by Zimmer and Renault (2003). Our estimate of the global consumptive water use for producing feed crops (1312 Gm^3/yr) does not significantly differ from the estimate by De Fraiture et al. (2007). Our estimate of global consumptive water use for grazing (913 Gm^3/yr) is 9% larger than the estimate by De Fraiture et al. (2007). The differences with three other studies that reported on the consumptive water use related to grazing are much larger, which is cause by another definition applied. Postel et al. (1996) estimated the water evaporated from grazing land to be 5800 Gm^3/yr. In more recent studies, Rost et al. (2008) and Hanasaki et al. (2010) estimate the total evapotranspiration from grazing land to be 8258 Gm^3/yr and 12960 Gm^3/yr, respectively. However, unlike the current study, the estimates in these three studies refer to the total evapotranspiration from grazing lands rather than to the evaporation related to the grass actually consumed.

According to De Fraiture et al. (2007), reported ‘grazing lands’ are only partly actually grazed. Besides, the harvest efficiency – the fraction of grass actually consumed by the animal compared to the standing biomass – is quite small. In a recent study in the USA, Smart et al. (2010) showed that, depending on the animal stocking density, harvest efficiencies reach between 14-38%.

Table 11. Comparison of the results of the current study with the results from previous studies.

Study	Period	Global water footprint* related to animal feed production (Gm^3/yr)		
		Grazing	Crops	Total
Postel et al. (1996)	1995	5800	-	-
Zimmer and Renault (2003)	2000	-	-	2340
De Fraiture et al. (2007)	2000	840	1312	2152
Rost et al. (2008)	1971-2002	8258	-	-
Hanasaki et al. (2010)	1985-1999	12960	-	-
Current study*	1996-2005	913	1304	2217

* The numbers in the table, also the ones from the current study, refer to the green plus blue water footprint. None of the previous studies included the grey water footprint component.

There are several uncertainties in this study in the quantification of the water footprint of animals and animal products. Due to a lack of data, many assumptions have to be made. There are a number of uncertainties in the study, but particularly two types of uncertainty may have a major effect on the final output of the study. First, data on animal distribution per production system per country for OECD countries is not available. Wint and Robinson (2007) provide livestock distributions per production system per country for developing countries but not for OECD countries. For these countries we are forced to use the data from Seré and Steinfeld (1996), who provide livestock distribution per economic region. These data have the limitation that they are not country-specific and may lead to wrong distribution of animals into the different production system for some countries. The second major uncertainty is related to the precise composition of feed per animal category per country. Such data are not directly available so that we had to infer these data by combining different data sources and a number of assumptions.

Although the scope of this study is very comprehensive, there are many issues that have been left out. One issue is that we neglected the indirect water footprints of materials used in feed production and animal raising. We expect that this may add at most a few per cents to the water footprint estimates found in this study (based on Hoekstra et al., 2009). In the grey water footprint estimations we have looked at the water pollution by nitrogen-fertilisers only, excluding the potential pollution by other fertiliser components or by pesticides or other agro-chemicals. Besides, we have not quantified the grey water footprint coming from animal wastes, which is particularly relevant for industrial production systems. Intensive animal production often generates an amount of waste that cannot be fully recycled on the nearby land. The large amount of waste generated in a concentrated place can seriously affect freshwater systems (FAO, 2005; Steinfeld et al., 2006; Galloway et al., 2007). Finally, by focusing on freshwater appropriation, the study obviously excludes many other relevant issues in farm animal production, such as micro- and macro-cost of production, livelihood of smallholder farmers, animal welfare, public health and environmental issues other than freshwater.

5. Conclusion

The present study estimates the water footprint of farm animals and animal products per production system and per country. The results show that:

- Although beef cattle, sheep and goat require much more feed per unit of meat produced than pig and broiler chicken, the fraction of concentrate feed in the total feed is much larger for the latter (Section 3.1). Since concentrate feed has a larger water footprint per unit of weight than roughages (Section 3.2), the water footprints of the different sorts of meat are closer than one would expect on the basis of feed conversion efficiencies alone (Section 3.3).
- The total water footprint of an animal product is generally larger when obtained from a grazing system than when produced from an industrial system, because of a larger *green* water footprint component. The *blue* and *grey* water footprints of animal products are largest for industrial systems (with an exception for chicken products). From a freshwater perspective, animal products from grazing systems are therefore to be preferred above products from industrial systems (Section 3.3).
- The water footprint of any animal product is larger than the water footprint of a wisely chosen crop product with equivalent nutritional value (Section 3.4).
- 29% of the total water footprint of the agricultural sector in the world is related to the production of animal products. One third of the global water footprint of animal production is related to beef cattle (Section 3.5).

The global meat production has almost doubled in the period 1980-2004 (FAO, 2005) and this trend is likely to continue given the projected doubling of meat production in the period 2000-2050 (Steinfeld et al., 2006). To meet this rising demand for animal products, the on-going shift from traditional extensive and mixed farming to industrial farming systems is likely to continue. Because of the larger dependence on concentrate feed in industrial systems, this intensification of animal production systems will result in increasing blue and grey water footprints per unit of animal product. The pressure on the global freshwater resources will thus increase both because of the increasing meat consumption and the increasing blue and grey water footprint per unit of meat consumed.

Managing the demand for animal products by promoting a dietary shift away from a meat-rich diet will be an inevitable component in the environmental policy of governments. In countries where the consumption of animal products is still quickly rising, one should critically look how this growing demand can be moderated. On the production side, it would be wise to include freshwater implications in the development of animal farming policies, which means that particularly feed composition, feed water requirements and feed origin need to receive attention. Animal farming puts the lowest pressure on freshwater systems when dominantly based on crop residues, waste and roughages. Policies aimed to influence either the consumption or production side of farm animal products will generally entail various sorts of socio-economic and environmental trade-offs (Herrero et al., 2009; Pelletier and Tyedmers, 2010). Therefore, policies aimed at reducing the negative impacts of animal production and consumption should be able to address these potential tradeoffs. Policies should not affect the required increase in food security in less developed countries neither the livelihood of the rural poor should be put in danger through intensification of animal farming.

This study provides a rich data source for further studies on the factors that determine how animal products put pressure on the global water resources. The reported incidents of groundwater depletion, rivers running dry and increasing levels of pollution form an indication of the growing water scarcity (UNESCO, 2009; Postel, 2000; Gleick, 1993). Since animal production and consumption play an important role in depleting and polluting the world's scarce freshwater resources, information on the water footprint of animal products will help us understand how we can sustain the scarce freshwater resources.

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