# African Livestock Futures

Realizing the potential of livestock for food security,
poverty reduction and the environment in Sub-Saharan Africa

Report

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Realizing the potential of livestock for food security,
poverty reduction and the environment in Sub-Saharan Africa

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Report

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Foreword

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If people can access milk, eggs, meat and other livestock products, they are likely to be able to enjoy food security and to be well-nourished. As people's disposable incomes increase, their demand for (and access to) livestock products tends to increase as well.

The degree to which people have predictable access to safe livestock products depends on the extent to which local markets respond to increasing demand and to which gaps in production can be met through imports from elsewhere. A growing market for livestock products, and the increasing production of livestock products, can be an important contributor to the resilience and productivity of rural people's livelihoods and food security. The potential for farmers and food producers to respond to increasing demand with greater production is important in determining the prosperity of rural communities in many developing countries.

Demand for livestock products in sub-Saharan Africa is increasing rapidly. The trend of increasing demand is currently not being matched by similar growth in local production. Several African governments, as well as regional organizations, are now working out how they can best ensure that their farmers can contribute to the better availability of high-quality livestock products, thus reducing the need for dependence on increased imports. At the same time, governments are increasingly aware that if increases in the production of livestock products are not carefully managed, there will be adverse consequences, including greatly increased pressures on natural resources (particularly water and land), greenhouse gas emissions, and threats of zoonotic diseases.

The risks associated with unmanaged increases in livestock production prompt national decision-makers to ask a number of questions. What kind of livestock policies will contribute to the expansion of livestock production in Africa in ways that bring equitable benefits to societies? What is the best way to ensure that they also contribute to people enjoying good health? What are the options for ensuring that livestock production practices are sustainable from social, environmental, economic and climatic perspectives?

Such questions prompted an investigation of plausible trajectories for African livestock up to 2050: the results are presented in this 2014 report on African livestock futures. The researchers build on their analytical work and offer a series of recommendations as to how farmers, societies, businesses and governments can realize the potential of livestock as an engine of economic growth, food security and environmental well-being. The researchers conclude that a strong and predictable African response to increasing demand will need to include long-term investment in sustainable intensification of African livestock systems. This will need to include year-round access to high-quality animal feeds, careful land-use planning and increased support for applied research into means for ensuring good animal health in livestock production systems.

The researchers also conclude that governments play a vital role in setting and executing policies for livestock development. It is in the interests of all involved in the expansion of livestock production that governments be in a position to enforce regulations and so limit the externalities associated with intensified production. This includes governments being enabled to combine the enforcement of regulations with the application of incentives in ways that take account of income inequalities, and being guided by applied research in areas where animals and humans intersect within different ecosystems.

The researchers also recommend ways in which the expansion of livestock production can improve the livelihoods of smallholder producers and pastoralists in ways that encourage resilience, avoid costs to the environment and limit adverse health impacts. The recommendations include the preservation of land rights, protecting the interests of women, managing water and land use, creating decent employment and paying for environmental services.

The researchers suggest ways in which intensified production can best contribute to animal health, e.g. through the creation of buffer zones in densely settled areas where there is intensive livestock production.

The results of this research set the scene for more intensive work on options for expanding livestock production in Africa. Follow-up work will explore how the dynamics of livestock markets will evolve in Africa and how changes in habitats will impact on the likelihood that new diseases will emerge and threaten the health of both animal and, if they are transmissible, human populations.

We look forward to receiving your reactions to this work.

David Nabarro
Special Representative of the UN Secretary General for Food Security and Nutrition

Acknowledgments
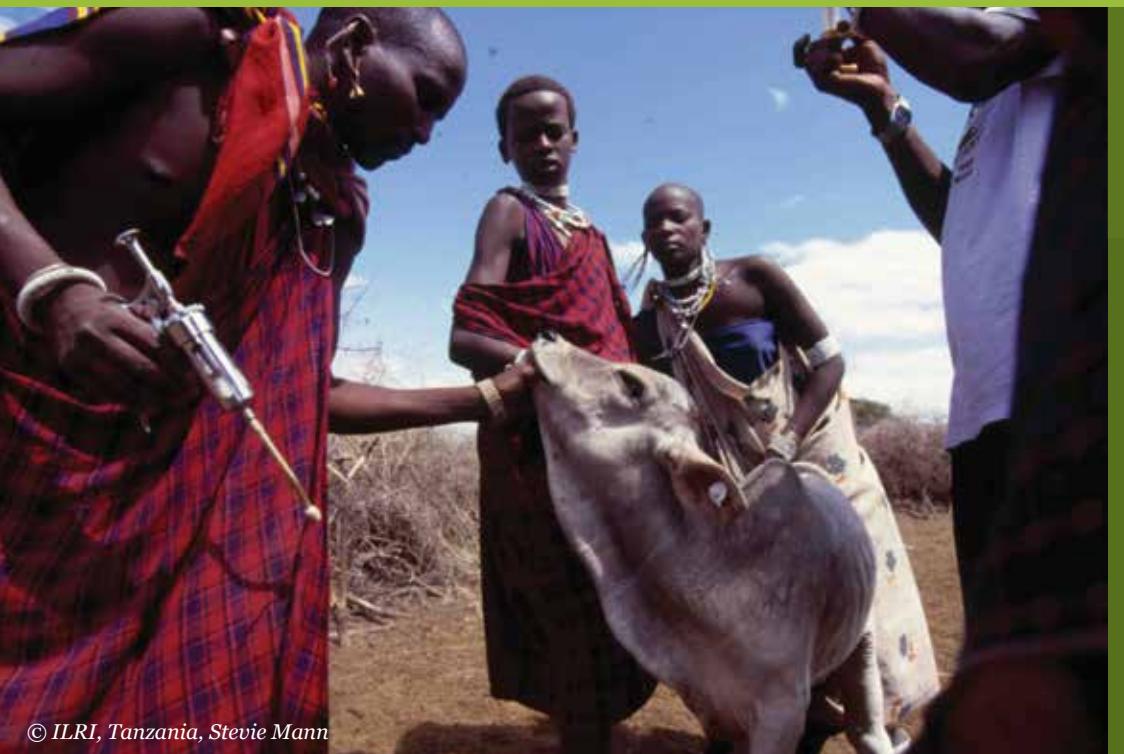
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This African Livestock Futures study was conceived early in 2013. It was initiated during the same year and completed in mid-April 2014.

