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Feeding the future

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Producing enough food

We can safely assume two things about the next 40 years: the demand for livestock products will continue to grow, and it will become increasingly challenging to meet that demand. At some point, perhaps as soon as 2050, it is estimated that there will be 9.15 billion people to feed, 1.3 times as many as in 2010 (UN Population Division, 2009). Much of the new population will be urban (UNFPA, 2010). Based on estimates published in 2006, the expanded population is expected to consume almost twice as much animal protein as today. While the projections are for a lower annual rate of growth than occurred during the livestock revolution, doubling supply would still place a considerable burden on already strained natural resources. This, in turn, would drive up the prices of livestock products and threaten food access by the poor.

However, there is a great deal of waste in food systems. Natural resources are not always converted efficiently into meat, milk or eggs, and a great deal of the food currently produced does not reach the plate. Improving efficiency and minimizing waste throughout livestock value chains could go a long way towards meeting increased demand. This chapter reviews the assumptions on which the projected demand for food is based and discusses how accurate they are likely to be. It then examines the three main systems in which livestock source food is produced to identify where efficiency might be improved and waste reduced.

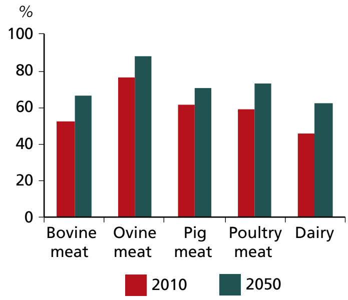
HOW MUCH LIVESTOCK SOURCE FOOD WILL BE NEEDED?

The most complete published projections at the time of writing (FAO, 2006c) suggest that in 2050, 2.3 times as much poultry meat and between 1.4 and 1.8 times as much of other livestock products will be consumed as in 2010 (Table 16). The additional demand beyond that expected from population growth will result from increases in income encouraging a higher consumption per person. The largest growth is expected in developing countries, which are anticipated to overtake developed countries in their total consumption of livestock products. The figures in Table 16 assume that purchas-

TABLE 16
PROJECTED TOTAL CONSUMPTION OF MEAT AND DAIRY PRODUCTS

	2010	2020	2030	2050	2050/2010
	(million tonnes)				
WORLD					
All meat	268.7	319.3	380.8	463.8	173%
Bovine meat	67.3	77.3	88.9	106.3	158%
Ovine meat	13.2	15.7	18.5	23.5	178%
Pig meat	102.3	115.3	129.9	140.7	137%
Poultry meat	85.9	111.0	143.5	193.3	225%
Dairy not butter	657.3	755.4	868.1	1 038.4	158%
DEVELOPING COUNTRIES					
All meat	158.3	200.8	256.1	330.4	209%
Bovine meat	35.1	43.6	54.2	70.2	200%
Ovine meat	10.1	12.5	15.6	20.6	204%
Pig meat	62.8	74.3	88.0	99.2	158%
Poultry meat	50.4	70.4	98.3	140.4	279%
Dairy not butter	296.2	379.2	485.3	640.9	216%

PERCENT OF TOTAL CONSUMPTION IN DEVELOPING COUNTRIES



Source: FAO, 2006c. Some calculations by authors.
Note these figures are based on World Population Prospects: The 2002 Revision.

ing power and eating habits will follow patterns broadly similar to those recorded in recent years. As changes in any of these drivers could change the projections, each of them will be examined in turn, starting with the population estimates.

Population estimates. In 2002, the UN projected a population of 6.83 billion in 2010 and 8.91 billion in 2050 with a peak population of 9.2 billion, possibly in 2075. In 2008, the figures for 2010 to 2050 were revised slightly upwards, as shown in Table 17. However, the growth between 2010 and 2050 is virtually identical in both estimates, at 130 percent and 132 percent respectively. Using the new population estimates, the total demand for livestock products might be expected to increase slightly, but the growth between 2010 and 2050 should be very close to what is shown in Table 16. On the basis of population growth, therefore, it seems reasonable to use the current projections of demand for livestock products. The assumptions related to purchasing power of livestock products will be examined next.

Consumption growth. The projected growth in consumption per person, shown in Table 18, is based on total consumption figures from Table 16 and the 2002 population estimates on which those projections were based. The 2007–08 economic crisis temporarily reduced the growth rate of GDP and therefore the purchasing power for livestock products, but expectations are that the effect will not be prolonged and that average long-term growth will be as expected.

Production costs. Purchasing power is also affected by the price of livestock products, which in turn is affected by the cost of production. The latter could increase if feed and fuel energy become more expensive, water becomes scarcer or livestock value chains are increasingly required to bear the costs of the negative externalities they create. All of these are possible. Crops that can be used as both food and feed are likely to increase in price (Thornton, 2010), since increased yields will depend in part on fossil fuels and scarce minerals. Competition for bioenergy also may drive up prices, although new technol-

TABLE 17
PROJECTED HUMAN POPULATION FROM 2002 AND 2008 ESTIMATES

	2010	2020	2030	2050	GROWTH 2010 TO 2050
			(population billions)		
2002 projections	6.83	7.54	8.13	8.91	130%
2008 projections	6.91	7.67	8.31	9.15	132%

Sources: World Population Prospects 2002 and 2008.

TABLE 18
PROJECTED CONSUMPTION OF LIVESTOCK PRODUCTS PER BILLION PEOPLE BASED ON 2002 POPULATION ESTIMATES

	2010	2020	2030	2050	GROWTH 2010 TO 2050
Human population billions	6.83	7.54	8.13	8.91	
			(Consumption million tonnes per billion people)		
Bovine meat	9.85	10.25	10.93	11.93	121%
Ovine meat	1.94	2.08	2.28	2.64	136%
Pig meat	14.98	15.29	15.98	15.79	105%
Poultry meat	12.58	14.72	17.65	21.69	173%
Dairy	96.24	100.19	106.77	116.55	121%

Sources: FAO, 2006c; World Population Prospects, 2002. Some calculations by authors.

ogy is likely to make it possible to use a wider range of non-food inputs to produce biofuel. Water availability is also a serious consideration, since the proportion of people living in water-stressed regions is expected to rise to 64 percent in 2025 compared to 38 percent in 2002 (Rosegrant *et al.*, 2002) and livestock are a major user of fresh water, currently estimated at 20 percent of green water flow[4] (Deutsch *et al.*, 2010). Livestock production creates externalities through water pollution and emission of greenhouse gases – costs for which it does not currently have to account. Research and pilot projects are exploring the extent to which environmental services provided by livestock, such as soil carbon sequestration through grazing land management (Conant and Paustian, 2002; Conant, 2010; Henderson *et al.*, in press), as well as more efficient recycling practices such as biogas production, could mitigate environmental problems and associated costs.

