Environmental impacts of a changing livestock production: overview and discussion for a comparative assessment with other food production sectors

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ABSTRACT

Growing populations and incomes, along with changing food preferences, are rapidly increasing demand for livestock products, while globalization is boosting trade in livestock inputs and products. While growing, the livestock production is undergoing a complex process of technical and geographical change, which is shifting the balance of environmental problems that the sector causes. 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: it is by far the single largest anthropogenic user of land, it is estimated to be responsible for 18 per cent of greenhouse gas emissions measured in CO_2 equivalent (a higher share than transport) and it is a key player in increasing water use, accounting for over 8 per cent of global human water use, mostly for the irrigation of feed crops. It is also probably the largest agricultural source of water pollution. Furthermore, as a consequence of the above, the livestock sector may well be the leading player in the reduction of biodiversity.

INTRODUCTION

Fuelled by a growing population, rising income and urbanisation, demand for animal products is burgeoning in the developing world: per capita consumption of meat rose from 15 kg in 1982 to 28 kg in 2002, and is expected to reach 37 kg by 2030 (FAO, 2003). In 1995, for the first time, meat volume produced in the developing countries exceeded that of developed countries and since then the gap in milk output between developing

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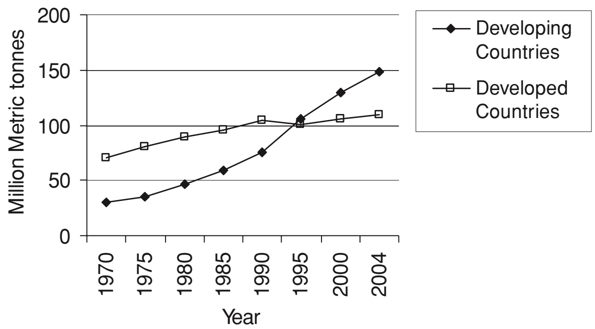
FIGURE 1
Trends in meat production in developed and developing countries



Source: FAO (2006)

countries and developed countries has been narrowing (Figure 1).

The livestock sector is responding to this demand-led surge in livestock products through some drastic transformations that have substantial influence on the sector's environmental impacts. Similar trends are observed in other food production sectors, taking place at similar pace (e.g. aquaculture) or slower (e.g. cropping).

This paper aims at reviewing main changes in the livestock sector and their implications on the sector's role in global environment issues, such as land use, climate change, water depletion and biodiversity erosion. It also briefly discusses the relevance and approaches for comparing environmental costs of aquaculture and livestock production sectors.

CHANGES IN THE LIVESTOCK SECTOR

In this section, we review both trends causing changes in the sector, such as change in demand, market internationalization and policy context, and resulting structural and technical changes in the sector. Focus is on processes that have environmental implications.

Changes in demands

Consumption of meat and milk worldwide has been rapidly growing since the early 1980s. Developing countries have accounted for a large share of this increase, and growth in poultry and pork consumption in developing countries has been particularly striking. Since the early 1980s, total meat and milk consumption grew at six and four percent per year, respectively, throughout the developing world.[2]

In developing countries, 70 percent of the additions to meat consumption are from pork and poultry; in developed countries, the comparable figure is 81 percent. Poultry consumption in developing countries is projected to grow at 3.4 percent per annum to 2030, followed by beef at 2.2 percent and ovine at 2.1 percent. In the world as a whole, poultry consumption is projected to grow at 2.5 percent per annum to 2030, with other meats growing at 1.7 percent or less. The growth rates have been particularly high in China, India and Brazil, and the sheer size and vigour of those countries will mean that they will continue to increase their dominance of world markets for livestock products.

The pace of dietary change, both qualitative and quantitative, accelerates as countries become richer and populations become increasingly urbanized. Urbanization is accompanied by changes in habitual food consumption patterns and dramatic lifestyle changes, which include a marked reduction in levels of physical activity. In developing countries which are urbanizing, quantitative changes in dietary intake have been accompanied by qualitative changes in the diet. Changes include shifts from cereal-based diets to energy dense diets with high animal protein and fat content, as well as increased consumption of sugars and sugar-based products.

Among the various drivers of change in animal production, the literature identifies purchasing power as the most influential (Delgado *et al.*,1999; Zhou *et al.*, 2003).

[2] Compound annual growth rates were estimated between 1983 and 1997.

Livestock product consumption rises with purchasing power. However, the effect of increased income on diets is the greatest among lower- and middle-income populations (Delgado *et al.,* 2002). Urbanization is recognized to be the second main factor influencing per capita consumption of animal products (Rae, 1998; Delgado *et al.*, 1999). Explanation for this trend may lie in the wider food choices and dietary influences found in urban centres, as well as a preference for convenience and taste over maximum caloric content (Delgado *et al.*, 1999). If purchasing power and urbanization are the most important factors contributing to patterns of per capita consumption, other factors are significant and can have great influence locally, such as culture and government intervention.

More recently, other factors have influenced consumption patterns. First is the emergence of the "concerned consumer" (Harrington, 1994) in Organisation for Economic Co-operation and Development (OECD) countries. The consumption patterns of these consumers are influenced not only by market and taste factors but by concerns about health, environmental, ethical, animal welfare and development issues. These consumers tend to reduce or even stop their consumption of particular animal products or to opt for certified products, such a free range or organic (Krystallis and Arvanitoyannis, 2006).

Trade and retailing

Increasing international trade as well as the rise of large retailers and integrated food chains are other drivers of change in the livestock sector. More precisely, they influence the relative competitiveness of producers and production systems in supplying the rising demand for animal derived foods.

Livestock production traded across international borders has increased from 4 percent in the early 1980s to approximately 10 percent at the present time. Developing countries are among the top 20 exporters and importers in value terms (FAOSTAT). Main exported products are live animals and the meat of cattle, sheep, goats, pigs, horses, chickens and ducks, fresh and condensed cow milk, as well as pig and cattle feed; while imports in large quantities include the meat of cattle, sheep, chickens and ducks, fresh and dried cow milk, ghee, animal feeds and live cattle, goats, sheep, buffaloes and chickens. Four structural developments in livestock markets can be discerned (FAO, 2005):

- **International market chains:** supplying livestock products from one country to retailers and consumers in another country. These chains are either controlled by large retailers, such as supermarkets, or by importing firms dealing with particular commodities.
- **Chains created by foreign direct investment**: vertically integrated market chains supplying a domestic, mainly urban market. Typically they are controlled by large retailers such as international or national supermarkets and fast food companies. The rapid expansion in supermarket penetration in developing countries is a fairly recent phenomenon. It has become significant only over the last five to ten years, and has proceeded at different rates in the various regions of the developing world.
- **Domestic markets affected by globalization**: effects of globalization on consumer demand and behaviour have led to responses in domestic market chains other than vertically integrated chains. For example, dairy processors, fast food chains and restaurants have developed and increased the diversity of products on the market, but are not part of vertically integrated chains.
- **Increasing local markets:** geographical concentration and intracountry specialization (cf. below) on the one hand, and urbanization on the other, lead to increasing livestock product (and feed resource) transfers at national level.

