Annex 3

Methodology of quantification and analysis

Annex 3
Methodology of quantification and analysis

3.1 Trends in land use for livestock

Methodology developed to assess arable land use for livestock

Derived from *nations' water footprints*, by Chapagain and Hoekstra, 2004.

Categories of arable crops included in the analysis are:

- cereals, e.g. wheat, maize, barley, buckwheat, sorghum, rye, millet, oats, mixed grains, rice paddy;
- oilseeds and fruits for oil, e.g. soybeans, sunflower, safflower, rapeseed, linseed, groundnuts, cottonseed, mustard seed, hempseed, coconut, oil palm fruit, olives, kapok fruit;
- roots and vegetables, e.g. cassava, yams, potatoes, sweet potatoes, cabbages, pumpkins, sugarcane, lupins, vetches, carobs, plantains;
- pulses, e.g. peas, beans, lentils ; and
- fruits, e.g. watermelons, apples, bananas, dates, citrus fruit.

The calculation differentiates crops fed directly (in their primary form) to livestock from those that are first processed, and for which by-products only are fed to livestock. Crop residues were not included because of data unavailability.

a) Direct feed products include primary crops obtained directly from the land and which do not undergo any real processing. Arable land area is obtained as the ratio of the feed element to the sum of the total supply utilization elements times the total area harvested .
b) By-products/derived feed products include:
   - cake from processing of oilseeds and fruit for oil;
   - bran, flour (maize and wheat), gluten (maize and wheat) and germ (maize and wheat) from processing of cereals;
   - citrus pulp; and
   - molasses from the processing of sugarcane and sugar beet

The quantity of harvested crop that is processed is first obtained from statistical databases. The arable land related to the amount of processed harvest is then calculated using the same technique as described above for direct feed.

As a next step we need to find out what fraction of this land can be ascribed to the production of by-products for feed. To obtain this we further multiply the arable land area related to processed product by the value fraction of the by-product with comparison to all product(s) from processing. The result is the amount of land attributed to the by-product.

The following data sources were used:

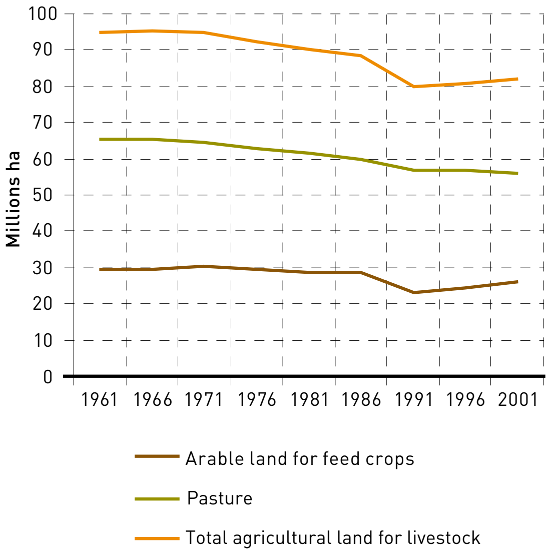
- FAO Supply utilization accounts (SUAs) the accounts give a detailed breakdown of the amount of crop supplied and how much is utilized in the different uses such as food, feed, waste, processing, seed and other, in a given period. The accounts also specify the area harvested, yield, production and area sown (FAO, 2006b). International commodity prices for primary products and derived products: (Chapagain and Hoekstra, 2004 and FAO international commodity prices)
- Commodity/product trees: These give the extraction rates/product fractions i.e. the

amount (in percentage terms) of the processed product concerned obtained from the processing of the parent product (FAO commodity Trees and Chapagain and Hoekstra, 2004).