Combining all of these factors, there is a strong possibility that prices of livestock products will increase. Projections by OECD and FAO suggest that average prices of poultry meat and beef will be higher in real terms during 2010–19 than they were in 1997–2006, with limits in supply, higher feed costs and rising demand all contributing to the effect (OECD-FAO, 2010). Average dairy prices in real terms are expected to be 16–45 percent higher in 2010–19 compared to 1997–2006. If this happens, it could reduce

[4] Green water is the precipitation on land that is stored in the soil or temporarily stays on top of the soil or vegetation. It is the source from which crops draw their water.

accessibility particularly for poor urban dwellers and result in a change in diet for the less well-off, including more vegetable protein and cheaper cuts of meat. The possibilities for improved technology to increase productivity are discussed in the next section.

Price of livestock protein. The relative price of livestock protein and substitute proteins also affects the demand for livestock products. The biggest direct competitor is fish, which is estimated to provide 22 percent of the protein intake in sub-Saharan Africa (FAO, 2006d) and 50 percent or more in some small island developing states and some ten other countries (FAO, 2008c). In the past 20 years, fish consumption per person has remained fairly stable (FAO, 2008c) while consumption of livestock products has grown, but this could change if relative prices change.

With marine stocks dwindling and caught sea fish more expensive, sea and inland aquaculture have become more important. Marine aquaculture production grew from 16.4 to 20.1 billion tonnes between 2002 and 2006, and inland aquaculture from 24 to 31.6 billion tonnes during the same period (FAO, 2008c) with two-thirds of all production in China. Aquaculture is now estimated to be responsible for almost 50 percent of fish consumption and it is set to overtake capture fisheries as a source of food fish (FAO, 2010b).

Some farmed fish are highly efficient feed converters of the same feeds used for livestock (fishmeal, soya and cereals), take little space and, in some cases, do not require fresh water. There are problems associated with intensive rearing such as contamination of the marine environment with algae, over-use of antibiotics, overfishing to provide low-value catch fish as feed, and contamination of fish with toxic chemicals. If these can be solved (Black, 2001; Stokstad, 2004), farmed fish have the potential to take a larger share of protein consumption.

Insects caught in the wild are consumed by over 2 billion people in Latin America, Asia and Oceania (FAO, undated), contributing to food supply and to the livelihoods of those who harvest them. Edible insects have the potential to be "farmed" and recent research suggests that they could be more efficient and produce lower methane emission than livestock (Oonincx *et al.*, 2010).

Meat produced "*in vitro*" (artificially) offers a possible future competitor to meat from animals for those who wish to consume meat sustainably or have concerns about animal welfare. It has the potential advantages of using less water and energy and being more welfare-friendly than rearing animals, but the technology has some way to go before it can produce marketable meat. Current techniques involve growing cultures from stem cells of farm animals into 3-dimensional muscle structures. Stem cells are currently obtained from muscle removed by biopsy and multiplied in culture, although it may in time be possible to maintain an independent stock of stem cells.

It is difficult to bulk up the cells, as each cell only divides a certain number of times (Jones, 2010), and while growth media not containing animal products are available, they are expensive. The resulting meat has poor texture and will need to have fat cells grown together with the muscle to improve its taste as well as added micronutrients before it is viable as a meat substitute. It is also expensive to produce, costing between €3 300 per tonne and €3 500 per tonne (The *In Vitro* Meat Consortium, 2008). However, this is a relatively new technology with relatively little spent on research thus far. Within the next 40 years, it may well become a part of the diet for some consumers.

Consumer lifestyle. Voluntary lifestyle choices, particularly by wealthier consumers, could result in consumption of fewer livestock products, particularly red meat. The newly wealthy have tended to eat more livestock products, particularly red meat and fatty foods, while some of the established wealthy tend to gradually diversify their dietary habits towards different cuisines and sources, "green" products and healthier diets. The current projections take these trends into account to some extent. McMichael *et al.* (2007) suggest that the average global consumption of meat should be approximately 90 g a day, compared with the current 100 g, and that not more than 50 g should come from red meat from ruminants. If this target were achieved, it would lower the peak demand for meat. However, government-sponsored nutritional and healthy-eating programmes have had limited success in changing dietary preference. It may be possible to envisage policies that could reduce over-consumption of meat through taxes and legislation, but it is impossible to imagine any economic incentive or legislative process that would not restrict access by poor consumers, who would benefit nutritionally from consuming animal products of high quality. Therefore any changes to diet are likely to be driven primarily through education, choice and exposure to healthy food. Strategies to bring healthy food within closer reach of everyone in the urban community could be helpful in this regard. In the UK, it is not the government alone but coalitions of the public and private sector that are driving current changes in consumption (Harding, 2010).

Pulling together all of the factors mentioned here, it seems likely that FAO's 2006 consumption projections represent a ceiling. Demographic and economic trends may act to keep livestock consumption at the forecast levels, while production costs and competition particularly from fish are likely to dampen consumption growth for livestock products. For the time being, it seems wise to assume that the demand for meat may grow by as much as 1.7 times and for milk by 1.6 times, as projected, and to consider whether it is feasible to produce that much.

REDUCING WASTE

The growth in production that took place during the livestock revolution was largely a result of an increase in the number of animals. Demand grew so fast that it was difficult for productivity improvements to keep up. Now, it is hard to envisage meeting projected demand by keeping twice as many poultry, 80 percent more small ruminants, 50 percent more cattle and 40 percent more pigs, using the same level of natural resources that they currently use. Part of any increase will need to be driven by efforts to convert more of the existing natural resources into food on the plate. In other words, efficiency needs to increase or, looking from another angle, there is a need to reduce waste of natural resources. In both cases, the end point is the same, but focussing on waste puts a spotlight on what is thrown away and might be recycled.

Waste occurs throughout livestock food systems. It can be due to production inefficiency resulting from disease or poor feeding. It also can result from loss of food between production and the plate, which may amount to as much as 33 percent for all global food production (Stuart, 2009). Food lost at or near the point of consumption, because of food safety and quality requirements, is a problem, but it will not be addressed here because there is little that the livestock sector can do about it. Losses that occur on the farm or in marketing and primary processing of livestock commodities are within the influence of the livestock sector and therefore will receive more attention.

Two issues related to waste reduction can be assessed further.

Choice of livestock system. If a larger percent of the world's livestock protein were produced within grazing and low-intensity mixed systems, would this leave more plant protein to be eaten by humans? According to FAO (2009b), the reality is not that simple. The main problem of food security is not currently one of supply but of demand. The 925 million undernourished people are not undernourished because the global food supply is deficient, but because they cannot afford to buy food or they live in places or societies where it is hard to obtain. Reducing the grain fed to livestock would not ensure that these people could access food. Neither would it automatically result in more plant protein being grown, as it might reduce the prices for those commodities to a level where it would be less attractive to grow them, although the higher number of people to be fed and increasing resource pressure may change this in future. Intensive systems also have economies of scale that make it possible to produce livestock protein in large quantities relatively cheaply, an important consideration for growing urban populations. The less intensive systems are an excellent option to supply food to rural populations with access to short food chains, or to consumers who can afford to buy "green" products, but they are less practical for the majority of city populations.