Impact of climate change on the livestock sector

Recent changes in climate, especially warmer regional temperatures, have already had significant impacts on biodiversity and ecosystems, especially in dryland environments such as the African Sahel. Ecosystem degradation is exacerbating problems of poverty and food insecurity in the developing world, particularly in the poorest countries. Global climate change is taking place against the background of a natural environment that is already stressed by resource degradation resulting from various factors including the use of some agricultural technologies and inputs.

Climate change is likely to have a significant impact on the global environment. In general, the faster the climate changes, the greater will be the risk of damage. The mean sea level is expected to rise 9–88 cm by the year 2100, causing flooding of low-lying areas and other damage. Climatic zones could shift towards the poles and vertically, disrupting forests, deserts, rangelands, and other ecosystems. As a result, many ecosystems will decline or become fragmented, and individual species could become extinct (IPCC, 2001).

Global agriculture will face many challenges over the coming decades, and conditions may be worsened by climate change. A warming of more than 2.5°C could reduce global food supplies and contribute to higher food prices (IPCC, 2001). Some agricultural regions will be threatened by climate change, while others may benefit. The impact on crop yields and productivity will vary considerably. The livestock sector will also be affected. Livestock products will become costlier if agricultural disruption leads to higher grain prices. In general, it seems that intensively managed livestock systems will more easily adapt to climate change than crop systems. This may not be the case for pastoral systems, however, where livestock depend more fully on the productivity and quality of the rangelands, which is predicted to decline and become more erratic (IPCC, 2001). In addition, extensive systems are more susceptible to changes in the severity and distribution of livestock diseases and parasites. Negative impacts of climate change on extensive systems in the drylands are therefore predicted to be substantial.

Industrialization of production[3]

Intensification

Over the last 24 years (1980 to 2004), off-take of pig meat, chicken and milk per unit of stock has increased by 61 percent, 32 percent and 21 percent respectively (FAO, 2006). Traditionally, livestock production was based on locally available feed resources, including local fodder, crop residues, and unconsumed portions of household food. Feed had no value as food. Traditionally, natural pastures were the venue of livestock production. In recent times, however, pasture land tends to be situated in areas which are unfit or marginal for cropping. As livestock production grows and intensifies, it depends less and less on locally available feed resources but increasingly on feed concentrates that are traded domestically and internationally. In 2004, a total of 690 million tonnes of cereals were fed to livestock (34 percent of the global cereal harvest) and another 18 million tonnes of oilseeds (mainly soy). In addition, 295 million tonnes of protein-rich processing by-products were used as feed (mainly bran, oilcakes and fish meal).

Declining grain prices, a trend that has prevailed since the 1950s, has been one of the factors driving the increased use of grains as feed. Despite growing feed demand over that period, the feed/food demand ratio remained stable and supply has not lagged behind. Conversely, the total supply of cereals increased by 46 percent over the last 24 years (1980 to 2004). In real terms (constant US$) international prices for grains have

[3] This section draws on Costales et al. (2006).

halved since 1961 (FAO, 2006). Expanding supply at declining prices has been brought about predominantly by intensification of existing cropped area and to a lesser extent by area expansion (globally, the areas of cereal harvested shrank by 5.2 percent over the same period).

Intensification draws on other technical improvements, such as genetics, health and farm management. Advances in technology go with an increasing reliance of producers on external service providers and with the specialization of production units. The tendency is to shift from backyard and mixed systems to commercial, single product operations.

Scaling up

Economies of scale (cost reductions realized through increasing the size of operations) at various stages of the production process trigger the creation of large production units. As a result, the number of producers rapidly diminishes even though the sector as a whole may expand. In many rapidly growing economies, the average size of operations is increasing and the numbers of livestock producers are in decline. In Brazil, between 1985 and 1996, pig farms with more than 200 animal places doubled as a proportion of the total number of farms (Sant'Ana de Camargo Barros *et al.*, 2003). In Thailand the proportion of large farms (more than 100 pig places) grew from 17 to 46 percent between 1993 and 1998 (Poapongsakorn *et al.*, 2003). Similarly, in Southern Luzon region of the Philippines, one of the main pig producing regions, pigs held in backyards remained fairly stable in number from 1980 to 2000, while the pig numbers in commercial farms grew almost fourfold (Costales, Gerber and Steinfeld, 2006).

Geographical concentration

As countries industrialise, livestock production follows a pattern of relocation. Traditionally, livestock production is based on locally available feed resources. The distribution of ruminant livestock can be explained by the availability of such resources, while the distribution of pigs and poultry follows closely that of humans, because of their role as waste converters.

As soon as urbanization and economic growth translate rising incomes into "bulk" demand for animal food products, large scale operators emerge that are initially located close to towns and cities. Livestock products are highly perishable, and their conservation without chilling and processing poses serious problems. Therefore, until effective transport infrastructures are developed, livestock are produced close to where the demand is.

Policy environment

Livestock public policies can be seen as forces that add to the drivers described above, and influence changes in the sector with the aim of achieving an identified set of societal objectives. Policies are designed and adjusted, taking into account the state of markets, available technologies and natural resources (the drivers previously described), and the current status of the sector. Experience in both developed and developing countries confirms that a laissez-faire approach, simply standing back and allowing market forces to play out, is not a viable option. In the absence of effective policies, many of the hidden costs of increased livestock production – cleaning up the environment, expanding safety nets and economic opportunities for poor traditional livestock owners, and fending off threats to veterinary and human public health, are eventually charged to governments and the public.

From this standpoint, public policies are both drivers of and responses to changes in the livestock sector. At any point in time, policies that are in existence and enforced are drivers of change, while policies in preparations are part of the public response to changes. The main regulatory and policy frameworks that have influenced the sector include:

- market regulation, regulation of Foreign Direct Investment, regulation on property rights (including intellectual property), and regulations on credit that shape the "investment climate" in a country;
- institutional and regulatory frameworks regarding the ownership and access to land and water resources;
- labour policy, including regulations affecting the cost of labour, the employment of migrant labourers and working conditions;
- mobility, security and migration policies, which particularly affect mobile forms of livestock production such as pastoralism;
- incentive frameworks, which shape relative competitiveness and production levels and practices; farm subsidies in OECD countries (US$257 billion in 2003) have, for example, substantially contributed to increased production levels;
- sanitary standards and trade policies, as previously discussed have direct impacts on competitiveness and access to national and international markets; and
- environmental policies have affected farm practices and, to a limited extend, increased the relative competitiveness of production in countries where environmental regulations are less stringent or not enforced.