David Nabarro
Special Representative of the UN Secretary General for Food Security and Nutrition

Abbreviations and acronyms

BMGF	Bill and Melinda Gates Foundation
CBPP	Contagious bovine pleuropneumonia
CO2	Carbon dioxide
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DALYs	Disability adjusted life years
DAYCENT	The daily version of the CENTURY biogeochemical model
ECF	East Coast Fever
EPIC	Environmental Policy Integrated Climate model
EU	European Union
FAO	UN Food and Agriculture Organization
FBS	Food balance sheet
GCMs	Global Circulation Models
GDP	Gross domestic product
GHG	Greenhouse gases
GLOBIOM	Global Partial Equilibrium Model
GMOs	Genetically modified
GrsLnd	Grasslands
HIV/AIDS	Human Immunodeficiency Virus
IFPRI	International Food Policy Research Institute
IIASA	International Institute for Applied Systems Analysis
ILRI	International Livestock Research Institute
ISI-MIP	The Inter-Sectoral Impact Model Intercomparison
LW	Losses and wastes
LAM	Latin America
LG	Grazing system
LGA	Grassland-based – arid

LGH	Grass-based – humid
LGT	Grass-based – temperate/highlands
LPS	Livestock production systems
LUC	Land-use change
MR	Mixed crop-livestock system
MRA	Mixed crop-livestock systems – arid
MRH	Mixed crop-livestock systems – humid
MRT	Mixed crop-livestock systems – temperate/highlands
N2O	Nitrous oxide
NatLnd	Natural land
OECD	Organisation for Economic Co-operation and Development
OIE	World Organisation for Animal Health
PES	Payment for environmental services
PriFor	Unmanaged forests
PPR	Peste des petits ruminants
RCPs	Representative concentration pathways
RVF	Rift Valley Fever
SSA	Sub-Saharan Africa
SLM	Sustainable land management practices
SSP	Shared Socioeconomic Pathways
UNICEF	UN Children's Fund
UNSIC	UN System Influenza Coordination
USAID	US Agency for International Development
USDA	US Department of Agriculture
VWC	Virtual water content
WHO	World Health Organization

Executive summary

This study investigates plausible trajectories for African livestock to 2050.

The study builds on the IPCC's Shared Socioeconomic Pathways (SSP) scenarios and examines three variants: a sustainable intensification scenario with high economic growth, high GDP growth, changing diets and a high degree of technological change (SSP1); a continuation of current trends (SSP2); and a degradation scenario with little technological change, poor economic growth and high population growth (SSP3).

Using a global partial equilibrium model (GLOBIOM), we determine consumption, production, prices and trade projections for different animal products (milk from cattle and small ruminants, meat from cattle, small ruminant and monogastrics, and eggs) for each scenario. We estimate the impacts of increasing production on key environmental dimensions (use of nitrogen, land-use change, greenhouse gases) and examine the role of different farming systems (pastoralists, smallholder mixed crop-livestock systems and industrial systems) in meeting the demand for livestock products. We compare Africa against selected regions of the world and also discuss how the results impact different regions in sub-Saharan Africa (East, West, and Southern Africa and the Congo Basin).

We also discuss the implications of our findings for the competitiveness of the sector, for what roles smallholders and pastoralists may play in the future, and discuss the potential disease impacts of meeting livestock product demand.

We conclude with policy recommendations for realizing the potential of livestock as an engine of economic growth, food security and environmental well-being in sub-Saharan Africa.

The key quantitative findings of the study are as follows.

1. Milk consumption is likely to triple under most scenarios in all SSA regions by 2050, with East Africa, traditionally the largest consumer of milk, dominating the growth in consumption.

2. The consumption of meat and eggs from poultry and pork have the highest projected rates of growth across SSA. West Africa is projected to have a six- to sevenfold increase in the consumption of monogastric products (mostly poultry) to 2050, followed by Southern and East Africa (fourfold increases).

3. The conditions for achieving high production growth (rapid technological change potential in livestock and crop yields, lower costs, remunerative product prices, more competition in input and product markets) are highest for milk in East and West Africa, for monogastrics in West Africa and for ruminant meat in East Africa.

4. Only under SSP1 (sustainability scenario), with the highest crop and livestock yield increases, the highest resource-use efficiencies and the lowest production costs, can the low trade-deficit conditions prevailing until 2000 for all animal products (around 10% of national production) be maintained to 2050. This suggests that investing in the sustainable intensification of livestock systems in Africa is an urgent matter.

5. Maintaining business-as-usual trends (SSP2) would lead to a doubling of imports of milk and monogastric products (poultry mostly) relative to production by 2050 and, potentially, to an increase in imports for ruminant meats from about 2 per cent of the share of production in 2000 to about 16 per cent in 2050.

6. Any negative deviation from the current trend (SSP2) in terms of production efficiency, prices and GDP growth, such as the potential impacts of climate change on agricultural productivity, would make the SSA livestock sector largely uncompetitive, with substantially lower resource-use efficiencies and high production costs (SSP3). This would have negative implications for both consumers and producers, and it would be likely to affect the continent's food security.

7. Smallholder mixed crop-livestock systems are, and will remain, the main producers of ruminant products to 2050, under all scenarios. However, under SSP1 and SSP2, pastoral systems in all regions and the mixed smallholder systems in more humid areas are likely to increase the production of meat and milk four- to eightfold relative to 2000 production.

8. Given the right socioeconomic conditions and technology to reduce costs and increase productivity, with modest expansion to guarantee feed sources, pastoral systems in arid regions could triple the production of cow's milk and increase small ruminant milk and meat production by a factor of five or six relative to the production levels of 2000.

9. Sustainable intensification of livestock production alone (SSP1) is not enough to meet the increasing demand for livestock products. Cropland and grassland expansion are needed in all scenarios to increase the production of livestock products to 2050.

10. The most common source of land for increasing cropland production in SSA has been, in order of importance, grasslands in relatively high-rainfall areas, followed by wooded savannahs and primary forests. This pattern is likely to continue to 2050 with continuous land conversion in grasslands and natural land, and a stabilization of the rate of reduction of primary forests across all scenarios.

11. A combination of demand management, intensification of land-based systems and structural change promoting more industrial monogastric systems could lead to increases in the environmental efficiency of livestock systems (for example, improved GHG emissions intensities) in sub-Saharan Africa without sacrificing pastoral and smallholder production.

12. There could be increasing threats of disease affecting animals and people under all SSPs.

Key policy recommendations

1. Invest in the sustainable intensification of African livestock systems.

As this study demonstrates, Africa is the continent where sustainable intensification of agriculture and livestock systems could yield significant benefits for food security, incomes, trade, smallholder competitiveness and ecosystems services. Such investments include agricultural research and extension, regional and rural roads, energy generation and transmission, and public irrigation.

2. There is a broad scope for increasing productivity at very high resource-use efficiency gains because current yields of milk and meat are low per animal and per unit of land.