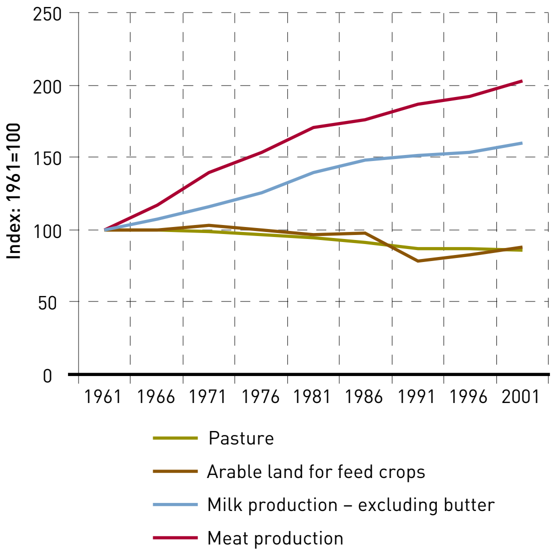
Selected results

EU –15

EU–15: trends in land-use area for livestock production

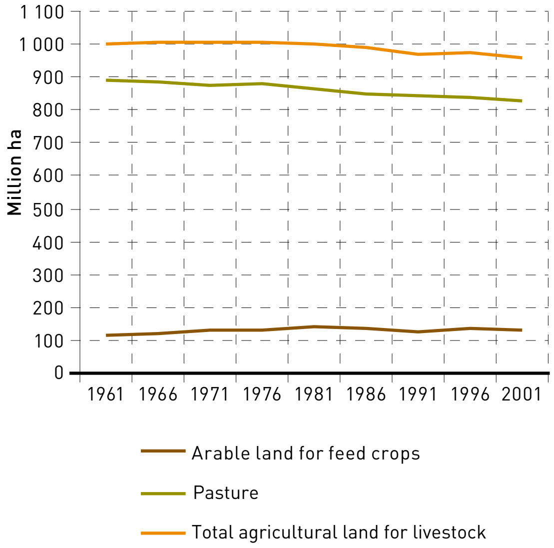


Trends in land-use area for livestock production and production of meat and milk

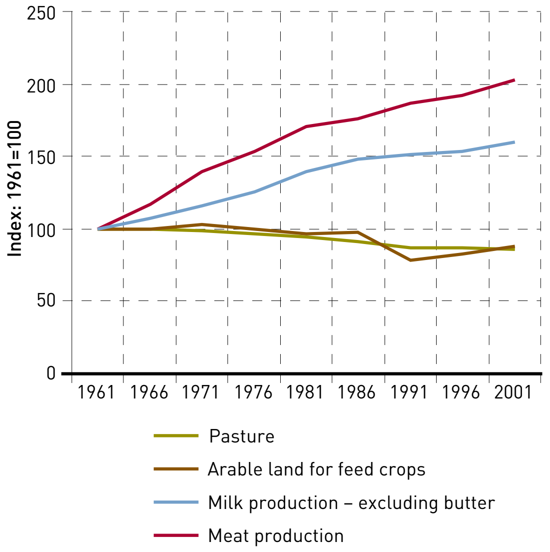


OECD

OECD: trends in land-use area for livestock production

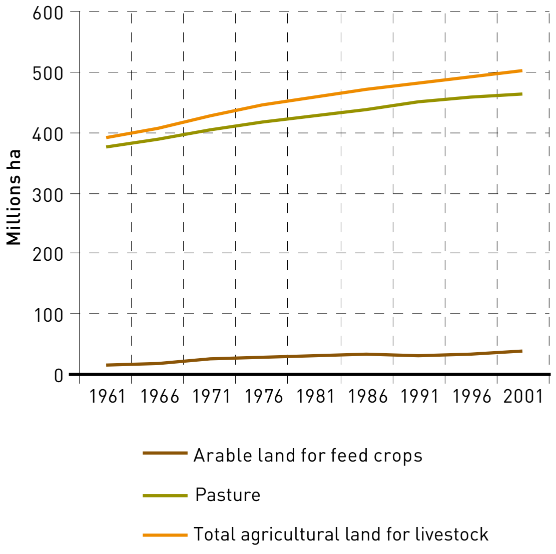


Trends in land-use area for livestock production and production of meat and milk

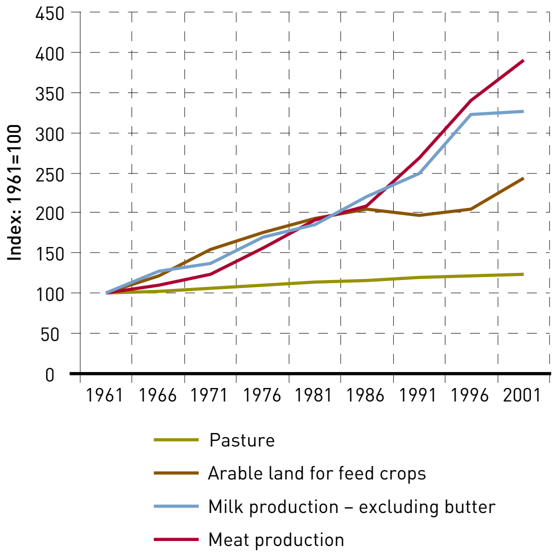


SOUTH AMERICA

South America: trends in land-use area for livestock production

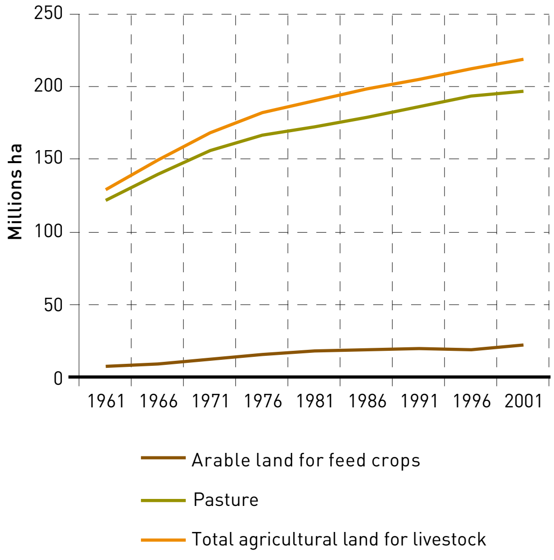