ENVIRONMENTAL ISSUES ASSOCIATED WITH LIVESTOCK PRODUCTION[4]

The changes detailed in the previous section are not neutral with regards to the sector's environmental impacts. Increasing herd size generally causes overall increasing damages. Technology changes can, in contrast, either improve or worsen environmental performances expressed in impact per unit of product. The combination of these two factors determines the trend of environmental impacts. This section reviews the sector's role in today's major global environment issues.

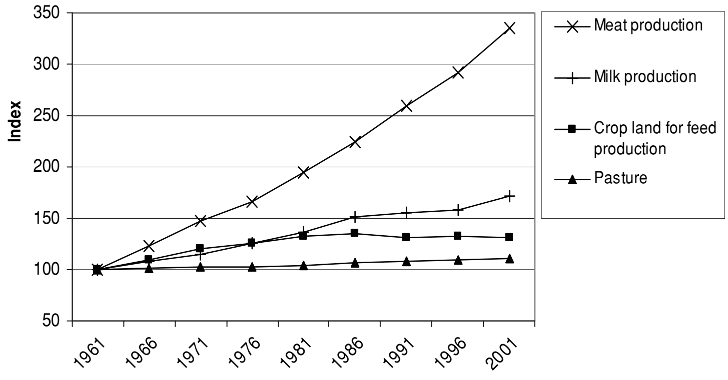
Land use

Today, the livestock sector is a major land user, spanning more than 3.9 billion hectares, representing about 30 percent of the world's surface land area. The intensity with which the sector uses land is however extremely variable. Of the 3.9 billion hectares, 0.5 are crops, generally intensively managed; 1.4 are pasture with relatively high productivity and; the remaining 2.0 billion hectares are extensive pastures with relatively low productivity. The sector is the first agricultural land user, accounting for about 78 percent of agricultural land and as much as 33 percent of the cropland. If the bulk of lands used by livestock are pastures, feedcrops are now estimated to account for 0.5 billion hectares, or about 34 percent of all crop land. Driven by a growing demand for livestock products, these figures will continue to increase. As the livestock sector develops, however, not only its land requirements grow, but the sector undergoes a geographical transition involving changes in land use intensity and geographical distribution patterns.

The first aspect of this transition is land use intensification. It relates to feed supply, the main purpose for which the sector uses land (either directly as pasture or indirectly as feedcrops). Feedcrops and cultivated pastures intensify in areas with developed transport infrastructure, strong institutions and high agro-ecological suitability. Figure 2 shows the marked difference in growth rates between the global areas dedicated to pasture and feed production, compared to the meat and milk outputs of the sector. This increasing productivity is the consequence of strong intensification of the sector on a

[4] This section draws on a recent assessment prepared by the Livestock, Environment and Development (LEAD) Initiative, entitled "Livestock's Long Shadow - Environmental Issues and Options" (Steinfeld *et al.* 2006).

FIGURE 2
Global trends in land area used for livestock production and total production of meat and milk



Note: Figures indexed to 100 in 1961
Source: Steinfeld *et al.* (2006)

global scale. The shift from ruminant species to monogastric species fed on improved diets plays a critical role in this process.

The growth in demand for livestock products will probably still play a dominant role over the next decades and lead to a net increase in the area dedicated to livestock, despite the intensification trend. Extensive pastures and feedcrop production will expand into natural habitats with low opportunity cost. It is however likely that the bulk of pasture and feedcrop spread has already occurred, and that the intensification process will soon overcome the trend for area expansion, leading to an eventual net decrease in the area under pasture and feedcrops.

There are regional variations to these global trends. In the European Union, and more generally in OECD countries, the growth of meat and milk production happened at the same time as a reduction in the area dedicated to pasture and feedcrops. Part of the reduction in local feedcrop area was however compensated by feed imports, in particular from South America. Indeed the comparable trends in South America show a strong growth of feedcrop areas. Feedcrops grew especially rapidly in the 1970s and late 1990s, when first developed countries and then developing countries engaged in livestock industrialization and started importing protein feed. This is for example currently under way in East and Southeast Asia, where production has grown dramatically faster than the area under feedcrops and pasture (which has remained stable). This difference in growth rates has been achieved by importing feed resources, and also through a rapid intensification of the livestock industry involving breed improvement, improved animal husbandry and a shift to poultry.

The second feature of livestock's geographical transition lies in the changing spatial distribution of production. Production and consumption mostly do not coincide anymore, as most consumption is now located in urban centres, far from the feed resources. The livestock sector has adapted to this new configuration by splitting up the commodity chain and locating each specialized production or processing segment where production costs are minimized. With the development of transport infrastructure, shipment of animal products is getting relatively cheap in comparison with other production costs. The trend towards more processed foods further contributes to reducing transport costs. Livestock production therefore moves closer to feed resources, or to places where the policy context (tax regime, labour standards, environmental standards), as well as access to services or disease conditions, minimize production costs. In essence, livestock is thus moving from a "default land user" strategy (i.e. as the only way to harness biomass from marginal lands, residues and interstitial areas) to an "active land user" strategy (i.e. competing with other sectors for the establishment of feedcrops, intensive pasture and production units).

This process leads to efficiency gains in the use of resources. However it usually develops within a context of environmental and social externalities which are mostly unaddressed, and inadequate pricing of resources on the basis of private rather than social costs. As a consequence, changes in livestock geography are associated with substantial environmental impacts. For example, the private costs of transport are distortedly low and do not reflect social costs. The increasing agricultural intensification is associated with profound land degradation problems. The continuous expansion of agriculture into natural ecosystems causes climate change and biodiversity loss. The disconnection of livestock production from its feed base creates inadequate conditions for good waste management practices, which often cause soil and water pollution as well as green house gas emissions.

On current trends, the ecological footprint of the livestock sector will increase because of land use expansion and land degradation. Confronting the global environmental challenges of land use will require assessing and managing the inherent trade-offs between meeting the current demand for animal-derived foods, and maintaining the capacity of ecosystems to provide goods and services in the future. Ultimately, reaching a sustainable balance will require adequate pricing of natural resources, the internalization of externalities and the preservation of key ecosystems.