Livestock and waste recycling. Livestock have a role as recyclers of waste. Mixed farming systems are known to be particularly good at this, but even intensive production systems use by-products. For example, distiller's dried grains with solubles (DDGSs), a by-product of biofuel production, can substitute for grain in animal feed, particularly dairy and beef. In doing so, it contributes to the food balance and helps improve the economic viability of biofuel production. Intensive livestock also can use other industrial by-products, including some from the food industry, provided they are processed appropriately.

Inefficiencies and waste arise in different ways and locations in the three food systems discussed in earlier chapters. We therefore return to the three food security situations – livestock-dependent societies, small-scale mixed farmers, and city dwellers – with their associated livestock production and marketing chains, to examine critical areas of inefficiency for each situation and to suggest where the emphasis might lie in addressing the inefficiencies.

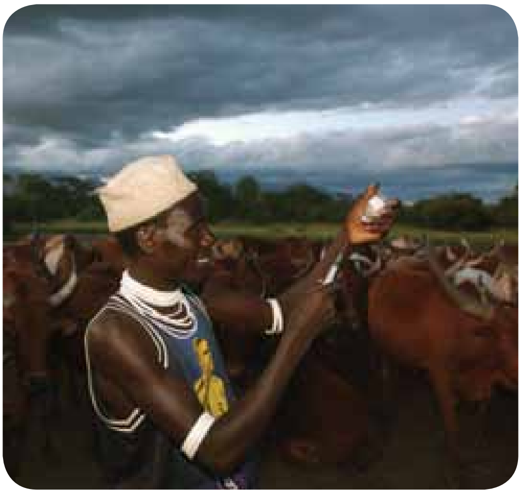
LIVESTOCK-DEPENDENT SOCIETIES

The pastoralist and ranching systems associated with livestock dependent societies are well adapted to their environments and quite efficient at using the forage they are able to access. Survival of animals is as much a yardstick of efficiency as production per animal, and traditional systems as well as ranching adopt forage management and conservation systems that will take animals through severe winters and dry seasons. In the future, the environmental restrictions on these systems are likely to persist or even worsen. Thornton and Gerber (2010) identify droughts, floods, temperature stress and reduced water availability as serious problems for grazing systems – events that are difficult to predict and even more difficult to mitigate. The following identifies areas that have possibilities for improvement.

Pasture management. Pasture restoration or, even better, good management that keeps pastures from being degraded in the first place and avoids the waste and high cost of restoration, offer the possibility of sequestering carbon and mitigating greenhouse gas emissions (Thornton and Herrero, 2010; Conant, 2010). Unfortunately, pasture degradation seems hard to prevent, particularly in pastoralist areas where institutions for resource management are weak. In addition to well known problems associated with loss of land to agriculture and decisions by herders to overstock, the impacts of climate change are adding extra disruption.

Animal health. Disease is an enormous source of inefficiency and waste. Diseases such as *peste des petits ruminants*, contagious bovine and caprine pleuropneumonia, swine fevers and some tick borne-diseases can kill animals that have been reared for months or years before they are fully productive, while internal parasites, tick damage, foot-and-mouth disease and abortions caused by brucellosis can reduce their ability to grow or produce milk. Zoonotic diseases which are passed from animals to people, such as brucellosis and tuberculosis, reduce the ability of people to benefit from their food.

Reaching livestock-dependent societies with well organized vaccination campaigns and essential drugs is critical to prevent production waste. This is logistically possible but institutionally challenging with problems in both supply and



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demand. During the Pan African Rinderpest Campaign, thousands of cattle were vaccinated annually, even in the most remote areas. This had a parallel benefit for sheep and goat owners whose animals could be vaccinated against other diseases at the same time but, when donor funds were withdrawn, the service stopped. Even when a supply chain for drugs and vaccines goes to every small town, providing ready access for livestock owners, many choose not to vaccinate their animals routinely, particularly the small animals of lower value. There is also limited quality control over drugs and vaccines that are sold in remote areas (Ngutua *et al.*, undated; Leyland and Akwabai, undated), and many local sales merchants do not have suitable cold storage to keep the products in good condition.

Governments often perceive that the cost of maintaining an animal health service in remote areas is too high. Ranchers pay for private veterinary services but these services are often completely absent for pastoralists. If global demand for livestock food outstripped supply and the value of products coming from livestock-dependent societies increased, there could be a strong incentive to invest in animal health to prevent waste. Alternatively, investment in cost-sharing systems, where farmers and the government each contribute, could prove viable in some places (Mission East, 2010). Para-professional veterinary services of various kinds have been tried and have been partly successful, but will need to be more sustainably supported in a variety of forms to have a long-term impact on reducing the waste caused by animal health problems.

Transportation infrastructure. Losses occur in marketing because of the long distances that animals and products must be transported. Poor roads and often the need to pass through conflict areas make it hard to provide reliable transportation. Animals travelling in poorly designed lorries without adequate water lose weight, suffer dehydration and bruising, and may die. Milk is in danger of spoilage unless local coolers and refrigerated trucks are available. If prices are low or transport unavailable, any excess milk that cannot be consumed by calves or people will be wasted. There are technical solutions to these problems when a demand exists for the product. Milk coolers and alternative forms of preservation such as lactoperoxidase have been provided in remote places in Africa (FAO, 2005), rest stops have been built where animals can be given water, and lorries are available that improve animal welfare during transport. The challenge, as always, is to find funds to invest in the necessary infrastructure and technology.

Markets. From a food security perspective, an emphasis on markets is critical for livestock-dependent societies. Ranchers and governments in developed countries are very well aware of this. In pastoralist systems, innovative approaches to improving access to markets for live animals and livestock products are essential and so are programmes to pay for environmental services. Together, these can be an incentive to reduce production and transport losses, and provide livestock-dependent communities with the means to co-finance animal health, pasture management and better transport facilities.

SMALL-SCALE MIXED FARMERS

Small-scale mixed farmers are efficient at using and recycling natural resources. Their animals eat crop residues, kitchen scraps, snails and insects. They grow forage at the edge of crop fields or around houses, or cut and carry it from communal grazing areas, forests or the side of the road. Mixed farming is probably the most environmentally benign agricultural production system and it has a great deal to contribute to minimizing waste, especially with all of the opportunities it offers for nutrient recycling (LEAD, undated). Given the number of small-scale mixed farms, if most of them increased their efficiency by even a small amount, it would be beneficial for the global food supply and food security. However, there are currently three major sources of waste that need to be addressed.