Sustainable intensification includes the increased provision of services, inputs, appropriate institutional support and markets, all of which are essential to transform traditional livestock industries into commercial operations.

3. Invest in the year-round provision of high-quality feeds.

Biomass from pastures, crop residues, planted fodders, grains and others are key for expanded livestock production. Policies to ensure that feed production and trade can occur dynamically through the region are an essential part of the sustainable intensification of the sector.

4. Invest in land-use planning and monitoring:

Even under the most optimistic intensification scenarios, the expansion of cropland and rangeland is required to meet the forecast production growth. It is essential that a choice of land that has relatively lower opportunity costs (economic and environmental) be used to expand animal production. This requires land-use planning, robust land-tenure structures, and adequate incentives for the implementation of sustainable land-use change practices (this is particularly important in places with significant land-use trade-offs, such as high-biodiversity areas, strategic watersheds and densely populated areas).

5. The evidence about production costs as functions of scale in monogastrics is clear: large enterprises can produce more cheaply because of economies of scale in housing, veterinary care, finance, feed and marketing, and large enterprises therefore do not need subsidies.

A related policy is to protect the land rights of smallholders – herders, arable farmers and mixed crop-livestock operators – against land diversions from large operators or from subsidized export sectors, such as natural-resource tourism or mining.

6. Governments should regulate the externalities of intensification.

Such externalities can occur in food safety, zoonoses, water quality, farm chemicals, managing the use of GMOs throughout food chains and preserving biological reserves against encroachment. Such regulation is most urgently needed in industrial production, as shifts to intensive production, especially in swine and poultry, will accelerate as demand grows because of economies of scale. Concentration has negative effects such as pollution from the excreta of animals confined together (in the absence of adequate biosecurity), the risk of diseases (including those that can be transmitted to humans or other species) and the eventual development of antibiotic resistance in microbes. Policy must therefore focus on developing regulatory and incentive capacity, including the use of benefit-cost tools for regulation economics. Regulating those externalities will require much more government capacity than currently exists.

Major policies are to:

(a) make large livestock enterprises pay the full environmental costs of their activities; and

(b) enforce animal and human health rules against urban and peri-urban livestock enterprises to reduce the risks of zoonoses and the rapid spread of diseases among confined livestock.

7. Invest in basic agriculture and livestock research.

Africa has underinvested in agricultural research and technology. As a result, its rates of productivity growth are lower and its capacity to use external innovations is weaker compared to other regions. Increasing the scale of agricultural research in Africa will require: (a) spending more for agricultural research on regional problems – tropical livestock diseases, animal productivity constraints caused by heat, crop adaptation to heat and moisture stress are a few examples – and for development of African scientific capacities; (b) spending more on basic research in African conditions especially on plant and animal genetics; (c) new research and technology spending must focus on small farmers and on the cost conditions – transport, communications, energy and water supply – in which they operate; (d) new public investment in agricultural research and technology for large farmers should be minimized except to study environmental costs – solid waste, the water footprint, zoonoses, and drug resistance; and (e) making better use of modern biology, especially in livestock science, where the problems are more complex than in crops and the potential for innovation is correspondingly greater.

8. Invest in animal health research.

As animal production intensifies and becomes more concentrated in places, risks of animal diseases – swine fever, poultry diseases, mastitis, zoonoses such as avian flu – will rise. Animal research must shift work to intensive problems of monogastrics in addition to its traditional focus on ruminants in extensive systems in view of the likely expansion of demand for monogastric production

9. Protect smallholders (and pastoralists).

The policy goal for smallholder agriculture should be to protect its competitiveness and its asset bases. The first thing to do is NOT to subsidize large producers, whether of animals or crops and whether of foreign or domestic origin. Subsidies are economically inefficient in that their cost per job created is high. They also have adverse effects on income distribution among groups of livestock producers, notably by having a bias against pastoralists and small-scale owners/operators.

10. Protect pastoralists.

The first policy to defend pastoralists is one of political and economic entitlement – creating rights to land, water, and grazing corridors. The second is to provide targeted public services for pastoralists where private services are lacking. This should include veterinary, research, financial, transport, infrastructure, education and health services. A third is to facilitate new forms of insurance, such as commercial index-based insurance products and links between those products and participatory disease surveillance and market information.

11. Protecting the interests of women

as livestock owners and managers should be a special policy objective. This is because women stockholders suffer from discrimination in access to services, creating both an efficiency and an equity cost; the goal of policy should be to reverse that discrimination and to avoid making things worse for women operators by subsidizing their larger, usually male, competitors.

12. Address income inequalities.

African states must manage the absolute income gaps that are likely to grow between small and large holders in animal agriculture, as economies of scale and preferential access to finance increase those gaps. Such income inequalities can be partially offset through social safety nets, public service pricing, and tax and trade policies. But governments must strengthen their capacities to create social safety nets and to target tax expenditures to avoid increasing wealth and income inequalities, especially among such groups as pastoralists who are facing the loss of their asset base and of their traditional livelihoods.

13. Manage environmental costs.

The environmental costs of livestock growth are GHGs, water use, manure disposal, and damage to range productivity from overgrazing. A particular problem of environmental management is the prevalence of small farms whose poverty and market isolation prevent them from self-insuring, either through physical investments or through financial instruments. Appropriate policies include: (a) strengthening governance of regional water bodies, including such issues as water levels, electricity production, irrigation, and biodiversity; (b) holding greater financial reserves, or contracting forward, against costs of food if domestic prices become more variable with higher temperatures and more severe storms; (c) creating public employment for those who have lost income or work, notably in pastoral areas affected by extreme climate events; (d) investing in regional research on plant materials and farming practices that will resist higher temperatures and deeper flooding, which might allow diversification of livelihoods by pastoralists who now specialize in livestock; and (e) promoting payments for environment services.

14. Protect animal health.

One focus in the area of animal health are the traditional major diseases of ruminant livestock, chiefly beef and dairy cattle, in which the public sector provides most services. The policy objectives should be to fund these services adequately for livestock sectors where private vets do not operate (e.g. pastoralism and isolated smallholders). The second path for the development of animal health is intensive ruminant and monogastric production. An intensive commercial livestock sector will create new problems related to breed specialization, feed, confinement, and food safety, all the more so if livestock products are exported. The policy objective is to regulate the providers of these services so that they do not contribute to externalities such as antibiotic resistance.

15. Policy must recognize the potentially conflicting roles of livestock in human health.

Buffer zones should be created in densely settled areas where there is intensive livestock production, especially where human water supply is not well developed; such zones may be even more necessary where high human and animal population densities are near irrigated areas, which can attract migratory birds and insect disease vectors.