Trends in land-use area for livestock production and production of meat and milk

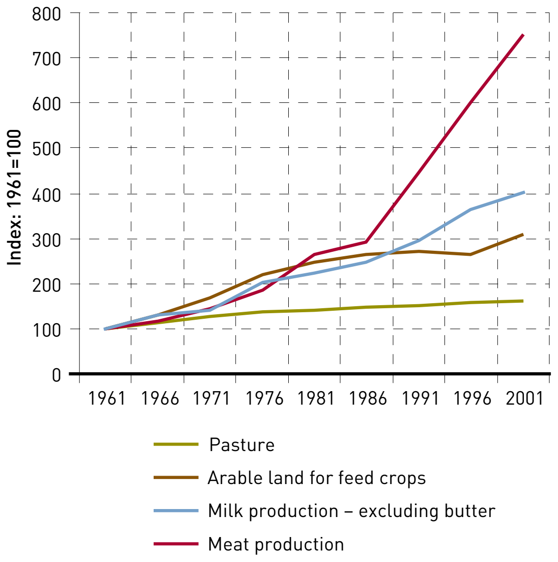


BRAZIL

Brazil: trends in land-use area for livestock production

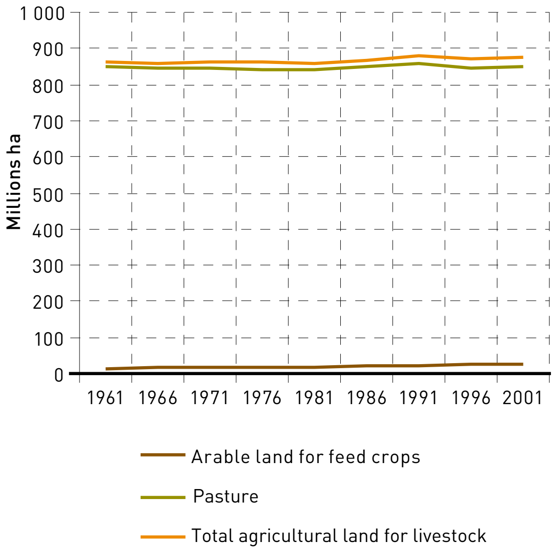


Trends in land-use area for livestock production and production of meat and milk

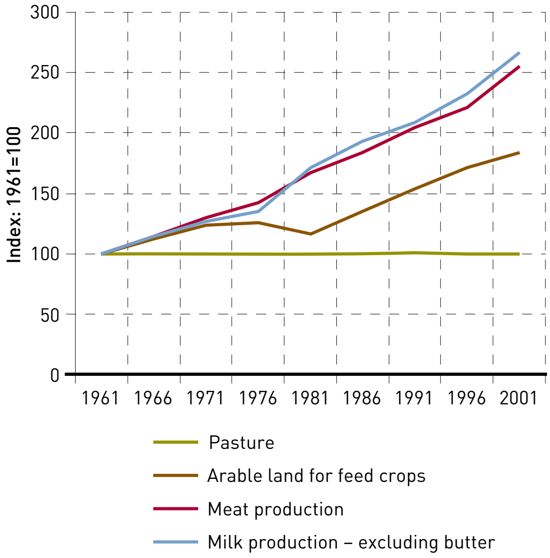


SUB-SAHARAN AFRICA

Sub-Saharan Africa: trends in land-use area for livestock production

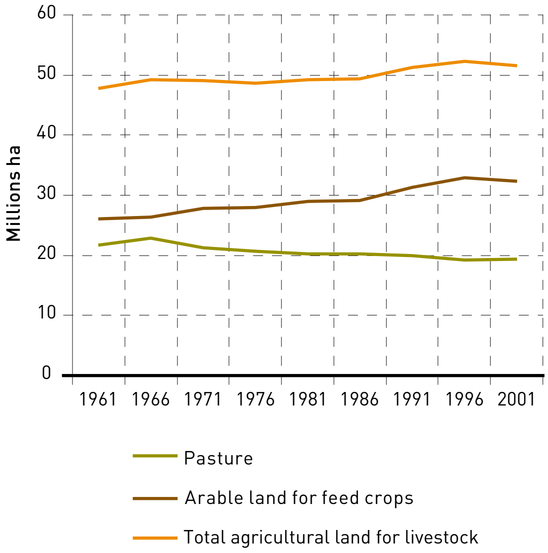


Trends in land-use area for livestock production and production of meat and milk

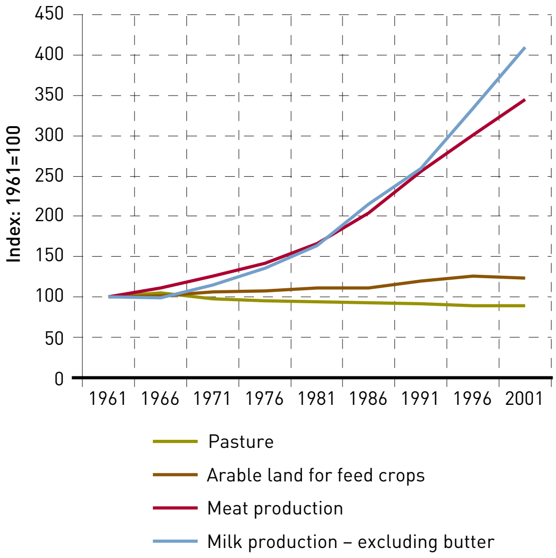