Poor animal health. Animals on small-scale mixed farms have a high prevalence of "production" diseases such as external and internal parasites (Mukhebi, 1996; Over *et al.*, 1992) and mastitis (TECA, undated; Byarugaba *et al.*, 2008) that rarely cause death but always reduce performance (Tisdell *et al.*, 1999), as well as zoonotic diseases such as brucellosis and TB that cause human illness and production losses. These can generally be controlled if farmers invest in basic prevention measures. Understandably, they tend to do this more for higher value animals such as dairy cows. Farmer cooperatives have proved valuable for small-scale dairy farmers to obtain animal health inputs, as have projects that give or loan animals to these farmers but require them to provide certain standards of housing and care.

Poor feeding. Poor feeding is problematic on its own, but even more so when combined with animal health problems. When traditional livestock breeds are reared in research stations, fed a balanced diet and provided with health care, they perform credibly compared to exotic breeds (Mhlanga *et al.*, 1999) and can out-perform those on mixed farms. Although a great deal of research has been done over the years on feeding animals in mixed farming systems, and some crop-breeding programmes have improved the quality of stover (stems), the problem of feed shortage still persists. Recent work with small-scale dairy farmers in Ethiopia found that they prioritized lack of feed over disease problems (K. De Balogh, FAO, pers. comm., based on unpublished research). Since one of the major constraints for intensification of small-scale livestock production is the lack of good quality feed resources, it will be worth persisting with research into ways to improve use of locally available feed resources, especially those not competing with human food. There may be long-term potential to breed for improved ability to digest cellulose (National Research Council, 2009). In Anand, India, through the efforts of the National Dairy Development Board (NDDB), milk production has been increased sustainably by feeding diets containing cereal straws, roughages and oilseed cakes. In Africa, 427 million tonnes of cereal residues (based on FAOSTAT grain data and average ratios of grain to residues) and 9.2 million tonnes of oilseed cake are available annually (FAOSTAT), but there is a logistical challenge to making it accessible. Exports of oilseed cake can be a strong competitor to domestic uses, but oilseed cake is produced in plants processing the primary products where it is not always easily accessible to small-scale farmers.

Post-harvest losses. A third source of loss is post-harvest spoilage of products. Stuart (2009) suggests that more of the loss occurs at the retail end of the chain in developed countries, while in developing countries more is lost on-farm. Spoilage on the farm is a particular concern for dairy farmers, and a great deal of effort has gone into finding small-scale technology for preserving milk (FAO, 2005). Meanwhile, Indian dairy farmers in several states benefit from daily or twice daily collection of their milk.

As previously discussed, marketing their products is a common constraint for small-scale mixed farmers. While for livestock-dependent societies, the challenge is mainly one of distance to markets, small-scale mixed farmers face problems of barriers posed by food safety and quality demands and of a concentrated market chain that makes it difficult for them to compete. The importance of this in the context of waste is that without a market outlet, farmers have little incentive to experiment with new technology that will make them more efficient. Food quality and safety regulations can contribute to minimizing losses further along the chain, by reducing waste at slaughterhouses and retail points. Supporting small-scale mixed farmers in improving their quality standards and biosecurity, while at the same time continuing to recycle waste efficiently, would be a very positive contribution to food security for the future. Not every small farmer will be able to benefit but for some, traditional products certified as safe or from a valued production system have the potential to command a higher price and attract investment into marketing.

FEEDING CITIES FROM LARGE-SCALE INTENSIVE PRODUCTION

Much of the future demand for livestock products, particularly for urban populations, will have to be met by integrated value chains served by intensive medium- and large-scale production units with the potential to increase production per animal, per unit of land and per unit of time. These food systems are economically competitive but can be highly wasteful of natural resources. However, they do have the potential to improve.

A large part of the loss is at the retail end of the value chain, to meet the demands placed on supermarkets and fast-food retailers for quality and freshness (Stuart, 2009). Feeding waste food to animals is severely restricted in developed countries because of concerns about the safety and variable quality of the waste (Kawashima, 2002). While livestock source food is not safe to feed to animals unless very thoroughly processed, because of the risk of disease spread, there are other examples of animals being used to recycle other kinds of organic waste. One scheme recycled 30 000 tonnes of waste a year from the USA city of Philadelphia through pigs owned by a cooperative in New Jersey. This was an estimated 8 to 10 percent of Philadelphia's municipal waste (Maykuth, 1998).

Food safety crises are frequent causes of waste in developed country food chains, examples being the 2009 withdrawal of ground beef from California markets because of e-coli contamination, the 2010 contamination of milk products by melamine in China and the 2011 contamination of eggs by dioxin in eggs in Germany. There is constant upgrading of safety management throughout food chains but since consumers and retailers pursue a near-zero risk policy, this kind of waste will always exist to some extent.

Moving further down the chain, there is waste during slaughter and processing. Some of this is due to parts of the animal or whole carcases being condemned or downgraded for health reasons or bruising (Martinez *et al.*, 2007; Tiong and Bing, 1989). Investment in animal health and welfare can prevent some of these losses.

At the farm, greater use of the agro-industrial by-products that make up part of animal feed could reduce the amount of human-edible food fed to livestock. Intensive livestock in the emerging economies make quite effective use of agro-industrial by-products. For example, in India's poultry industry, feed manufacturers include waste from the food industry, the gum and starch industry, fruit and vegetable processing and the alcohol industry in poultry feed (Balakrishnan, 2002). This forms quite a large proportion of India's feed input (H. Steinfeld, pers. comm. based on recent unpublished analysis), while the Malaysian ruminant industry uses crop residues and food industry by-products in ruminant feeds. However, there are very strict restrictions on the use of the livestock industry's own by-products. For example, meat and bone meal is forbidden to be used in animal feed because of its potential to spread BSE. In the UK, approximately 60 000 tonnes annually of ash from incineration of meat and bone meal is sent to landfill (Environment Agency, UK, undated).

Feeding and health systems are also important to exploit the genetic potential for feed conversion. Therefore another way to limit waste is to ensure that all farmers move closer to the standards set by the most productive. Ruminant systems still have some potential to increase their productivity through breeding (Thornton, 2010), particularly if the balance of grain to roughage can be reduced. Some would argue that feedlot cattle are fed too much grain for their own health or for optimum productivity. Animal welfare standards, which are becoming more demanding in developed countries, may increasingly influence the limits on feed conversion and other productivity improvements. For example, there will be no battery production of eggs in the EU after 2015, and the use of bovine somatotrophin has been banned there for several years.

It is possible to recycle livestock waste through large-scale anaerobic digesters that turn solid food waste into biogas, or large-scale composters to turn food waste into compost that can then be used as farm fertilizer (Harvey, 2010). China has emphasized biogas production and some European countries are placing emphasis on using biogas technology (Kaiser, undated).