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Introduction

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Livestock are critical to incomes, livelihoods, nutrition and food security, and resilience in much of Africa.

Increasing demand for livestock products in Africa is not yet matched by increasing production, however, implying that there could be widespread benefits to farmers and consumers alike if the former can respond to the new demand for animal products in African and in global markets.

An accelerated supply response is not automatic.

There are difficult technical and policy problems to be solved before production can grow. These problems include land and water scarcity, animal diseases, zoonotic effects on human health, institutional degradation, and environmental effects through greenhouse gas emissions and manure management.

More animal production will not be a pure gain.

More production will bring adverse consequences, including pressure on water and land, more greenhouse gas emissions, and greater risk of zoonoses. More animal production, if associated with shifts in production from pastoralists and smallholders to industrial producers, would damage the wealth and income of pastoralists and smallholders and perhaps create an underclass of poor rural people. A shift of livestock production to urban areas can aggravate environment costs of intensive systems and raise risks of zoonoses. These shifts in animal production – in systems, in regions, in enterprise scale, in environmental effects, in consumption patterns – will occur under the broad heading of intensification for higher productivity across the world.

Global changes will present new challenges for African livestock sectors. Such challenges might include:

- Realizing the genetic potential of indigenous stock so as to keep pace with productivity growth of genetic origin in competing regions;

- Preventing the emergence and spread of zoonoses;

- Contributing to the global effort against antibiotic resistance originating in industrial livestock production;

- Lowering feed costs through technology generation and transfer without immiserizing poor cereal consumers;

- Mediating conflicts for land among activities – crops, extensive livestock, industrial livestock, biodiversity, cities, and natural reserves – so that traditional assets and incomes are not destroyed;

- Managing the spread of vectors and associated diseases related to climate change and the associated disease costs of vector spread.

- What scope is there for long-term improvement of indigenous meat and dairy breeds?

This paper proceeds as follows. It first sets (Section I) the global context in which African livestock systems will evolve. It reviews world and African production, consumption, and trade issues before discussing livelihood, health, nutrition and environmental questions related to animal production and consumption.

Section II describes the global model and its use in creating development scenarios for world and African livestock production. Section III presents in greater detail the model results for sub-Saharan Africa. In Section IV, the paper discusses policies to promote higher productivity while preserving the livelihoods of traditional producers, avoiding environmental costs and limiting the deleterious health effects of more intensive livestock production.

Africa in the World Livestock Economy

2

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This section places the livestock systems of sub-Saharan Africa in the world livestock economy.

After defining the chief animal production systems, it reviews the stocks of animals by type (ruminants and non-ruminants) and region; the stocks by farming systems (commercial, smallholder mixed, pastoral) within regions; production flows (mainly meat and milk); consumption patterns by region and national income levels; shares of world trade by region and income level; commodity price trends for products and tradable inputs; patterns of feed use (pasture, crop residues, browse, and concentrates); and the environmental costs (GHG, water, solid waste, health risks) of animal production. A concluding section evaluates levels and trends of basic productivity measures per animal and per unit of land for the major African systems in comparison to competing systems.

Livestock production, consumption and trade

Livestock production in the developing world occurs in diverse systems.

These range from pastoral/grassland systems, which occupy most of the land area and typically have low human population densities with higher ratios of ruminant animals to people; through mixed crop-livestock systems, usually in areas suitable both for arable and livestock production and where human population density is higher; intensive systems, usually in peri-urban/urban areas; and landless systems, which are often in urban areas. Such systems in developing countries produce about 50 per cent of the world's beef, 41 per cent of the milk, 72 per cent of the lamb, 59 per cent of the pork and 53 per cent of the poultry, globally (Herrero and others, 2009). These shares are likely to increase, as more future growth in livestock production is projected to occur in the developing world (Bruinsma, 2003; Rosegrant and others, 2009).

Most meat and milk in the developing world comes from mixed systems

(Herrero and others, 2009; 2013; FAO, 2013). These systems play a very important role in global food security, as they also produce close to 50 per cent of the global cereal output (Herrero and others, 2009 and 2010). The highest recent rates of increase in animal production are in the intensive pig and poultry sectors of the developing world (Delgado and others, 1999; Bruinsma, 2003; Steinfeld and others, 2006).

Livestock contribute high-value products when compared to crops.

The average global price of a ton of red meat is more than 10 times higher than the price of soybean, while that of milk is 70 per cent higher (FAOSTAT, 2011). This makes milk and meat some of the agricultural commodities with the highest gross value of production (VOP) in the developing world (FAOSTAT, 2011). In the past decade, livestock have represented between 17 and 47 per cent of the total agricultural VOP in developing-country regions (range defined by South-East Asia and Central America, respectively) (FAOSTAT, 2011). Over the past 40 years, the value of livestock production has seen an average of 2.7 per cent growth per year in sub-Saharan Africa (SSA), 3.4 per cent in Central America, and 4.1 per cent in South-East Asia (SE). These growth indicators compare favourably with, for example, a mean annual growth in VOP of 1.2 per cent in North America over the same period (FAOSTAT, 2011).

Global trade has grown in recent years

as a result of trade liberalization and shifts in regional comparative advantages associated with technical change (Table 1 in FAO, 2009). Dairy and eggs dominate trade, but meat exports are important for a few nations (e.g. Brazil, Thailand) (FAO, 2009). Most trade in livestock products occurs within an individual country, with the movement of animal products, inputs and services being very dynamic due to increased internal connectivity, transport networks, improved value chains and an increasing need to supply growing urban populations.

Trade is of mixed importance in African livestock economics.

Local consumption dominates livestock product demand, and international trade is relatively small. For example, trade in most animal products in 2000 was 10 per cent of the production volumes in SSA (FAOSTAT, 2011).

Table 1 - Numbers of livestock keepers living on less than $2 per day

Region/sub-region	Number of poor livestock keepers ('000)
Sub-Saharan Africa	319,908
Central Africa	29,815
Western Africa	132,742
East Africa	104,816
Southern Africa	52,534
South Asia	606,967
India	546,012
Bangladesh	60,955
Total	**926,875**

Staal and others, 2009 (updated from Thornton and others, 2002). These are rough estimates.

Livestock and livelihoods in developing countries

Livestock are important in supporting rural livelihoods across the tropics. Nearly 1 billion people living on less than $2 a day in South Asia and sub-Saharan Africa keep livestock (Table 1). More than 80 per cent of poor Africans keep animals (FAO, 2009).