Climate change

Animal agriculture emits green house gases at various levels of the food chain: feedcrops and pasture (mainly N_2O and NH_3); animal (mainly CH_4 from enteric fermentation); manure (CH_4, NH_3, and N_2O, to a lesser extent); and transport and other fossil fuel consumption (mainly CO_2 and N_2O). In ruminant based systems, enteric fermentation and emissions from manure represent the bulk of emissions, whereas manure management and feed production represent the bulk of emissions associated with monogastrics.

Overall, livestock activities contribute an estimated 18 percent to total anthropogenic greenhouse gas emissions from the five major sectors for greenhouse gas reporting: Energy, Industry, Waste, Land Use, Land Use Change and Forestry (LULUCF) and Agriculture. Taking agriculture alone, livestock constitute nearly 80 percent of all emissions from the agricultural sector. We summarize below the impact for the three major greenhouse gases.

Carbon dioxide

When deforestation for pasture and feedcrop land, and pasture degradation are taken into account, livestock-related emissions of carbon dioxide are an important component of the global total (some 9 percent). However, as can be seen from the many assumptions made in preceding sections, these totals have a considerable degree of uncertainty. LULUCF sector emissions in particular are extremely difficult to quantify and the values reported to the (United Nations Framework Convention on Climate Change) UNFCCC for this sector are known to be of low reliability. This sector is therefore often omitted in emissions reporting, although its share is thought to be important.

Although small by comparison to LULUCF, the livestock food chain is becoming more fossil fuel intensive, which will increase carbon dioxide emissions from livestock production. As ruminant production (based on traditional local feed resources) shifts to intensive monogastrics (based on food transported over long distances), there is a corresponding shift away from solar energy harnessed by photosynthesis, to fossil fuels.

TABLE 1
Current yearly total and animal food production induced emissions of carbon dioxide, expressed in billion tonnes CO_2. Livestock emissions are attributed to the main production system. Values between brackets are or include emission from the Land Use, Land Use Change and Forestry category

Source	Mainly related to extensive systems	Mainly related to intensive systems
Livestock activities		
- N fertilizer production		0.04
- on farm fossil fuel, feed		~0.06
- on farm fossil fuel, livest.		~0.03
- deforestation	(~1.7)	(~0.7)
- cultivated soils, tillage		(~0.02)
- cultivated soils, liming		(~0.01)
- desertification of pasture	(~0.1)	
- processing		0.01 – 0.05
- transport		~0.001
Total livestock activities		~0.16 (~2.5)
Total anthropogenic emissions		24 (~31)
Livestock activities within total		~0.7 percent (~8 percent)

Table 1 summarizes livestock's overall impact on carbon dioxide emissions, by source, and by type of production system.

Methane

For methane emissions, the leading role of livestock has long been a well-established fact. Together, enteric fermentation and manure represent some 80 percent of agricultural methane emissions and about 35 to 40 percent of the total anthropogenic methane emissions. With the decline of ruminant livestock in relative terms, and the overall trend towards higher productivity in ruminant production, it is unlikely that the importance of enteric fermentation will grow much more. However, methane emissions from animal manure, although much lower in absolute terms, are considerable and growing rapidly.

Nitrous oxide

Livestock activities contribute in a major way to the emission of nitrous oxide, the most potent of the three major greenhouse gases. They contribute almost two thirds of all anthropogenic N_2O emissions, and 75–80 percent of agricultural emissions. Current trends suggest that this level will substantially increase over the coming decades.

Technical options are available to mitigate gaseous emissions of the sector. CO_2 emissions can be limited by reducing deforestation (e.g. promoting agricultural intensification) and the sector can contribute to carbon sequestration through a range of practices including: restoring organic carbon to cultivated soils, reversing soil organic carbon losses from degraded pastures and sequestration through agro-forestry. Improved efficiency and diets as well as better manure management can substantially reduce methane emissions, while careful nutrient management (i.e. fertilization, feeding and waste recycling) can mitigate N_2O emissions and NH_3 volatilization. Among the technical options available, those that contribute to the mitigation of several gases at a time (anaerobic digestion of manure), as well as those that provide other environmental benefits in parallel (e.g. pasture management) deserve special attention.

Water resource depletion

The water used by the sector exceeds 8 percent of the global human water use. The major part of this is water used for feed production, representing 7 percent of the global water use. Although it may be of local importance, for example in Botswana or in India, the water used for product processing and animal drinking and servicing remains insignificant at global level (below .1 percent of the global water use and less than 12.5 percent of the water use by the livestock sector).

Evaluating the role of the livestock sector on water depletion is a much more complex process. The volume of water depleted is only assessable for water evapotranspired by feedcrops during feed production. This represents a significant share of 15 percent of the water depleted every year.

The contribution of the livestock sector to water depletion is not easily quantified with our current knowledge but there is strong evidence that the sector is a major driver. The volume of water evapotranspired by feedcrops represents a significant share (at 15 percent) of the water depleted every year. In the sediments and nutrients are considered to be the main water-polluting agents. The livestock sector is responsible for an estimated 55 percent of erosion and for 32 percent and 33 percent respectively of the N and P load into freshwater resources. The livestock sector makes a strong contribution to water pollution by pesticides (37 percent of the pesticides applied in the United States of America), antibiotics (50 percent of the volume of antibiotics consumed in the United States of America) and heavy metals (37 percent of the Zn applied on agricultural lands in England and Wales.

Livestock land use and management appear to be the main mechanism through which livestock contribute to the water depletion process. Feed and forage production, manure application on crops, and land occupation by extensive systems are among the main drivers for unsustainable nutrient, pesticide and sediment loads in water resources worldwide. The pollution process is often diffuse and gradual and the resulting impacts on ecosystems are often not noticeable until they become severe. Therefore, the pollution process is often extremely hard to control, especially when it is taking place in areas of widespread poverty.

The pollution resulting from industrial livestock production (consisting mainly of high nutrients loads, increased BOD and biological contamination) is more acute and more noticeable than from other livestock production systems, especially when it takes place near urban areas. As it impacts human well-being very directly, and is easier to control, mitigating the impact of industrial livestock production usually receives the strongest emphasis among policy-makers.

Livestock production has diverse and complex regional impacts on water use and depletion. These impacts can be assessed through the concept of "virtual water" – defined as the volume of water required to produce a given commodity or service (Allan, 2001). For example, one litre of milk requires an average 990 litres to produce (Chapagain and Hoekstra, 2004). "Virtual water" is of course not the same as the actual water content of the commodity: only a very small proportion of the virtual water used is actually embodied in the product (e.g. 1 out of 990 litres in the milk example). Virtual water used in various segments of the production chain can be attributed to specific regions. In the case of intensive livestock production, virtual water for feed production may be used in a different region or country from water used directly in animal production.