SOUTH ASIA

South Asia: trends in land-use area for livestock production

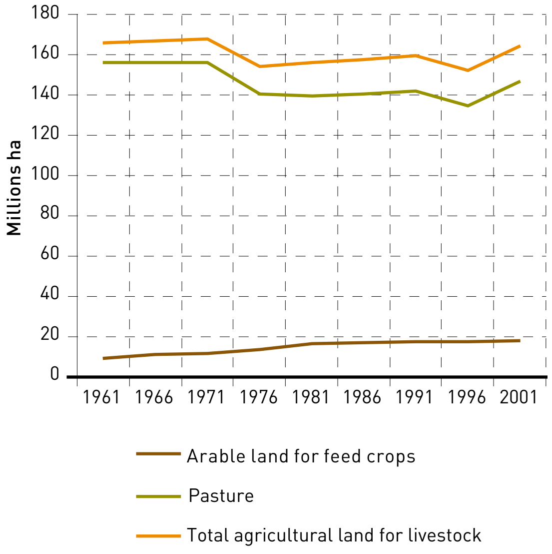


Trends in land-use area for livestock production and production of meat and milk

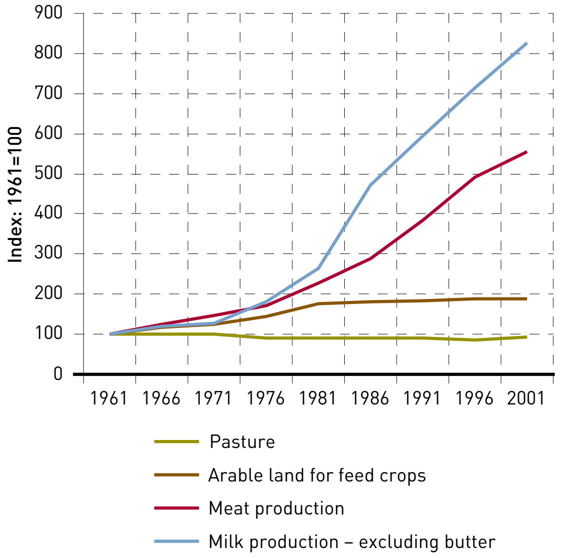


EAST AND SOUTHEAST ASIA

East and Southeast Asia: trends in land-use area for livestock production

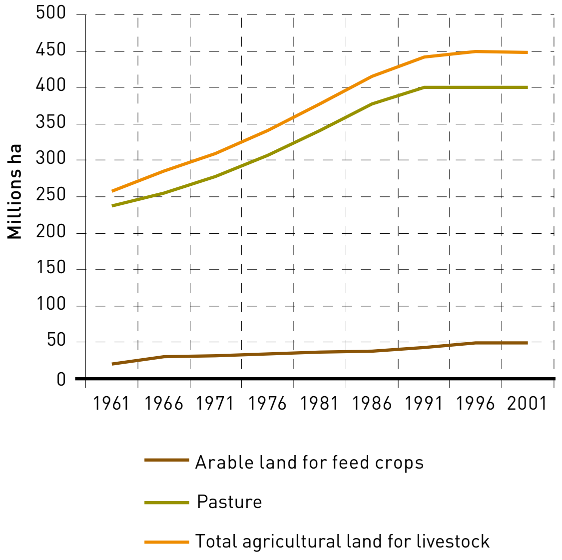


Trends in land-use area for livestock production and production of meat and milk

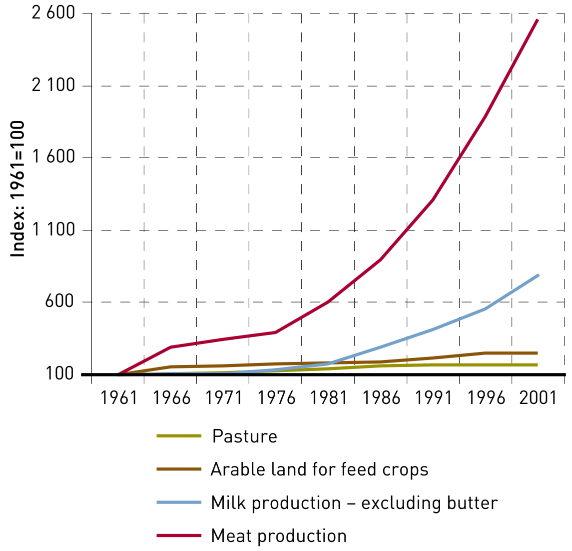


CHINA

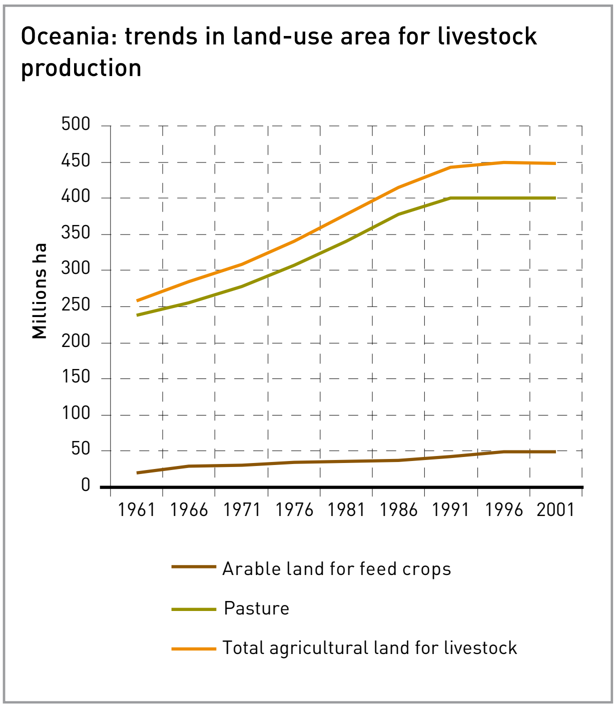
China: trends in land-use area for livestock production