In addition to feed conversion, indicators that measure the environmental impact of production are also important, because this affects the quality of natural resources on which production depends. Manure from pig and dairy enterprises contributes to greenhouse gas emissions through the handling and storage of slurry (Henderson *et al.*, in press), but this can be processed through biogas units. Manure from grazing livestock creates N_2O emissions when it is broken down by microbes (Steinfeld *et al.*, 2006). Beef is the most emission-intensive meat while chicken is the least (Fiala, 2008). Improved productivity, on the whole, reduces emissions per unit of meat produced.

There is quite a strong potential to reduce waste throughout the food systems that supply livestock source food to cities. At each point on the chain, technology is either available or being investigated that could be helpful in this regard. In both developed and emerging economies, the private sector is making quite substantial

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investments in technology that reduces waste and saves costs. The role of the public sector is to provide an environment in which there is an incentive to minimize waste throughout the market.

However, this does require a balancing act among welfare (which may indicate less intensive farming), productivity (more intensive farming), emission reduction (less beef) and safety (certified biosecure farming and no recycling of animal products through livestock). Middle class consumers have not yet begun to take an interest in waste from livestock systems. Once they do, it may lead to a small overall reduction in the demand for animal products, and a small shift in demand towards food products with waste-saving credentials.

This chapter has thrown up several challenges for the livestock sector, and some possible directions, such as efforts to minimize waste and increase efficiency, that will contribute to assuring livestock's role in food security for the future. The next chapter looks at possible directions for building resilience into a sector that is experiencing the growing pains of increased demand in a globalizing world that brings with it new threats of disease and external economic shocks as well as those caused by more extreme weather events linked to climate change.

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Building resilience

The livestock revolution was characterized by rapid increases in production, driven by rising livestock populations and income on the demand side and cheap feed and fuel on the supply side. Today, demand continues to grow in spite of economic shocks, but supply conditions have changed – a scenario that has profound implications for the way the livestock sector will develop and the role it will play in food security in the future. As the previous chapter discussed, the pressures on natural resources may force the price of livestock source foods to rise, making them less accessible to the poor, but it also proposed that improving efficiency and reducing waste in livestock production will make important contributions to ensuring the supply and accessibility of livestock source food.

Today's livestock sector must be prepared to respond with a shift in focus and investment towards building greater resilience into food systems, meaning an increased ability to deal with change and recover from shocks. There is increasing concern about the instability of food supply and access in what are termed "protracted crises" (FAO, 2010a). This chapter therefore reviews some of the factors that may create vulnerability in livestock food systems and looks at ways in which they can be mitigated.

Livestock have a certain inherent resilience as ruminants and camelids can withstand a wide range of temperature and moisture conditions while poultry and pigs are less adaptable to heat and cold but can easily be housed. Notwithstanding the adaptability of animals, however, livestock food systems face hazards from several sources. Climate change is creating new shocks and trends; boths are certain but hard to predict and have potential to make the production environment uncertain in ways similar to El Niño events. It also will probably create future hotspots, with higher temperatures and lower rainfall which will affect water availability and average temperatures, both critical to crop production.

The following section looks at three potential hazards the livestock sector faces: water shortages, spread of persistent or emergence of new diseases including those transmissible to humans, and market volatility, particularly for producers trying to import feed or export food, and for food-importing countries and cities.

WATER SHORTAGE

With an increasingly large population living under conditions of water stress (Rosegrant *et al.*, 2002), agricultural systems will need to develop more built-in resilience particularly related to water use, and some crops may need to be relocated or different ones grown. Irrigated crops occupied around 20 percent of the arable area in 2002, an increase from 16 percent in 1980, but there were large regional differences.

In sub-Saharan Africa, only 4 percent of arable land was irrigated in 2002 compared with 42 percent in South Asia (FAO, 2008b). In the future, irrigated cropland may need to expand if larger areas become water stressed, but this irrigated agriculture will only be viable if it is highly efficient and more proficient at using water and preventing pollution from runoff than much of today's production. Steinfeld *et al.* (2010) identified a number of policy instruments which reflect scarcity, such as water pricing, pollution taxes and state recovery of the maintenance costs of irrigation systems. The success of some water-scarce places, such as Israel, shows how much can be done by careful use of water and recycling water resources.

Livestock systems are affected by water and temperature ranges but, in addition to direct changes in response to climate change, they can be expected to undergo second order changes that follow the shifts in agriculture.

- Grazing systems. The location of grazing and browsing livestock has always been determined in relation to crops, with livestock taking the land that is too wet, dry, mountainous, distant or stony for cultivation.
- Intensive systems. Animals on feedlots tend to be located near the source of crops or agro-industrial by-products. Intensive pigs and poultry have more flexibility and, since their feed is brought to them, they provide high returns on each unit of land and can be located quite close to urban areas. They also have the potential to relocate to areas that are marginal for crops, perhaps to the fringes of deserts where solar powered air-conditioning and pumps for waste may provide a solution to rising energy costs. However "landless" livestock (those that are housed and take up little physical space) are major users of water through their feed, which means the efficiencies in crop water use will factor into livestock systems.

Although the livestock sector is in some sense a secondary responder to water shortage problems – due to its responding to changes in cropping systems – it can also take positive actions to deal with pressures on water stress. In livestock-dependent societies, pasture improvement can help livestock keepers adapt to climate change, and changes in land tenure may also be necessary to provide pastoralists the incentive to make necessary investments (Steinfeld *et al.*, 2010).

Cropland for food crops is already becoming squeezed by growing civil and industrial infrastructure, biofuel needs and nature conservation. If it must also be farmed differently to conserve water, there may be even less left for livestock. More than ever, animals will need to fit into the gaps left by cropping, using residues and roughage, wasting as little as possible of scarce inputs and having the flexibility to cope with fluctuations in crop yields. It may be necessary to rediscover crops suitable for small-scale mixed farming systems so that more of their by-products are available for livestock. Interactions between livestock and crops, lost when systems scaled up and intensified, may need to be revisited, not simply by returning to the past but by thinking innovatively about what is possible with the systems of the future. All of this is a far cry from the early days of the livestock revolution when feed appeared to be in limitless supply.

HUMAN AND ANIMAL HEALTH THREATS

Sudden disease shocks are problematic for food supplies. Persistent diseases such as internal and external parasites or mastitis create vulnerability by eroding the production and income base of livestock keepers. Certain animal and human diseases are likely to expand their range as a result of climate change, especially when they or their vectors (insects, mites and ticks) depend on warm annual temperatures and humidity. In new ecological niches, they will undoubtedly find new hosts to infect. Concern for new threats to human health is setting the direction for the major animal and public health initiatives of the international community, translating into various efforts in support of "One Health" and related initiatives (FAO/OIE/WHO/UNSIC/UNICEF/World Bank, 2008; Public Health of Canada, 2009; CDC, 2010).