Differences in virtual water used for different segments of livestock production may be related to differences in actual water availability. This partly helps to explain recent trends in the livestock sector (Naylor and Steinfeld, Science, 2005; Costales *et al.*, Livestock report FAO, 2006) where there has been an increased spatial segmentation at various scales of the animal food chain, especially the separation of animal and feed production. The latter is already clearly discernable at national as well as sub-national level when the map of main global feed production areas is compared to the distribution of monogastric animal populations. At the same time international trade of the final animal products has increased strongly. Both changes lead to increased transport and strongly enhanced global connectivity.

These changes can be considered in the light of the uneven global distribution of water resources. In developing regions, renewable water resources vary from 18 percent of precipitation and incoming flows in the most arid areas (Near East/North Africa) where precipitation is a mere 180 mm/year, to about 50 percent in humid East Asia, which has a high precipitation of about 1 250 mm/year. Renewable water resources are most abundant in Latin America. National level estimates conceal very wide variations at sub-national level – where environmental impacts actually occur. China, for instance, faces severe water shortages in the north while the south still has abundant water resources. Even a water-abundant country like Brazil faces shortages in some areas.

Regional specialization and increased trade can be beneficial to water availability in one place, while in another it may be detrimental.

Spatial transfer of commodities (instead of water) theoretically provides a partial solution to water scarcity by releasing pressure on scarcely available water resources at the receiver end. The importance of such flows was first evaluated for the case of the Middle East, i.e. the most water-challenged region in the world, with little freshwater and negligible soil water Allen (2003). The livestock sector clearly alleviates this water shortage, via the high virtual water content of the increasing flows of imports of animal products (Chapagain and Hoekstra, 2004; Molden and de Fraiture, 2004). Another strategy for saving local water by using "virtual water" from elsewhere is to import feed for domestic animal production, as in the case of Egypt which imports increasing quantities of maize for feed (Wichelns, 2003). In the future, virtual flows like these are likely to significantly increase the impact of the livestock sector on water resources, considering that a great deal of the rapidly increasing demand for animal products is met by intensive production of monogastrics, relying heavily on the use of water-costly feed.

But the global flows of virtual water also have an environmental downside. They may even lead to harmful environmental dumping if the environmental externalities are not internalized by the distant producer: in water-scarce regions like the Middle East the availability of virtual water from other regions has probably slowed the pace of reforms that could improve local water efficiency.

Multiple and effective options for mitigation exist in the livestock sector that would allow to reverse current water depletion trends. Mitigation options usually rely on three main principles: reduced water use (e.g. improved irrigation efficiency and animal cooling systems), reduced depletion process (e.g. increased water productivity and mitigated pollution from waste management and feedcrop fertilization) and improved replenishment of the water resources through better land management.

Biodiversity erosion

The Millennium Ecosystem Assessment Report (2005) identifies the most important direct drivers of biodiversity loss and ecosystem service changes as:

- habitat change (such as land use changes, physical modification of rivers or water withdrawal from rivers, loss of coral reefs, and damage to sea floors due to trawling);
- climate change;
- invasive alien species;
- overexploitation; and
- pollution.

The livestock sector contributes to all these mechanisms and in particular to habitat change, climate change and pollution. The overall cumulative loss from extensive systems to date is much higher than that induced by the more intensive systems. This legacy is partly explained by the incomparably higher land requirements of extensive systems, and partly by the fact that intensive systems appeared only a few decades ago. It is however estimated that for a number of processes, losses induced by intensive system in the future are increasing rapidly and may well surpass those of the more extensive ones. Some processes are related only to extensive systems (e.g.

desertification), others only to intensive systems (e.g. overfishing). The most dramatic losses in the past have been caused by extensive grazing, in the forms of forest fragmentation/deforestation and alien plant invasions, and by intensive systems, in the form of habitat pollution.

Conversion of forest to pasture continuous to be an important process of biodiversity loss in Latin America, but this situation is rather atypical. At the global level, the land requirements of the livestock sector may soon reach a maximum and then decrease. More marginal land will revert back into (semi) natural habitat, and from there, under some circumstances, it may lead to biodiversity recovery.

International conservation organizations have collected vast amounts of data on the global status of biodiversity over the past decades. Data from organizations like the World Wildlife Fund (WWF), Conservation International and the World Conservation Union (IUCN) contain information on the nature of current threats to biodiversity. These data collections, even though they do not cover the entire range of livestock related processes, provide clear evidence that the livestock sector's role in biodiversity erosion is very substantial.

An analysis for this report of the 825 terrestrial ecoregions identified by WWF shows that 306 of them reported livestock as one of the current threats - even though pollution from livestock is not considered, and important segments of the animal product food chain are ignored. The ecoregions threatened by livestock are found across all biomes and all eight biogeographical realms.

The effect of livestock on biodiversity hotspots may indicate where livestock production is having the greatest impact on biodiversity. Conservation International has identified 35 global hotspots which are characterized both by exceptional levels of plant endemism and by serious levels of habitat loss.[5] Twenty three of the 35 biodiversity hotspots are reported to be affected by livestock production. The reported causes are related to habitat change and associated with the mechanisms of climate change, overexploitation and invasive alien species. Major reported threats are: conversion of natural land to pastures (including deforestation), planting of soybean for animal feed, introduction of exotic fodder plants, use of fire for pasture management, overgrazing, persecution of livestock predators and feral livestock. The role of the livestock sector in aquatic impacts (pollution and overfishing) is not singled out.

An analysis for this report of the IUCN Red List of Threatened Species, the world's most authoritative source of information on extinction risk, indicates that the 10 percent of the world's species which face some degree of threat are suffering habitat loss from livestock production. Livestock production appears to have more impacts on terrestrial than on freshwater and marine species, as the important effects of habitat loss and habitat degradation are most significant on land.