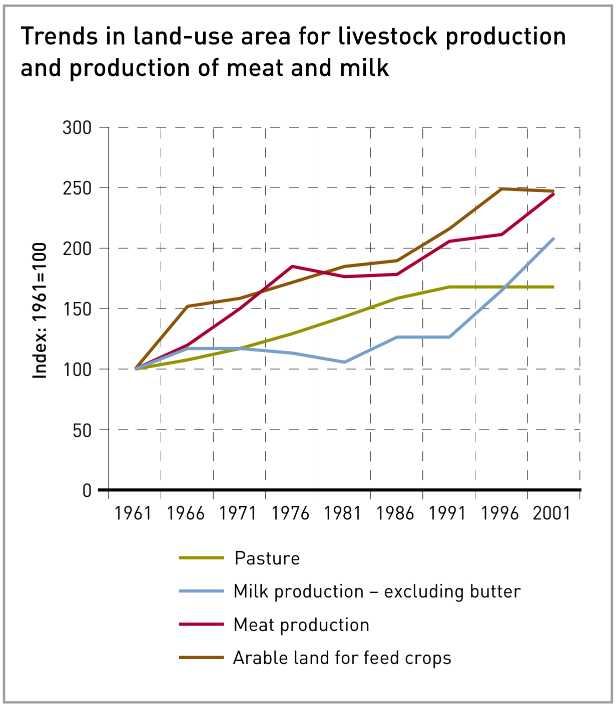


Trends in land-use area for livestock production and production of meat and milk



OCEANIA





3.2 Current enteric fermentation methane emissions per production system, species and region

Much of the information used by the IPCC to establish region-specific default emission factors for methane was published twenty years ago. As described in Chapter 2, livestock production characteristics in many regions have evolved considerably since then. An assessment was made for this report to evaluate the resulting discrepancy. The IPCC Tier 2 methodology was used to derive enteric fermentation emission factors for the most important animal categories dairy and other cattle (Houghton *et al.*, 1997). The following data were required to derive the average daily energy intake of the animal, which is then combined with a methane conversion factor for specific feed types:

- live weight;
- average daily weight gain (not relevant for dairy cattle);
- feeding situation (confined, grazing good pasture, extensive grazing);
- milk production per day;
- work performed per day (draft animals not relevant for dairy cattle);
- proportion of cows that give birth per year; and
- feed digestibility.

For each region and production system, average milk yield per dairy cow and mean livestock weight for other cattle were taken from the FAO database. Other data required were derived from the IPCC Guidelines Reference Manual (Houghton *et al.*, 1997), Table A3.1, appropriate to each world region. Feed digestibility and methane conversion rates were derived both from Houghton *et al.* (1997) and the EPA Livestock Analysis Model.

For all other livestock types, the Tier 1 approach was used as more detailed activity data were not available and the sources are relatively minor compared with cattle.

Therefore, for buffaloes, sheep, goats and pigs, default emission factors as given in Table 4-3 of the IPCC manual were used, with that for 'Developed countries' being used for 'Industrial

TABLE A3.1

Enteric fermentation emission factors (EF) for cattle (kilogram CH_4 per head per year) by production system and world region. Tier 2 based estimates compared to tier 1 emission factors

Region	Dairy cattle				Other cattle				
	Grazing	Mixed	Weighted EF	Tier 1 EF	Grazing	Mixed	Industrial	Weighted EF	Tier 1 EF
Sub–Saharan Africa	79	39	60	36	44	27	-	36	32
Asia excluding China and India	79	53	54	56	66	38	-	38	44
India	70	45	45	46	41	17	-	18	25
China	102	63	84	56	85	38	-	49	44
Central and South America	93	62	78	57	58	33	23	47	49
West Asia and North Africa	91	60	61	36	49	31	-	32	32
North America	115	100	100	118	50	33	26	35	47
OECD excluding North America	102	97	98	100	45	27	26	32	48
Eastern Europe and the CIS	-	59	59	81	-	45	24	41	56
Other developed	96	129	99	36	45	27	28	45	32

Source: Own calculations.

systems' where appropriate (e.g. for intensively reared swine in developing countries).

Table A3.1 allows us to compare the results with the currently used IPCC Tier 1 emission factors. In comparison, the main effects of using IPCC Tier 2 methodology to derive enteric fermentation methane emission factors for cattle have been:

- an increase in the weighted average emission factor for dairy cattle in most developing regions (by the proportion of animals associated with each livestock system); and
- a decrease for other cattle in OECD and transition regions.