The most important aspect of making one's living from animal production is, of course, household income. According to nationally representative data from across the developing world, some 68 per cent of households earn income from livestock (Davis and others, 2007). In the study by Davis and others (2007) covering mixed crop-livestock systems in 15 countries, livestock's share of rural household income ranged from 1.6 to 33.8 per cent depending on the livestock-keeping objectives (traction, assets or production), and the importance of cropping, off-farm income and monetary transfers.

Table 2 - Global trade in livestock products

Product	World exports		Share of total production (%)	
	1980	2006	1980	2006
Meat	9.6	32.1	7.0	11.7
Pig	2.6	10.4	4.9	9.8
Poultry	1.5	11.1	5.9	13.0
Bovine	4.3	9.2	9.1	14.2
Ovine	0.8	1.1	10.6	7.7
Dairy	42.8	90.2	8.7	12.7
Eggs	0.8	1.5	3.1	2.2

Source: FAO, 2009.

The average share of livestock income was lower than that of crops, 12 per cent versus 30 per cent; however, it tended to grow much faster than crop income. While the share of income from cropping remained stable or even declined between 1992 and 1998, the share of income from livestock grew by 75 per cent during the same period, by 110 per cent in Vietnam between 1992 and 1998, and by 290 per cent in Panama between 1997 and 2003 (Davis and others, 2007).

Staal and others (2009) analysed 92 case studies from the developing world (Figure 1 -- Average income derived from livestock by production system) and found that livestock contributed, on average, 33 per cent of the income in mixed crop-livestock systems, with higher incomes being associated with dairy and poultry production. They also reported average livestock incomes from pastoral production of 55 per cent of total income. In studies of Maasai pastoralists, BurnSilver (2009), Nkedianye and others (2009) and Thompson and others (2009) found livestock incomes ranging from 37-85 per cent of total income. These depended on the level of diversification and market access of the studied groups. Bernués and Herrero (2008) found a similar range of incomes (37-88 per cent) from livestock in systems with different degrees of crop-livestock integration and diversification in lowland Bolivia (the more diverse and integrated with crops, the lower the share of the total income; the more specialized towards dairy, the higher the share).

Figure 1 - Average income derived from livestock by production system
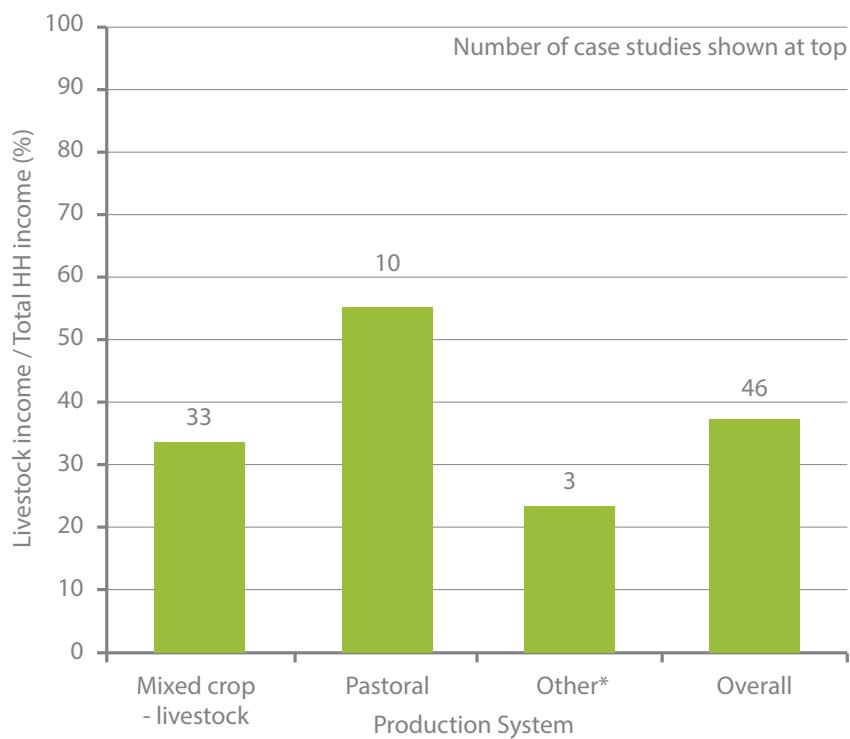
Source: Staal and others (2009). Data from 92 case studies from the developing world.

Employment.

The growth in demand for milk and meat, mainly driven by urban consumers in developing countries, has been increasing in recent decades and is projected to double by 2050 (Delgado and others, 1999; Rosegrant and others, 2009). This rising demand for milk, meat, fish and eggs has generated jobs all along the livestock value chain, from input sales through animal production, trading and processing to retail sales. It is now estimated that up to 1.3 billion people globally are employed in different livestock product value chains (Herrero and others, 2009). Employment in the livestock sector is especially high in the informal sectors of Asia and Africa, where most meat, milk, eggs and fish are sold (Grace and others, 2008) and where many of the people selling and buying livestock foods are themselves poor (Omore and others, 2001; Kaitibie and others, 2008). Street food is a large part of the informal sector in most developing countries—the largest in South Africa (Perry and Grace, 2009)—and therefore a major source of income and employment for the poor. Animal-source foods are among the most commonly sold street foods (Perry and Grace, 2009), and it is poor women who do most of the work preparing and selling these foods.

Livestock are one of the main assets of rural households.

Ownership and management of assets are critical aspects of well-being (Sherraden, 1991; Carter and Barrett, 2006). While livestock ownership is often a sign of wealth (Dercon and Kirshnan, 1996; Deshingkar and others, 2008; Ellis and Freeman, 2004; Kristjanson and others, 2005), livestock's share of income was highest in the poorest income quintile (Davis and others, 2007). Animal assets, because they are liquid, can be cheaply used to finance investments such as school fees or in time of need, such as an illness or drought. In their study of "voices of the poor", Narayan and others (2000) found that "the poor rarely speak of income, but focus instead on managing assets—physical, human, social and environmental—as a way to cope with their vulnerability".

Accumulation of livestock assets is commonly followed by a shift to more non-farm income in comparison to farm income (Barrett and others, 2001; Ellis and Freeman, 2004; Reardon, 1997). For example, in a livelihoods analysis of four African countries by Ellis and Freeman (2004), the highest income quartile of the rural poor had the largest livestock holdings and the highest share of total income from non-farm sources. Ellis and Freeman conclude that "livestock is a substitutable asset that can be sold in order to invest in land or small businesses, and vice versa, non-farm income can be used to build up herds" (Ellis and Freeman, 2004).