A number of technical options could lessen the impacts of intensive livestock production. Concerning feed cropping and intensive pasture management, integrated agriculture provides a technology response by reducing pesticide and fertilizer losses. Conservation agriculture could restore important soil habitats and reduce degradation. Combining such local improvements with restoration or conservation of an ecological infrastructure at the landscape level and the adoption of good agricultural practices (sanitary measures, proper handling of seed lots avoiding contaminants, etc.) may offer a good way of reconciling the conservation of ecosystem functioning and the expansion of agricultural production. Improvements in extensive livestock production systems can also make a contribution to biodiversity conservation. Successfully tested

[5] The hotspot approach aims to identify the places where the most threatened biodiversity needs to receive the most urgent action. To qualify as a hotspot, a region must meet two strict criteria: it must contain at least 1 500 species of vascular plants (> 0.5 percent of the world's total) as endemics, and it must have lost at least 70 percent of its original habitat.

options exist to restore some of the habitat lost by expansion of badly managed grazing land. In some contexts (e.g. Europe) extensive grazing may provide a tool to maintain a threatened but ecologically valuable level of landscape heterogeneity. Such options are commonly grouped under the denominator "silvopastoral systems".

Differences between species, products and production systems

There are huge differences in environmental impact between the different forms of livestock production, and even the species.

Cattle provide a multitude of products and services, including beef, milk, and traction. In mixed farming systems, cattle are usually well integrated in nutrient flows and can have a positive environmental impact. In developing countries, cattle and buffaloes still provide animal draught for field operations, and in some areas, animal traction is on the increase (parts of sub-Saharan Africa) so that animals substitute for potential fossil fuel use. Livestock also use crop-residues some of which would otherwise be burned, thus making net contributions to environmental objectives. However, cattle in extensive livestock production in developing countries are often only of marginal productivity. As a result, the vast majority of feed is spent on the animal's maintenance, leading to resource inefficiencies and high levels of environmental damage per unit of output.

The dairy sector is much better connected to land than is the case for other forms of market-oriented production. Most milk operations tend to be close to areas of feed supply because of their daily demand for fibrous feed, and so they are predominantly well integrated with nutrient flows, although excessive use of nitrogen fertilizer on dairy farms is one of the main causes of high nitrate levels in surface water in OECD countries. There is a risk of soil and water contamination by large-scale dairy operations, as witnessed by "dairy colonies" in South Asia, and by industrial-type operations in North America and increasingly also in China. Dairy production is also labour-intensive and less subject to economies of scale. Therefore, dairy is the livestock commodity where small-scale or family-based operations can resist market pressures for longer than is the case for poultry or pork.

Beef is produced in a wide range of intensities and scales. At both ends of the intensity spectrum there is considerable environmental damage. On the extensive side, cattle are instrumental in degradation of vast grassland areas and are a contributing factor to deforestation (pasture conversion), and the resulting carbon emissions, biodiversity losses and negative impacts on water flows and quality. On the intensive side, feedlots are often vastly beyond the capacity of surrounding land to absorb nutrients. While in the feedlot stage the conversion of concentrate feed into beef is far less efficient than into poultry or pork, and therefore beef has significantly higher resource requirements per unit than pork or poultry. However, taking the total life cycle into account, including the grazing phase, concentrate feed per kilogram of growth is lower for beef than for non-ruminant systems (CAST, 1999).

The production of sheep and goats is usually extensive. Except for small pockets with feed lots in West Asia and North America, intensive production based on feed concentrate barely exists. The capacity of small ruminants, in particular goats - to grow and reproduce under conditions otherwise unsuitable for any form of agricultural production - makes them useful and very often essential to poor farmers pushed into these environments for lack of alternative livelihoods. Because of their adaptive grazing, sheep and goats have extended their reach further into arid, steep and otherwise marginal territory than cattle. The browsing of goats affects land cover and the potential for forest re-growth. Under overstocked conditions, they are particularly damaging to the environment, through degradation of vegetative cover and soil. However, the low economic value of sheep and goat production means that it does not usually lead directly to mechanized large scale deforestation, as is the case for cattle ranching in Brazil.

Extensive pig production, based on use of household waste and agro-industrial by-products, performs a number of useful environmental functions by turning biomass of no commercial value – and that otherwise would be waste – into high-value animal protein. However, extensive systems are incapable of meeting the surging urban demand in many developing countries, not only in terms of volume but also in sanitary and other quality standards. The ensuing shift towards larger-scale grain-based industrial systems has been associated with geographic concentration, to such extents that land/livestock balances have become very unfavourable, leading to nutrient overload of soils and water pollution. China is a prime example of these trends. Furthermore, most industrial pig production in the tropics and sub-tropics uses waste-flushing systems involving large amounts of water. This becomes the main polluting agent, exacerbating negative environmental impact.

Poultry production has been the species most subject to structural change. In OECD countries production is almost entirely industrial, while in developing countries it is already predominantly industrial. Although industrial poultry production is entirely based on feed grains and other high value feed material, it is the most efficient form of production of food of animal origin (with the exception of some forms of aquaculture), and has the lowest land requirements per unit of output. Poultry manure is of high nutrient content, relatively easy to manage and widely used as fertilizer and sometimes feed. Other than for feedcrop production, the environmental damage, though perhaps locally important, is of a much lower scale than for the other species.

In conclusion, livestock-environment interactions are often diffuse and indirect; and damage occurs at both the high and low end of the intensity spectrum, but is probably highest for beef and lowest for poultry.

COMPARISON WITH OTHER FOOD PRODUCTION SYSTEMS

The world population of 6.0 billion of 2000 is projected to grow to 8.1 billion in 2030 and to 8.9 billion in 2050 (UN, 2005). Despite the drastic fall in the growth rate, the absolute annual increment continues to be large. Practically, all increase will come from developing countries, and in particular from sub-Saharan Africa (by 2050, 18 million of the 26 million added annually to the world population will be in sub-Saharan Africa). In parallel, per capita food consumption is expected to grow from 2 789 kcal/person/day in 2000 to 3 040 in 2030 and 3 130 in 2050. The gains predominantly take place in developing countries where per capita consumption is projected to increase from 2 654 kcal/person/day in 2000 to 2 960 in 2030 and 3 070 in 2050; generally driven by economic growth.

The agricultural sector will have to supply such growing demand in a context of limited natural resources (e.g. land, water, fossil fuel) and often saturated or declining ecosystem services (e.g. natural water depuration, food production from natural ecosystems such as oceans). In addition, there will be increasingly pressure from the civil society to reduce the environmental impacts from agriculture and improve environmental quality.

Against this background, the comparative assessment of environmental costs across food production sectors appears to be of prime importance. The assessment can be conducted at various levels, to support different types of decision making. According to the level of aggregation and the final user of the results, the analyst shall select specific techniques to evaluate and compare environmental impacts.