The main reasons for these differences is better differentiation of both the feed digestibility and methane conversion factors associated with different feed types according to production system. For dairy cattle, IPCC default Tier 1 assumes feed digestibility of 60 percent for all regions except North America (65 percent) and India (55 percent), and a methane conversion factor of 6 percent for all regions.

For the Tier 2 approach, feed digestibility and methane conversion factors were estimated for the different production systems and world regions according to recommendations given by the US-EPA (EPA Ruminant Livestock). Following these, common feed digestibility for cattle ranges from 50 to 60 percent for crop by-products and rangelands; 60 percent to 70 percent for good pastures, good preserved forages, and grain supplemented diets; and 75 to 85 percent for high quality feedlot grain diets. The methane conversion factor for 'good quality feeds' is given as 6 percent, while that for 'poor quality feed', which might be taken to describe pastoral systems in most developing countries, is given as 7 percent. Therefore, the association of low feed digestibility and high methane conversion factor in pastoral systems, in developing countries, where both of these apply, has led to a greater emission factor being derived using Tier 2 methodology in these systems than those given under Tier 1. In addition, there were some differences in the default milk yields used to obtain the Tier 1 values and those derived from recent FAO statistics and used in the Tier 2 calculations. Obviously, great improvements to the estimates of emission factors could be made if more data on nutrition and production were available.

3.3 Current manure methane emissions per production system, species and region

As in the case of the enteric fermentation emission factors, the IPCC default manure methane emission factors were established some time ago and may not represent the current situation correctly. The structural changes in the livestock sector may have an important impact on overall methane emissions from manure.

Again an assessment was made for this report to evaluate the discrepancy: an IPCC Tier 2 approach was used to derive the methane from manure management emission factors for dairy cattle, other cattle and pigs (Houghton *et al.*, 1997). The emission factor per head was derived from the calculated volatile solids (VS) content of the manure per livestock type, together with an estimate of the methane-producing potential of the manure (Bo value) and a methane conversion factor, dependent on the manure management system.

Calculating VS required data for feed energy intake, digestibility and ash content of manure. For dairy cattle, the feed energy intake as calculated in the enteric fermentation emission factors was used, together with default IPCC values for digestibility and ash. For other cattle and pigs, default IPCC values for these parameters were used. For industrial pig systems in developing regions, we used values otherwise applied to developed countries. Emission factors were derived with the following assumptions for manure management system allocations:

- For cattle (dairy and other) in a grazing production system it was assumed that all manure management would be regarded as pasture/range management (i.e. 100 percent in that category).
- For 'other cattle' on an 'industrial' system it was assumed that all manure management would be regarded as 'drylot' (i.e. 100 percent in that category).
- The remaining cattle manure management categories (see Houghton *et al.*, 1997) were assumed to be associated with 'mixed' production systems, with the assumption that pasture/range was 15 percent of manure for mixed dairy systems and 20 percent for mixed beef systems.
- For pigs, responses to survey questionnaires were used together with the assumption that in developed countries, industrial systems would be predominantly slurry/lagoons with over one month of storage.
- For other livestock, default values (Houghton *et al.*, 1997) were used for appropriate systems ('developed' = 'industrial') and temperature regions. Again, this Tier 1 approach was used because less activity data were available for these livestock categories and they represented minor emission sources.

For the manure management methane emission factors, the IPCC Tier 2 methodology has again given estimates that are often greater than the Tier 1 defaults (Table A3.2), giving particularly large values for industrial systems. This is largely owing to the use of revised methane conversion factors for slurry storage systems as given by IPCC, 2000. These were increased from 10, 35 and 65 percent for cool, temperate and warm climates, respectively (being the values on which the Tier 1 default values are based) to 39, 45 and 72 percent for cool, temperate and warm climates, respectively. In addition, the feed digestibility characteristics, as described above, influenced the calculation of the manure volatile solids output per animal, on which the manure management methane emission factor is based.

The impact of the difference of course depends on the relative importance of the corresponding livestock populations, as well as whether Tier 1 factors are currently used (non-Annex 1, i.e. developing, countries). In this respect the increase of the estimated emission factor with respect to Tier 1 for cattle in Africa and the CIS is important to note. Similarly pig emission factor differences in rapidly industrializing developing regions such as Asia (particularly China) and

Table A3.2

Manure management methane emission factors (EF) for cattle (kilogram CH_4 per head per year) by production system and world region. Tier 2 based estimates compared to tier 1 emission factors

Region	Dairy cattle		Other cattle		Pigs	
	Weighted EF	Tier 1 EF	Weighted EF	Tier 1 EF	Weighted EF	Tier 1 EF
Sub–Saharan Africa	2.5	1	1.5	1	1.6	2
Asia excluding China and India	18.6	16	0.8	1	7.4	4-7
India	5.3	6	1.5	2	12.4	6
China	12.9	16	1.0	1	7.6	4-7
Central and South America	2.4	2	1.0	1	9.6	2
West Asia and North Africa	3.8	2	2.4	1	1.7	6
North America	51.0	54	9.5	2	22.7	14
OECD excluding North America	41.8	40	10.9	20	11.1	10
Eastern Europe and the CIS	13.7	6	9.1	4	2.8	4
Other developed	12.8	1	1.9	1	21.7	6

Source: Own calculations.