To mitigate the risk of diseases, the focus of the animal health system will need to change. Currently, the attention of animal health professionals and finance systems is focussed on preventing the *transmission* of diseases when outbreaks occur, and the *prevention* of disease through import restrictions, quarantine and screening, biosecurity measures, and damping down the impact and spread of diseases using vaccination when it is available. Intervention measures to break transmission and prevention are important, but for the food systems of the future it will not be enough to focus only on them. Neither confronts the *root causes of disease emergence* and, as a result, veterinary and public health systems are constantly running to catch up with diseases that represent a threat to the stability of food supplies and to human health.

To build sustainability and resilience, more attention is needed to the drivers of disease. These fall into three areas, described in Box 9, each of which relates to a different kind of disease threat, creates a different kind of impact and therefore requires a different kind of response.

Building animal health and veterinary public health systems from knowledge of the drivers will make it possible for them to be more proactive in supporting food production. Food security is an important concern to the international animal health community but arguably a secondary one to the concern of dealing with disease. However, well managed disease control initiatives can minimize the market shocks caused by livestock diseases or their control. This is translating into research on drivers of disease, with more detailed contingency planning and business response planning in developed countries, and increased investment in response capacity and biosecurity in developing countries. If successful these various initiatives would improve the stability of food supplies, but there are still major institutional and investment gaps to be filled (Perry and Sones, 2008; McLeod and Honhold, 2010).

VOLATILE MARKETS FOR FEED AND LIVESTOCK PRODUCTS

Farmers no longer can rely on cheap feed. Prices have risen since the height of the livestock revolution and, equally important, they are unpredictable (Von Braun, 2008; Walker, 2010; BFREPA, 2010; *Beef Magazine*, 2008). The cost of fuel, competition from human food, biofuel and aquaculture, and climate shocks all contribute to these effects.

Market volatility for livestock products can occur because of disease shocks, other natural disasters, natural price cycles and economic shocks that reduce consumption. Longer term market changes occur when changes are made to production systems to improve biosecurity, which often result in smallholders being excluded. As discussed in earlier chapters, small-scale producers and pastoralists at the end of long market chains are particularly vulnerable as they have very little control over the market. Some efforts can be made to connect them to more lucrative markets (e.g. contract farming, cooperative action, niche markets) and to exclude them from some of the shock effects (e.g. commodity trading rather than disease free zones), but they remain vulnerable to competition from larger players. Large producers and companies are also vulnerable because of the size of the asset invested but big companies have some potential to diversify into feed, drugs, more than one species of livestock, or processed as well as fresh

BOX 9

DRIVERS OF DISEASE AND POSSIBLE RESPONSES

Land use. Big changes in the patterns of land use have been driven by climate change, urbanization and global movements of people in response to opportunities or crises. This allows disease agents to move to new geographic areas with similar ecosystems, adapt and survive. Disease agents on the move cause food instability when they initially infect naive animal populations. When a disease problem is caused by land-use changes and human demographic factors, it may not be possible to prevent its moving into a new environment, but early knowledge of a new problem makes it possible to take steps to protect animals by promoting vaccination or biosecurity measures.

Scaling up and intensification. Growing demand for livestock products has meant scaling up and intensification of livestock production and marketing systems. Intensive livestock farms and traditional, extensive holdings in proximity pose risks to each other since diseases emerge, spread and are controlled differently in each type of system. A disease agent may move from a dispersed population of wild animals or extensively kept livestock, into an intensive system, where the possibilities of spread are many times greater. In addition, if the newly susceptible animals are from a single genotype, the invading agent can move through the population quickly. It finds opportunities to transmit in order to promote its own survival, and continues to adapt in response to ineffective control strategies imposed by humans such as misuse of antibiotics.

A large intensive unit infected with a disease agent has the potential, if the disease escapes, to infect many other farms as disease is transmitted through the air, on vehicles and clothes and through market chains. Occasionally, a change to an existing intensively managed system creates the conditions for a disease agent to become more widespread in animals and pass to humans. When the driver of disease is the production and marketing system rather than the natural environment or climate change, prevention requires proactive changes to livestock systems.

Habitat change. The interface between wildlife, humans and livestock is changing, as humans encroach on wildlife habitat, or habitat becomes degraded forcing wild animals to range further in search of food and water, or wildlife are used as food. As the contact between humans and wildlife becomes closer, it provides the opportunity for viruses such as SARS and avian influenza or influenza to jump species and, in some cases, become a new strain, gaining or decreasing in virulence as they spread within the new host niche. Direct impacts manifest as human sickness and death, but there also can be enormous indirect effects from efforts taken to contain the diseases. For example, measures that prevent the movement of animals, people or goods are hugely disruptive to global food chains and, in extreme cases, can have a short but significant impact on business, incomes and GDP. Health threats of this kind require excellent disease intelligence, timely reporting and the ability to mount a very rapid response should an outbreak begin.

products. Good business strategy is the key to survival. Urban populations are very vulnerable to instability in market chains.

The approach that China has taken to making its mega-cities reasonably food self-sufficient through zoning and subsidies may be one way to reduce vulnerability. Another is to limit monopolies and reliance on a few concentrated supply chains and, instead, to spread the sources of food so that many nations and regions supply many others.

Increased ethical concerns such as mitigating environmental damage and animal welfare requirements are beginning to affect livestock food supply. Currently the greatest effort in both of these areas is being undertaken in developed countries, particularly the EU (EUROPA, undated).

On the environment side, Brazil has invested in poultry production units with neutral impact on carbon emissions. It also recently moved to ban production of sugarcane in the Amazon area (BBC, 2009) and large supermarket chains and cattle companies have agreed to stop sourcing cattle from illegally cleared land (*Meat Trade*, 2009). China and some European countries have invested in biogas plants, as discussed earlier.

On the welfare side, the World Organisation for Animal Health (OIE) has introduced seven animal welfare standards for terrestrial animals covering transport, slaughter and culling (OIE, undated) and has a working group on animal welfare. Developing country governments have made limited investment in animal welfare initiatives, but there have been a number of special interest group initiatives.

If "green" initiatives gain wider traction, they will introduce new requirements into intensive production that may make it more expensive in the short term but should improve long-term sustainability.

BUILDING SUSTAINABLE SYSTEMS

If the changes outlined above were unidirectional and reasonably predictable, then it would be possible to adjust through changes in technology and management systems. But this is unlikely. We can expect climate events to become more frequent and more severe, with all of the related effects on health and markets. This variability hits smallholders and livestock dependent communities worse than intensive producers because their resources are already stretched, which limits their potential to withstand prolonged crises or adapt to new situations. Shoring up fragile societies indefinitely with emergency aid is not an option nor is leaving them to starve. Those who continue to live in marginal areas will need support in planning for their own future livestock production and sustaining their families and local communities. For growing urban populations, larger and more intensive systems better adapted to shocks are likely to be the main source of livestock protein for the future.