Livestock in human health and nutrition

The relationships among livestock, human nutrition and human health are complex (Figure 2). Livestock can damage human health if animal source foods contribute to poor diets and if they create a reservoir for zoonoses. For example, poor livestock keepers worldwide face daily trade-offs between selling their (relatively expensive) milk, meat and eggs to increase income or consuming the same foods to improve nutrition. Because animal source foods are so dense in nutrients, including micronutrients, consumption and sale decisions have major implications for nutritional and economic health.

Figure 2 - Interactions among people, animals and diseases
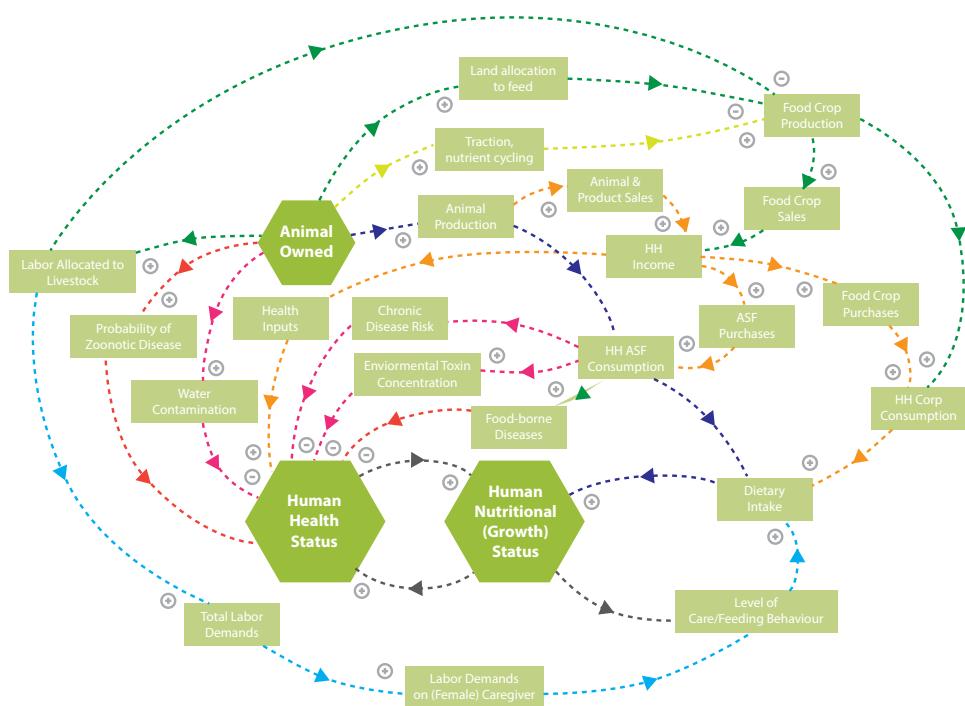
Source: Randolph and others (2007)

Livestock and fish make significant contributions to total energy and protein consumption in poor countries.

In East Africa, for example, livestock provide on average 11 per cent of energy and 26 per cent of protein in poor people's diets (FAOSTAT, 2011). For some vulnerable groups, such as the world's 180 million pastoralists, the contribution of livestock products to diet is much higher; for example, among Nuer agro-pastoralists in Sudan, half of the total energy intake of children under 5 years of age comes from milk (Fielding and others, 2000).

Animal source foods have an even greater role in nutrition security.

Because animal source foods are dense and palatable sources of energy and high-quality protein, they are important for vulnerable groups, such as infants, children, pregnant and nursing women, and people living with HIV. They also provide a variety of essential micronutrients, some of which, such as vitamin A, vitamin B12, riboflavin, calcium, iron, zinc and various essential fatty acids, are difficult to obtain in adequate amounts from plant-based foods alone (Murphy and Allen, 2003). Animal source foods provide multiple micronutrients simultaneously, which can be important in diets that are lacking in more than one nutrient: for example, vitamin A and riboflavin are both needed for iron mobilization and haemoglobin synthesis, and supplementation with iron alone may not successfully treat anaemia if these other nutrients are deficient (Allen, 2002). Micronutrients in animal-source foods are also often more readily absorbed than those in plant-based foods (Murphy and Allen, 2003).

Consumption of even small amounts of animal-source foods has been shown to contribute substantially to ensuring dietary adequacy and preventing undernutrition and nutritional deficiencies (Neumann and others, 2003). Extensive longitudinal studies in Egypt, Kenya and Mexico (Neumann and others, 2003) have shown strong associations between intake of animal-source foods and better growth, cognitive function and physical activity of children, better pregnancy outcomes and reduced morbidity from illness. Consumption of adequate amounts of micronutrients, such as those that can be found in animal-source foods, is associated with more competent immune systems and better immune responses (Keusch and Farthing, 1986; Neumann and others, 1975, 1991). Low levels of consumption of animal-source foods by the poor are due to limited supply in some regions, such as sub-Saharan Africa, as well as income constraints. It has been estimated that to effectively combat undernutrition, 20 g of animal protein per person per day is needed, which can be achieved by an annual consumption of 33 kg of lean meat, 230 kg of milk or 45 kg of fish (FAO, 2009).

Undernutrition is widespread among poor populations and has been linked to the deaths of one-third of all children under 5 (Black and others, 2008). An estimated 195 million children are too short for their age (stunted) and 129 million children are underweight (UNICEF, 2008). This undernutrition is at times associated with low consumption of animal-source and other protein-rich foods.

Consumption of animal-source foods can have adverse effects.

In rich countries, consumption of animal-source foods has been linked to chronic illnesses, including obesity, cardiovascular disease and cancer (McMichael and others, 2007). Many developing countries face a "double burden of malnutrition", that is, the persistence of undernutrition along with a rapid rise of illnesses associated with overnutrition. In South Africa, for example, over a quarter of rural children are stunted, while nearly 60 per cent of women are overweight or obese (Toriola and Goon, 2012). Similar syndromes have been observed in developing countries with large, expanding middle classes (such as Brazil, China and India).

Livestock and infectious disease

Infectious disease in poor nations accounts directly for around 40 per cent of years lost to sickness and death (WHO, 2008).

Livestock contribute to this burden via diseases transmitted through animal-source foods, through zoonoses transmissible between livestock and people, and through human diseases emerging from livestock. A recent estimate suggests that 12 per cent of the infectious-disease burden in least developed countries is due to zoonoses, and the majority of this is transmitted to people from livestock hosts through consumption of animal-source foods, vectors or direct contact (Grace and others, 2012).

Food-borne diseases are the world's most common illnesses and are most commonly manifested as gastrointestinal diseases. Diarrhoea is one of the top three infectious diseases in most developing countries, killing an estimated 1.4 million children a year (Black and others, 2010). The great majority of cases are caused by bacteria and viruses, not chemicals, although the latter are often of more concern to the public (Kafetstein and others, 1997; De Boer and others, 2005). In countries where reliable data exist, zoonotic pathogens are among the most important causes of food-borne disease (Thorns, 2000; Schlunt and others, 2004).