Latin America will induce differences between our quantification and existing ones.

3.4 Estimating water consumption for feed production

Generally the estimation of the amount of water consumed by a particular crop is done in a mechanistic manner, using a more or less sophisticated modelling approach. At the regional and global level these approaches are generally simple and, therefore, subject to strong assumptions. Chapagain and Hoekstra (2004) for example, estimating water footprints of nations, base their crop water use estimate on the method of Allen *et al*. (1998), multiplying a reference crop evapotranspiration with a crop coefficient.

Crop variety and climate are considered in the method of the latter author, but climate is not considered by Chapagain and Hoekstra (2004). It is supposed that adequate soil water is maintained by rainfall and/or irrigation so that it does not limit plant growth and crop yield. This leads to considerable overestimates in the warm and drier regions, which the authors claim to be compensated by their neglect of irrigation losses, but the latter locally unused portion of irrigation water is now widely acknowledged as not being lost at all (Molden and de Fraiture (2004).

For this report, we circumvented such problems by adopting a more deductive approach: detailed spatial information on arable land in general as well as separately for a number of important feedcrops has recently become available at the global level. This information was combined with spatially detailed and calibrated water balance and irrigation water-use estimates (FAO, 2003a: Box 4.3). The water balance calculation considers local precipitation, reference evapotranspiration, soil moisture storage properties, extents of areas under irrigation and irrigated areas for all major crops. Irrigation water consumption (in equipped areas) is calculated as the water required in addition to water from precipitation (including runoff from upstream areas) for optimal plant growth during the growing season.

This information avoids using statistics on water use or withdrawal, which would involve the difficult consideration of irrigation efficiency. At the same time the detailed information on the spatial distribution of important feed crops avoids having to combine the previous water consumption information with national level yield statistics, which would have been incompatible with assumptions of the water balance calculation.

One important difficulty remained though: before overlaying the overall crop maps with the irrigation and rainfed water consumption maps it needs to be determined in what locations crops are destined to be used for feed. Such information does not exist at the global level. However, we can assess the situation using two possible extreme hypotheses:

Hypothesis 1: ***spatial concentration of feed.*** Certain areas are entirely dedicated to the production of feed, and by matching their production with the national feed production statistics it is assumed that feed production elsewhere is insignificant.

Hypothesis 2: ***area wide integration of feed.*** Supposing a uniform distribution of both food and feed across cropland, it is assumed that anywhere where one of the considered crops is cultivated, a portion of the production equal to the national average is dedicated to feed.

In order to get an idea of the precision with which feed water consumption can be estimated, we used both approaches. A large difference between the two results would have suggested considerable uncertainty. The actual results (given in Chapter 4) show that the two approaches yield similar outcomes, indicating a degree of confidence in the results. Unfortunately, the detailed global crop maps are only available for a limited number of feedcrops. The crops considered in this assessment are barley, maize, wheat and soybean (hereafter called BMWS).