Animal health strategies carry useful lessons for food security. They do not assume that it is possible to predict and prepare for every change in conditions. However, well organized animal health systems have plans and resources in place to respond to surprises. An important consideration for food security is building in a sufficient margin for error. If a system is set up to use 100 percent of the available resources and produce at a high level in a "normal" year when things go well, then in a shock year, it will be badly hit and there will be a big drop in production. If this happens only once, the system will adjust, but if shocks happen often, there will be no reserve to draw on and eventually the system will be unable to recover. We can see this, for example, if rangelands are too heavily stocked to accommodate droughts and snowstorms and, at the same time, there is no built-in destocking process to allow the pasture to recover. The same is true for smallholder systems where the loss of crops or animals over several seasons leaves families with no safety net on which to draw.

Building preparedness into food systems requires changing the approach to risk analysis. This means planning production with wider margins of error and greater attention to what might happen if things fail, or emphasizing sustainable rather than short-term productivity to accommodate the possibility of failures or reduced levels of production over more than one production cycle. Rather than attempting to bring all to the highest level of productivity, a sustainable goal for mixed farming in particular might call for bringing lower performers up towards the middle. Some "slack" is needed in food systems to maintain stable food supplies in spite of extreme weather events and other supply disruptions. There may be benefits from intensification with limited concentration of production units, in order to reduce disease risk and environmental pollution, although this may be unpopular because of the infrastructure costs involved.

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Conclusions

Livestock are important to the food security of millions of people today and, as shown in this review, will be important to the food security of millions more in the coming decades. Livestock source food is not essential to human nutrition but it is highly beneficial. In livestock systems that primarily consume roughage and agro-industrial waste products, livestock add to the food supply beyond what can be provided by crops. Moreover, they make a very important contribution to food access and stability through the income and products they provide to small-scale mixed farmers and pastoralists, the asset value of animals and their flexibility of use. The role that livestock play in feeding the future will be shaped by three distinct human populations, each with its own particular needs, namely: urban dwellers, small-scale mixed farmers and livestock-dependent populations.

URBAN CONSUMERS

The largest and fastest growing population lives in towns and cities, and its demand for reasonably priced meat, milk and eggs has been a strong inducement to intensify livestock food systems so that economies of scale can be realized and market chains managed efficiently. If current projections prove accurate, the largest growth in human population will remain in large urban centres, and the city populations will have even greater influence on the nature of demand for livestock products – the amount and type of livestock source food that is consumed, the way that farms and rangelands are managed, the distance products travel and the prices that farmers are paid.

Through its purchasing habits, this population has steadfastly supported global value chains for livestock and livestock products and, in turn, has benefited from intensive livestock production systems. Yet these are the same systems that currently cause great concern because of their emissions of greenhouse gases, pollution of water systems and competition for cereals. At the same time, small pockets of the urban population have driven "green" consumerism for livestock products through strongly voiced animal welfare and environmental concerns. Yet, as it stands, there are no technically or economically viable alternatives to intensive production for providing the bulk of the livestock food supply for growing cities. The future challenge is to factor environmental protection and system resilience into intensive livestock production.

Environmental challenge. An urgent challenge is to make intensive production more environmentally benign. Based on existing knowledge and technology, there are three ways to do this: reduce the level of pollution generated from greenhouse gases and manure; reduce the input of water and grain needed for each output of livestock protein; and recycle agro-industrial waste through livestock populations. All of these require capital investment and a supporting policy and regulatory environment.

Resilience challenge. Meeting the challenge of planning for food system resilience in a population that cannot feed itself requires a solid and stable production base for livestock source food. Higher food prices have encouraged investment in food production. This is potentially beneficial for urban food supply since it provides some scope to adapt and change, one of the conditions for resilience. Livestock diseases also must be dealt with, since intensive systems, and those that encroach upon forest environments or peri-urban areas without proper hygiene, are a fertile ground for new diseases, and many of them are managed in ways that are detrimental to animal health and welfare. It is not enough to pour funding into coping with the urgent disease threats of today – disease intelligence and epidemiological research must be financed to anticipate future diseases in the countries that produce the bulk of livestock source food.

Robust international trade systems also are essential to the resilience of food systems. City populations depend on trade for their food supply, and the production base can be hundreds of miles away. Governments have a vital role in securing and stabilizing trade agreements and promoting a sufficiently wide network of sources to act as a buffer against natural disasters and other shocks. Even where the foodshed for livestock products is wrapped closely around the urban population, as with Chinese megacities, the feed supplying the animal may be imported. There has been discussion recently (Von Braun and Torero, 2009) about the advisability of replenishing or re-establishing buffer stocks for food staples. Given the periodic instabilities in world supplies, this may be helpful. However, it is equally important for governments to look beyond their immediate national food self-sufficiency needs to the stability of the world supply.

PRODUCER–CONSUMERS

Mixed farmers and livestock-dependent populations, as producer-consumers, have different concerns from city populations. As suppliers of food to their own communities and contributors to the world food supply, they should benefit from investment in food systems and elevated prices. As excellent users of roughage and recyclers of waste, they make an important contribution to the food supply. However, they have a very limited ability to compete with large-scale intensive production.

Within small-scale and extensive systems, livestock make an important contribution to preserving food security, but people depending on these systems have very limited prospects to increase their income or expand their assets. This is evident from a rich-poor division that can be seen, for example, in the Horn of Africa, where some pastoralists have been forced to become contract herders because of economic circumstances (Aklilu and Catley, 2009) and in Mongolia where some herders with non-viable herd sizes have moved into cities.

Once this gap forms, it is extremely difficult to bridge. It is also evident from the numbers of small-scale producers who leave livestock production when competition pushes them out or when more secure off-farm opportunities beckon.

From a food security perspective, much of what can be said is already well known. Perhaps the most important argument to be made here is to stress the importance of rigorously applying a twin-track approach – dealing with short-term and long-term food insecurity issues in parallel.

Short-term response. The guiding principle for dealing with short-term shocks is to focus on protection of livestock assets. Households and communities able to maintain their assets during a crisis will be able to rebuild more easily when the shock is over. This might involve providing feed as well as food aid during a natural disaster, having a food security contingency plan as well as a disease-control contingency plan for dealing with major disease outbreaks, or using targeted culling during a disease outbreak to minimize asset destruction and the erosion of stocks of indigenous animals.