Animal-source foods bear health risks (Lynch and others, 2006) because meat and milk are excellent media for microbial growth.

Food-borne diseases cost the United States $152 billion, or about 1.1 per cent of GDP, in 2006. Less is known about food-borne diseases in developing countries; on the one hand, less animal-source food is consumed, thereby decreasing risk, but, on the other hand, there are greater hazards in the animal-source foods that are consumed. Estimates of the costs of food-borne disease in Nigeria amounted to $3 billion in 2010, or about 1.25 per cent of GDP (Scharff, 2010 and Okike and others, 2010).

Many human diseases are zoonotic (that is, transmissible between animals and humans), including many of the most important causes of sickness and death. Echinococcosis is responsible for 1 million lost DALYs in addition to human-associated economic losses (including medical costs, wage losses) estimated at $1.9 billion and livestock losses of $2.1 billion (Maudlin and others, 2009). Sleeping sickness, rabies, leishmaniasis, cysticercosis, brucellosis and leptospirosis are other zoonoses of similar importance that also have livestock reservoirs.

Zoonoses (diseases transmissible between animals and people) and human diseases that recently emerged from animals (mostly HIV/AIDS) make up 25 per cent of the infectious-disease burden in least developed countries (Gilbert and others, 2010). Many other important human diseases, such as HIV, measles and smallpox, were originally diseases of animals but jumped species when people changed their ways of farming and keeping animals. In the first epidemiological transition, unprecedented

levels of globalization, urbanization, animal production, and environmental degradation are driving new epidemics of infectious diseases. Currently, one new disease is emerging every four months, and 75 per cent of these originate in animals (Jones and others, 2008).

Other health problems

include: fungal toxins (mycotoxins) in animal source foods; water contaminated with animal waste for agriculture; misuse of agricultural chemicals and antibiotics in livestock, resulting in direct toxicity and contributing to antibiotic resistance; and the health impacts of environmental degradation resulting from livestock production. Another local example are the dams constructed for livestock watering, which can be linked to water-associated diseases such as schistosomiasis. A global example is the changing distribution of diseases, associated with the changing distribution of vectors, related to global warming.

The greatest burden of livestock-associated disease falls on poor producers, traders and consumers.

They are frequently economically and socially disempowered with little access to medical services. As a result, zoonoses (sleeping sickness, cysticercosis, zoonotic tuberculosis) thrive among these populations. Diseases that have been controlled among richer populations (e.g. rabies, brucellosis, hydatid disease) persist. There is often competition over declining resources, which may lead to intensified interaction among people, livestock and wildlife (e.g. around water sources in pastoral areas) and increased transmission of disease; such risks are great among the world's 180 million pastoralists.

Another population of concern are people living in rapidly intensifying and/or changing agriculture and food systems.

These include the urbanizing and rapidly developing systems of Latin America and South-East Asia, but also areas of South Asia (e.g. the Karachi buffalo colony, with more than 300,000 animals) and Africa (e.g. the bush meat value chain associated with the opening-up of the rainforests by road building). These systems are characterized by growing populations and standards of living, high demand for livestock products, and relatively good market access but low levels of regulation. Retail transitions are important in some areas (e.g. Latin America, Southern Africa), while, in others, a preference for wet markets and traditional eating habits (e.g. consumption of wildlife) persist (e.g. South Asia). This drives highly dynamic peri-urban production systems, as well as lengthening food supply chains. Malnutrition is less of a problem but food- and water-borne diseases and environmental hazards have become more important. Because these systems are highly dynamic, have high densities of genetically homogeneous livestock, and have high contact rates among people, livestock and wildlife, they are considered sources for the emergence of new diseases.

Livestock as users of land and water

Livestock systems are one of the main users of land. Steinfeld and others (2006) estimate that animals use 3.4 billion hectares for grazing and 500 million hectares of cropland for the production of feeds (33 per cent of global arable land). Of the grazing areas, 2.3 billion hectares are in the developing world. Expansion of pastureland at the expense of natural habitats in the developing world has been in the order of 330 million hectares in the past 40 years (FAO, 2009). This expansion has occurred mainly in Latin America, and is projected to increase by a further 100-120 million hectares by 2050 under current practices (Smith and others, 2010).

The expansion of cropland to produce grain for monogastrics is an indirect effect of livestock production. Cropland has expanded by 190 million hectares in the same period and is expected to increase at a faster rate than rangelands because of the need to supply feed for monogastrics and intensive ruminant production (Smith and others, 2010). One estimate is that 450 million tons of grain will be needed to meet human demand for animal products by 2050 (Rosegrant and others, 2009).

Land use is closely linked to water cycles. Not surprisingly, 90 per cent of the water used by livestock is used through the impacts of grazing and the production of feed. The fraction used for drinking water accounts for less than 10 per cent of the total (Peden and others, 2007). Recent research (Heinke and others, 2011) suggests that, globally, the production of feed for the livestock sector appropriates 5,315 km³ yr-1 of evapotranspiration (9 per cent of global evapotranspiration). Feed production uses 37 per cent of all water for crop production, and the biomass consumed by livestock from grazing lands appropriates 32 per cent of the total evapotranspiration from grazing lands. The rest of the ET supports a range of key ecosystem services, which seems to be a key role that rangelands are playing globally. Enhancing this role through improved rangeland management could be of essential importance for enhancing global green water cycles (Rockstrom and others, 2009). At the global level, the aggregated virtual water content (VWC) of livestock products has an average value of 5.63 m³ 1,000 kcal-1. In contrast, the VWC of vegetal products from croplands is estimated to be only 0.66 m³ 1,000 kcal-1 (Heinke and others, 2011). Producing 1 kcal of animal products used on average nine times the amount of water that it took to produce 1 kcal from crops.

The total VWC for individual products ranged from 1.50 m³ 1,000 kcal-1 for pork up to 35.24 m³ 1,000 kcal-1 for meat from dairy sheep and goats, with the range reflecting vast differences in intensity of production (feeds, agro-ecology, species, type of production systems and others). Green water represented 97 per cent of the water used by livestock.

Livestock as nutrient recyclers

Livestock plays an important role in nutrient cycles. Bouwman and others (2011), in a historical analysis of nutrient cycles, show that it was the introduction of synthetic fertilizers after the 1940s that allowed the explosive increase in livestock production. Agriculture based only on the recycling of organic resources and supported on N-fixing legumes could not have supported the current global production and consumption of animal protein. The widespread use of fertilizers has helped to intensify not only agricultural production but also the rate of nutrient cycling, with the accumulation of nutrients in certain environments creating threats for human health and nature (Sutton and others, 2011).