As demonstrated by other papers in this report, the analysis at sector level (e.g. livestock and fisheries) can be conducted either globally or nationally to support decisions in the area of public investment and national policies for sector development. Potential users of results are the "global community" (e.g. Global Environment Facility, United Nations, donors, international Non-Governmental Organizations) and national policy makers. Suitable techniques are those that can support a high level of aggregation, such as Material Flow Analysis (MFA), Energy Analysis (EA), Human Appropriation of Net Primary Production (HANPP) or Cost Benefit Analysis (CBA). Implementing such analysis would require substantial data collection efforts to capture the variability of production systems and of their environmental impacts.

Analysis at product level (e.g. frozen chicken wings versus smoked salmon) can support consumers' purchasing decisions. The LCA or Ecological Footprint can provide aggregated indicators that are easily understood by the consumer. The issue with such level of analysis is that results are specific to the selected product, varying with origin, production system, processing technique and distribution mode. They therefore may suffer from being rather anecdotic.

Conducting the analysis at sub-sector level (e.g. landless poultry production versus salmon aquaculture) may represent an adequate compromise in terms of data collection and representativity of results, both for the consumer and for policy making. Results from such compared analysis could also provide useful information and incentive to the private sector to identify key areas for the improvement of environmental performance.

The LEAD Initiative experience

Since 1997, the Livestock, Environment and Development (LEAD) Initiative, a multidonor project based at FAO/AGA has assessed these impacts and tested policy options to reduce the sector's environmental impact. LEAD prepared a first global assessment of environmental impacts associated with livestock production in 1998 (De Haan *et al.*, 1998; Steinfeld *et al.*, 1998). The assessment was made using a livestock production classification (grazing; mixed; industrial) adapted from Sere and Steinfeld (1996) as entry point for the analysis. Impacts on the environment were grouped under land, water, air and biodiversity.

The perspective is inverted in the new assessment of livestock and environment interactions prepared by LEAD and that served as a basis for the previous section. The analysis is structured along the main global environment issues: land scarcity, depletion of water resources, climate change and biodiversity erosion. For each issue, the relative contribution of livestock is investigated.

The shift from a livestock system centred approach to a global environment centred approach has a number of advantages. In particular, the latter allows analysing the livestock sector in its context, i.e. as one of the human activities impacting the global environment. The main strength and weaknesses of the two approaches are included in Table 2.

On the basis of these two assessments, LEAD could draw a global picture of environmental impacts associated with livestock production, raise awareness, indicate technical and policy options and identify priority issues and geographical areas for action. The assessments however fell short of expressing the efficiency of the livestock food chain, in terms of natural resource use and emissions per unit of delivered product. These elements are critical to the responsible policy maker and consumer who want to compare the environmental impacts of animal derived foods to other foodstuffs.

Responding to such questions may require using complementary methodologies. Life Cycle Assessment (LCA) may prove useful in this regard. The literature provides only few examples of LCA methodology applied to the livestock sector. These include a national livestock sector analysis in Sweden , the comparison of intensive, extensive and organic grassland farming in Germany (Haas, *Wetterich and Köpke*, 2001), the evaluation of livestock manure management practices (Sandars *et al.*, 2002) and the assessment of Galician milk production (Hospido, Moreira and Feijoo, 2003). These examples tend to show that for well defined products and corresponding food chain, the LCA yield valuable results. However, Cederberg (2002) concludes from her research at national level that considering the complexity of livestock production, the variety of

TABLE 2
Strength and weaknesses of the two approaches used by LEAD to evaluate environmental impacts associated with livestock production

Approach	Strengths	Weaknesses
Approach based on a Farming Systems perspective	– results are well understood by the "livestock community" – direct link between assessment and technical options for improved livestock management, i.e. help to answer questions such as what are the key environmental management issues for each farming system?	– comparison with other food production sectors is nearly impossible – no overall assessment of the role of livestock in global environment issues – only production is considered: no "food chain approach"
Approach based on a Global Environment Issues perspective	– the assessment provides the basis for prioritizing action with regard to the global environment, i.e. to answer questions such as where to start to reduce the contribution of livestock to climate change? – can support a food chain approach – set the bases for comparison with other food production sectors and integrated assessment such as Live Cycle Analysis – results are well understood by the "environment community"	– global perspective, lack of connection with practical livestock management – do not support integrated assessment of all environmental impacts associated with specific products: the analysis is segmented along global environment issues – does not evaluate environmental efficiency with regard to resource use or emissions

production systems and its interaction with all the environment compartments, LCA can not represent as a sole basis for their comprehensive assessment.

There are indeed a number of peculiarities to the livestock sector that tend to cause complexity in assessing its environmental impacts: i) tight connection to the land: extended land use and wide range of land use types, from extensive pastoralism to intensive feedcrop production and industrial land use; ii) large impact on water cycles, in terms of use (feed production), pollution (animal and feed production), and replenishment (pasture management) and iii) wide range of traded products, at various levels of the food chain: fertilizers, feed, live animals, primary products, processed products.

Comparing livestock and aquaculture production; the central role of feed production

We have shown in section 3 that most of the environmental impacts associated with intensive livestock production are associated with feed production, processing and transport. This is particularly true with monogastric production. Animals are however not the sole users of crops, crop wastes and by-products. The food crop, aquaculture and energy sectors are competing users, thus indirectly competing with livestock for land and water resources.

FAO projections suggest that the share of cereals used as feed will remain roughly stable until 2030, driving cereal production growth from 1.9 to 2.8 billion tonnes between 1997/99 and 2030. An increasing share of this feed use will be taken by the aquaculture industry, which is expected to grow at four to six percent per year to 2015, and two to four percent per year over the following 15 years (FAO, 1997). Indeed, with feed conversion ratios[6] better than those for livestock. Aquaculture will become a significant competitor to monogastric species in regions such as South East Asia and Sub-Saharan Africa.

The use of soybean meal as feed grew even more sharply, soaring from ca. 20 million tonnes in the 1970s to over 120 million tonnes in the early 2000s. Part of that increase came from the strong demand for fishmeal from the fast expanding aquaculture sector, which, with a rather inflexible supply of fishmeal, forced the livestock sector to search for other protein substitutes in livestock feed. Aquaculture is more dependent

[6] Fish are cold-blooded, use less energy to perform vital functions and do not require the heavy bone structure and energy to move on land. Fish catabolism and reproduction is also more efficient.

on fishmeal (and fish oil) than terrestrial animals, and the share of fishmeal used by aquaculture grew from 8 percent in 1988 to about 35 percent in 2000 (Delgado *et al.*, 2003) and 45 percent in 2005 (World Bank, 2006) despite efforts to reduce the proportion of such products in the fish feed ration. Another factor is the prohibition of using animal offal in animal feed to reduce the risk of mad-cow disease, which put more pressure on the production of vegetable protein for animal feed.