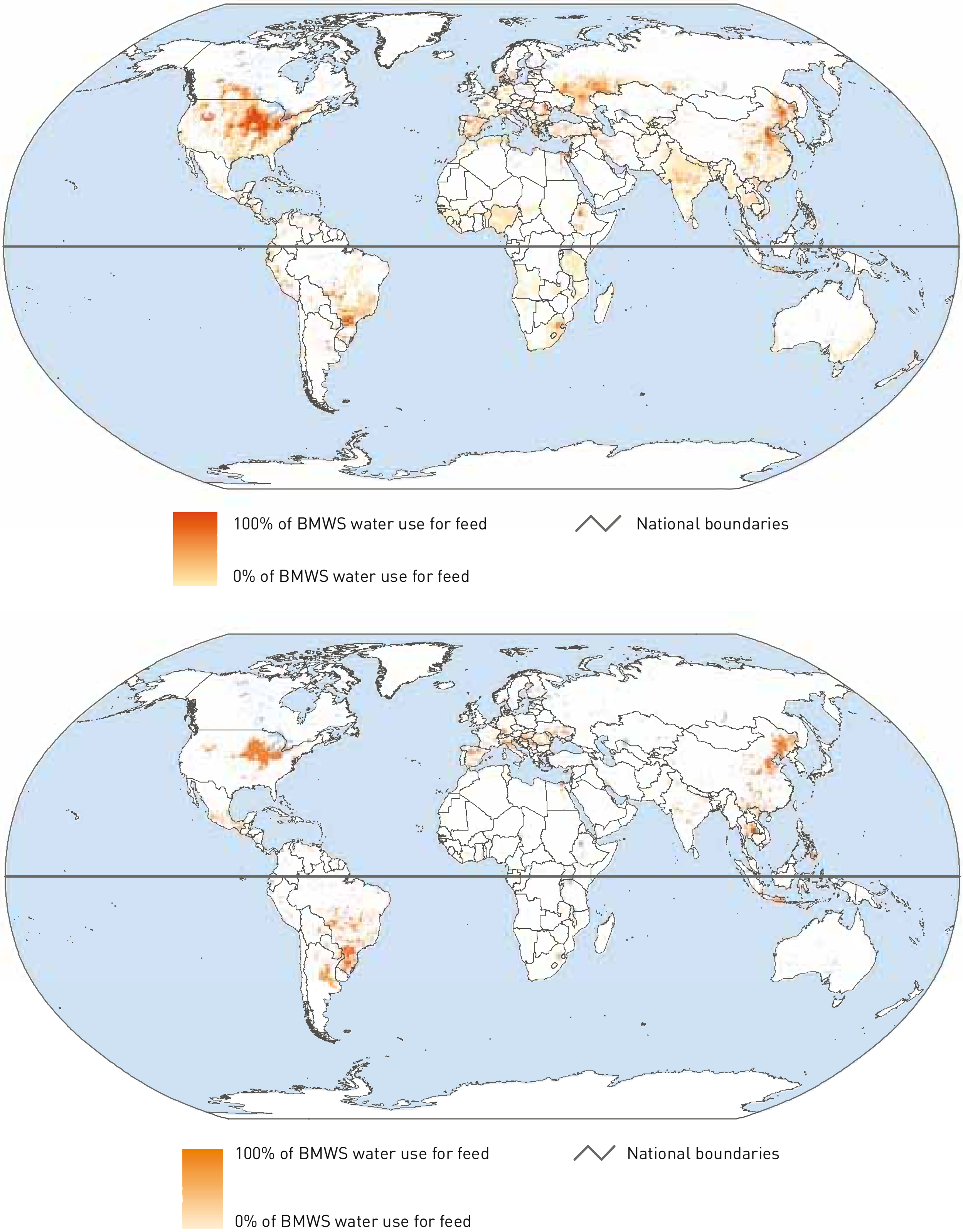
The area corresponding to hypothesis 1 is estimated in the following way: BMWS production dominates total local crop production. In addition, the combined production of barley, maize and soybean in this area is to be much larger than that of wheat (of which, generally, considerably less is used for feed). This latter criterion was used as an adjustable parameter to calibrate the area's size with respect to the national statistics on the barley, maize and soybean combined harvested area. Areas of BMWS production dominance were defined as those areas where the combined yield (making use of a recent detailed cropland area fraction map; exceeds 100 tonne/km^2. In the resulting areas country specific "aggregate" feed fractions are used to attribute water consumption in the area to the production of feed. This aggregate fraction is calculated as a weighted mean based on the production of barley, maize and soybean in the area and their corresponding national average feed use fractions (FAO, 2006b). In the particular case of soybean a fixed fraction of 66 percent was used, corresponding to the soymeal value fraction (Chapagain and Hoekstra, 2004).

Under hypothesis 2 the entire BMWS area covered (as shown in the respective crop production maps) is considered to produce feed, but only to the extent corresponding to the national feed fraction of production (according to the supply utilization accounts in FAO). Again for soybean the 66 percent value fraction is used. Dividing the resulting summed BMWS feed production by the total summed BMWS production results in a map of local BMWS feed production fractions. In a final step towards determining the local fraction of water consumption for feed, the feed production fractions are multiplied by the BMWS cultivated fraction of the area (respective to other crops). These area fractions are defined as the sum of the individual crop areas (estimated by dividing production maps by national average yields) divided by the total cropped area.

The maps at the end of this annex show the contrasting feed production distributions resulting from both approaches. The apparent contrast in the corresponding water consumption is less dramatic than it seems, because different portions of consumption are attributed locally to the production of feed under the two hypotheses. These portions are generally higher under hypothesis 1 than under hypothesis 2.

The BMWS feed water consumption that

Map 1 **Water consumption for feed production: barley, maize, wheat and soybean**



Source: LEAD. Feed production areas (all non-white land area) and the feed fraction of BMWS water use resulting from Area Wide Integration of Feed approach (top map) and the Spatial Concentration of Feed approach (bottom map).

results from this assessment (Table 4.7) does not represent the entire water consumption for the production of feed. Figures 2.6 and 2.7 (Chapter 2) showed that these four crops together constitute about three quarters of feed concentrates for pig and chicken, i.e. the global total water consumption for feed may roughly correspond to 1.3 times that of BMWS feed. Finally, it is worth emphasizing that these estimates exclude water consumed for the production of natural but grazed grass and cultivated fodder. Their inclusion would substantially change the feed water consumption estimates, particularly on the rainfed consumption side. However, much of the consumption of grazed grass does not have an opportunity cost as is the case for cultivated areas. Including this, if it had been possible would, therefore, reduce the environmental relevance of the result.

This report aims to assess the full impact of the livestock sector on environmental problems, along with potential technical and policy approaches to mitigation. The assessment is based on the most recent and complete data available, taking into account direct impacts, along with the impacts of feed crop agriculture required for livestock production.

The livestock sector emerges as one of the top two or three most significant contributors to the most serious environmental problems, at every scale from local to global. The findings of this report suggest that it should be a major policy focus when dealing with problems of land degradation, climate change and air pollution, water shortage and water pollution, and loss of biodiversity.

Livestock's contribution to environmental problems is on a massive scale and its potential contribution to their solution is equally large. The impact is so significant that it needs to be addressed with urgency. Major reductions in impact could be achieved at reasonable cost.

ISBN 978-92-5-105571-7

9 789251 055717

TC/M/A0701E/1/11.06/5000