Long-term resilience. Dealing with long-term resilience for livestock-dependent populations and mixed farmers is a more difficult prospect than dealing with short-term shocks. These people undoubtedly benefit from the capital provided by their livestock. To grow economically, however, they need an institutional, policy and research environment that proactively supports them – as demonstrated by comparing the growth of cooperatives of small-scale producers in the Indian dairy subsector with the scaling-up of dairying in Brazil. Support in establishing access to the markets that offer longer term viability for smallholders, developing technology focussed on efficient use of roughage and by-products, and supporting land tenure and credit, particularly for women, can all help increase production from these systems and, thus, food access for those involved. Policies to promote the use of livestock for other economically valuable tasks, such as environmental services, also can improve the food security of their owners. However, in the end, there are no "magic bullets", and people may benefit most when livestock production is supported with parallel support in developing other livelihoods opportunities.

There are, therefore, two challenges with respect to livestock-dependent and small-scale mixed farmers. One is to make objective assessments of their contributions, based on social, economic and environmental factors, and to offer proactive support in activities, locations and economies where their contribution is greatest. There are examples of good practice from the field on which to build, although many of them are on a small scale. The other challenge is to manage the transition of those for whom livestock production is not a viable long-term prospect, by offering support and training to move into other livelihoods with more growth potential. However, this is a complex task, accompanied by considerable danger that the most vulnerable people will fall through the cracks, especially given the division of labour in most governments, research organizations and the international community.

A REGIONAL PERSPECTIVE

In all of the above, emerging economies will continue to play an important part as they have increasingly done for the past 40 years. Fan and Brzeska (2010) highlight the important role of emerging economies in global food security, which will depend not only on their capacity to produce but also their ability to invest wisely in their own rural societies, in agricultural research, rural infrastructure, markets and safety nets. The more advanced Latin American economies together with China, India and Russia have the potential to contribute a large percentage to both demand growth and future supply. These countries have all of the major production systems operational within their borders and are experiencing all of the food security challenges described in this report. They have a considerable capacity to produce food and potentially to stabilize supply, and a great deal of experience on which to draw in improving food access.

All of these countries are connected to global trade to varying degrees. They also are all urbanizing rapidly and will need to deal with an increasing challenge of feeding cities, which they currently handle in very different ways. All except India have some land into which to expand, although they also are looking for investment opportunities in other countries. All have the potential to make renewable energy from solar power or biofuels. All have growing economies that can provide public and private investment capital.

Latin America and China are moving in the direction of upscaling and intensification, meaning that the problems with intensive systems that have been described in this report will have to be solved in these countries. Russia is investing in intensive production and, as a relatively new investor, it has the opportunity to do this sustainably. India, with its high demand for dairy products and excellent local distribution networks, may be the place where innovation in small-scale mixed systems is taken furthest.

Africa barely participated in the livestock revolution yet now, in spite of widespread poverty and hunger, it is experiencing rapid demand growth for livestock source food, much of which has to be imported. A split is also developing in its livestock sector between the traditional production base which consists mainly of rangelands and small-scale farming, and a growing intensive poultry subsector near the cities. A number of constraints limit production levels and competitiveness of the livestock sector, including variable quality of feed supplies, water scarcity, food safety and inefficient trade within the continent that hampers its ability to pursue comparative advantage on a regional scale. However, with sufficient political will and some investment, there may be potential for African livestock production to make a larger contribution to food security in the continent than in the past.

WHO DOES WHAT?

Looking toward the future, it is obvious involvement in assuring the contribution of livestock to food security should come from across the board. The private and public sectors, food producers and consumers, research and technology development will all need to play a part.

Finance. Much of the growth in supply of livestock source foods will come from large-scale intensive systems in which the private sector is the main driver. The costs of changes to management to reduce environmental impact, improve efficiency and meet welfare standards are likely to be borne by the private sector for the most part, with some costs passed on to consumers in the price of food. Public sector finance is needed for basic infrastructure, and for research that takes a long-term view or that benefits the poor. It also can support animal health services in remote areas by contracting private providers to carry out government programmes. Public sector finance, both national and international, is also necessary to provide a temporary buffer to short, severe shocks during food crises.

Private sector foundations and NGOs that use both public and private finance can invest in initiatives that underpin the access of livestock dependent societies and small-scale mixed farmers to essential services. As systems change and some livestock keepers diversify or leave the sector altogether when they are unable to provide the quantity or quality demanded by the market, a combination of private and public finance will be needed to support them in developing specialized livestock enterprises, applying more efficient water management, carrying out pilot activities in environmental services or establishing new livelihoods outside of farming.

Policy, regulations and standards. Public regulation can enable the private sector to bring its efficiency and innovation into finding ways to improve the efficiency of livestock systems and their roles in recycling waste. We now are well aware, thanks to public sector overviews, that livestock are polluters. But we also have seen that the innovative private systems with the potential to feed the cities are capable of rising to the challenge of controlling pollution within intensive systems. In providing the policy to support the private sector and intensification, it is also critical to make sure the smallholder and extensive producers are not pushed aside. Policy also underpins the land-use patterns that influence the choices livestock keepers can make in rangeland management.

Public regulation and standards for animal health are strongly guided by the international animal health systems and embedded in international trade regulation through the sanitary and phytosanitary agreement of the World Trade Organization. In the same context, Codex Alimentarius, an international commission created by FAO and WHO defines global standards for food safety. However, in other aspects of livestock development important to the sustainability of food systems, such as environmental regulation, public regulation and standards are less well defined. In addition, they do not form part of international trade agreements, making their implementation more a matter for individual countries or companies and, in the future, for negotiation between public and private sectors. Policies guiding or supporting use of marginal lands and recycling the waste of other systems into on-the-hoof protein will also require negotiation between governments, private sector, civil society and local communities.

Research and technology. Some of the proposals and opportunities mentioned in this report will need research into technologies and institutions to increase understanding and generate knowledge that can guide the sector as well as national policy development. For example, improving the efficiency of livestock production may require developing breeds better adapted to particular production niches, while dealing with climate change and water stress will require finding ways to manage water more efficiently. Reducing environmental damage, developing innovative animal health systems and recycling waste all need new knowledge as well as ways of better applying existing knowledge.

Consumer choice and communication. Consumer choice will influence directions for livestock systems in terms of the products chosen and the way that animals are managed. Consumers themselves are influenced by many forces, most of all their immediate social and peer groups. This means that public sector influence on good nutrition choices is limited, whether this means providing a balanced diet for children or not over-consuming livestock products. Governments can influence choices to some extent, through regulating what is provided in school meals and how foods are advertised, or through providing nutrition education. However, the rise in obesity over the past two decades would suggest that this has not been sufficiently effective. A more innovative and diverse approach to communicating about nutrition is obviously required, based on sound knowledge and relayed by respected individuals, peer groups and media.

Livestock's role in food security will not be driven by any one part of the livestock sector. It will depend on finding a way to create a coalition of all parties who in reality have very different backgrounds, responsibilities and goals but understand the big picture of what livestock has to offer to the world's food security and also of what it has to lose if they do not act together to ensure the sector has the tools it needs to sustain production at levels which meet the world's constantly increasing and changing demand.