How livestock and aquaculture will compete for feed resources is uncertain. Products from fish fed on similar feed as livestock (e.g. tilapia) may be increasingly substituted for livestock products. Because of their substantially better feed conversion ratio than livestock (typically 1.6 to 1.8 for tilapia), aquaculture may play the role poultry played in the past, depressing feed demand for cereals. Although possible, a significant shift to fish products would however require both the organization of supply chains and changes in consumers' preference and would thus probably only occur over a long period. The development of comparative environmental analysis would help in designing public policies to ensure that this competition for resources improves the efficiency of their use.

CONCLUSION

The rapid growth of the livestock sector and the technical and structural transformations that go with it shape the environmental impacts of the sector. This paper has shown the substantial impact the sector has on major environmental issues such as land degradation, climate change, water depletion and biodiversity erosion. Most impacts relate to feed production, either in the form of crops or pastures; waste management and enteric fermentation further contributing to water depletion and GHG emissions.

In a context of rapidly growing food demand, we identify a need for the comparative assessment of food production chains and their respective environmental impacts; with sub-sectoral level being identified as a potentially relevant degree of aggregation. Comparative assessments are specially relevant in the case of highly substitutable products or where new food chains are rapidly developing and require public policies to guide food production on a sustainable path.

REFERENCES

Allan, J.A. 2001. Virtual Water – economically invisible and politically silent – a way to solve strategic water problems. *International Water and Irrigation*, 21(4):39–41.

CAST. 1999 *Animal Agriculture and Global Food Supply*. Council for Agricultural Science and Technology, Ames.

Chapagain, A.K. & Hoekstra, A.Y. 2004. *Water footprints of nations.* Volume 1: Main Report. Value of Water Research Report Series No. 16. UNESCO-IHE. p. 76. (Available at http://www.waterfootprint.org).

Cederberg, C. 2002. *Life Cycle Assessment (LCA) of animal production*. Göteborg University, Göteborg.

Costales, A., Gerber, P. & Steinfeld, H. 2006. Underneath the livestock revolution.In A. McLeod (Ed.). *The 2006 Livestock Report* FAO, Rome. pp 15-27.

De Haan, C., Steinfeld, H. & Blackburn, H. 1998. *Livestock and the environment, finding a balance*. European Commission Directorate-General for Development, Food and Agricultural Organization of the United Nations.

Delgado, C., Rosegrant, M., Steinfeld, H., Ehui, S. & Courbois, C. 1999. *Livestock to 2020 The next food revolution*. International Food Policy Research Institute, Food and Agriculture Organisation of the United Nations, International Livestock Research Institute, Washington

Delgado, C., Narrod, C.A. & Tiongco, M.M. 2003. *Policy, technical and environmental determinants and implications of the growing scale of livestock farms in four fast–growing developing countries*. International Food Policy Research Institute Washington, DC.

FAO. 1997. *Review of the state of world aquaculture*.FAO Fisheries Circular, No. 886, Rev.1., Rome.

FAO. 2003. *World agriculture: towards 2015/2030*. FAO, Rome.

FAO. 2006. *FAOSTAT*. World Agriculture Information Centre, FAO, Rome.

Haas, G., Wetterich, F. & Köpke, U. 2001. Comparing intensive, extensified and organic grassland farming in southern Germany by process life cycle assessment. *Agriculture, Ecosystems and Environment*, 83: 43–53.

Hospido, A., Moreira, M.T. & Feijoo, G. 2003. Simplified life cycle assessment of Galician milk production. *International Dairy Journal*, 13: 783–796.

IPCC. 2001. *Climate change 2001: Impacts, adaptation and vulnerability - IPCC Third Assessment Report.* Cambridge University Press.

Krystallis, A. & Arvanitoyannis, I.S. 2006. Investigating the concept of meat quality from the consumers perspective: the case of Greece. *Meat Science*, 72:164–176.

Molden, D. & de Fraiture, C. 2004. *Investing in water for food, ecosystems and livelihoods. Comprehensive Assessment of Water Management in Agriculture*, IMWI, Colombo.

Naylor, R., Steinfeld, H., Falcon, W., Galloway, J., Smil, V., Bradford, E., Alder, J. & Mooney, H. 2005. Losing the links between livestock and land. *Science*, 310: 1621-1622.

Poapongsakorn, N., NaRanong, V. , Delgado, C., Narrod, C., Siriprapanukul, P., Srianant, N., Goolchai, P., Ruangchan, S., Methrsuraruk, S., Jittreekhun, T., Chalermpao, N., Tiongco, M.M. & Suwankiri, B. 2003 *Livestock Industrialization, Trade and Social-Health-Environment Impacts in Developing Countries: Phase II - Annex IV: policy, technical, and environmental determinants and implications of the scaling-up of swine, broiler, layer and milk production in Thailand.* FAO - LEAD, Rome.

Rae, A.N. 1998. The effects of expenditure growth and urbanisation on food consumption in East Asia: a note on animal products. *Agricultural economics* 18: 291-299.

Sandars, D.L., Audsley, E., Cañete, C., Cumby, T.R., Scotford, I.M. & Williams, A.G. 2002. Environmental benefits of livestock manure management practices and technology by life cycle assessment. *Biosystems Engineering*, 84: 267–281.

Sant'Ana de Camargo Barros, B., De Zen, S., Rumenos Piedade Bacchi, M., Galvão de Miranda, S.H., Narrod, C. & Tiongco, M.M. 2003. *Livestock Industrialization Project: Phase II - Annex V - Policy, technical, and environmental determinants and implications of the scaling-up of swine, broiler, layer and milk production in Brazil.* FAO, Rome.

Sere, C. & Steinfeld, H. 1996. *World livestock production systems*. FAO animal production and health paper, FAO, Rome.

Steinfeld, H., De Haan, C. & Blackburn, H. 1998. *Livestock and the environment, issues and options*. European Commission Directorate-General for Development, Food and Agricultural Organization of the United Nations.

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M. & de Haan, C. 2006. *Livestock's long shadow - Environmental issues and options*. FAO Agriculture Technical paper, Rome.

United Nations. 2005. *World Population Prospects, the 2004 Revisions: highlights*. United Nations, New York.

World Bank. 2006. *World development indicators*. Washington, DC.

Zhou, Z.Y., Wu, Y.R. & Tian, W.M. 2003. *Food consumption in rural China: preliminary results from household survey data*. 15th annual conference of the association from Chinese economics studies, Australia.