Livestock plays a very different role in nutrient cycles in the developed-industrialized world and in the poor developing world. While in large parts of Africa and East and SE Asia, agricultural production and nutrient cycles are closely related to local-scale recycling of organic residues (including animal manures), in Western Europe and North America crops are fully sustained on synthetic fertilizers and livestock production on the import of feeds produced sometimes thousands of kilometres away. In much of the industrialized world, the link between livestock and the land has been broken, with animals separated spatially from the places where their feed is produced (Naylor and others, 2005).

Meeting the increasing demand for crop production in the developing world requires managing nutrient cycles more efficiently. Expansion of agricultural land has led to marginal increases in livestock production in parts of the developing world because the production systems remain low-input, and the natural resources are often poor or degraded to a state that cannot support large outputs per unit of land. This, together with low investment in agriculture, means that places like sub-Saharan Africa have experienced very little technological change in ruminant production in the last 40 years (FAOSTAT, 2011). In places with a high human population density, where most suitable land is already occupied, increasing livestock production will compete with the production of food crops and will result in associated environmental costs. More intensive livestock production (e.g. dairy, fattening systems, monogastrics) may achieve higher technical efficiency. However, the concentration of animal wastes around urban centres raises serious concerns for water pollution and for GHG emissions, which may increase significantly in places of large livestock density (Gerber and others, 2005).

Costs and benefits of cycling nutrients through livestock

Livestock wastes – considered a nuisance in the developed world – are a critical agricultural resource in large parts of Africa, where soils are often poor (Rufino and others, 2007; Petersen and others, 2007). Liu and others (2010) estimated that manure contributes between 12 and 24 per cent of the nitrogen input into cropland in the developing world. Recycling of animal manure is practised in most mixed crop-livestock systems, although efficiencies are rarely close to those of the developed world (Rufino and others, 2006). Synthetic fertilizers are unaffordable for most small-scale farmers, who depend on the (poor) fertility of their soils to produce food crops, or on livestock and biomass to concentrate nutrients.

Intensifying livestock production requires using additional nutrients to produce feeds. Nitrogen-fixing legumes play a very important role in the developed world's dairy industry, with soybeans produced in South America and the United States used as protein supplements in Europe. Researchers in the developing world have tried to adapt this model of using legumes produced at farms on a local scale in, for example, African mixed systems, with some success (Sumberg, 2002), but this model has not been adopted widely enough to supply current or future feed demand.

Designing technologies for intensification requires addressing the trade-off between income growth and environmental impact. One example is the use of grain legumes or fodder legumes, which often require the addition of phosphorus fertilizers, and which can induce GHG. Dual-purpose legumes such as cowpea may be used as food and feeds, and their production can be justified, as they contribute to income and nutrition (Singh and others, 2003). However, the production of feeds, including legumes, results in GHG emissions (e.g. Baggs and others, 2006; Chikowo and others, 2004) attributable to the livestock sector.

Nutrients, livestock manure, soils and poverty

It is generally accepted that African soils are more fragile and have fewer nutrients than those of other continents. Problems of low soil fertility are solved not only by adding mineral fertilizers but by adding nutrients from biomass resources, such as crop residues and animal manure (Chivenge and others, 2011). Biomass is already vital in many African farming systems where arable and permanent crop production is directly or indirectly related to livestock production. Direct relationships arise from the use of animal manure to increase the effectiveness of mineral fertilizers (Vanlauwe and Giller, 2006). Indirect relationships arise from the competition for biomass to restore degraded agricultural soils or to feed livestock (Rufino and others, 2011).

Although animal manure can be a very effective soil amendment, its availability at the farm level is often limited. This implies that designing technologies for soil fertility restoration that depend only on animal manure is infeasible. Mineral nutrients, including carbon, must be included in the land management analysis. Increasing food security will require a sensible use of the natural resources, and in many places a strategy to store carbon and to reduce GHG emissions from livestock.

Greenhouse gases

Livestock are an important contributor to greenhouse gas emissions. Estimates attribute from 8.5 per cent to 18 per cent of global anthropogenic GHG (O'Mara, 2011), with the range reflecting differences in methods (inventories vs. life cycle assessment), to land use (O'Mara, 2011; Herrero and others, 2011) and uncertainty in parameter values (FAO, 2010). According to Steinfeld and others (2006), methane from enteric fermentation, nitrous oxide from manure management and carbon dioxide from land use contribute 25, 31 and 36 per cent of livestock emissions, respectively (Table 3). Livestock in the developing world contributes 50-65 per cent of global livestock emissions. Emission intensities also vary, and these are mainly related to the species (monogastrics are more efficient than ruminants), products (milk, white meats and eggs are more GHG-efficient than red meat) and the productivity of the animals (the higher the productivity the lower the emissions per unit of product, FAO, 2010). These aspects are largely dependent on feed type, quantity, quality and provenance and the manure management system implemented.

Table 3 - Livestock contributions to greenhouse gas emissions

Step in animal food chain	Estimated emissions[1]		Estimated contribution by species[2]			
			Cattle and buffaloes	Pigs	Poultry	Small ruminants
	(Gigatonnes)	(% of total livestock sector emissions)				
Land use and land-use change	2.50	36	■■■	■	■	ns
Feed production[3]	0.40	7	■	■■	■■	ns
Animal production[4]	1.90	25	■■■■	■	■	■■
Manure management	2.20	31	■■	■■■	ns	ns
Processing and transport	0.03	1	■	■	■■	ns

[1] estimated quantity of emissions expressed as CO_2 eqivalent
[2] ■ lowest to ■■■■ highest
[3] excludes changes in soil and plant carbon stocks
[4] includes enteric methane, machinery and buildings
Note: ns = not significant

There is wide variance in emissions intensities (GHG per kg of product) across the world (Herrero and others, 2013). The following order usually prevails: industrial systems are less GHG-intensive; these are followed by mixed crop-livestock systems and by grazing systems. Emission intensities in tropical highlands are usually lower than in drier areas. Nevertheless, livestock systems, in general terms, generate significantly more emissions per kilocalorie when compared with crops. However, the mitigation potential in the livestock sector is very large (1.74 Gt CO_2-eq per year, Smith and others, 2007), with land-use management practices (carbon sequestration in rangelands, land-sparing impacts of reduced animal numbers/production intensification) representing over 80 per cent of this potential (Smith and others, 2007). Most of the mitigation potential (70 per cent) lies in the developing world (Smith and others, 2007; see Henderson and others, 2011, for a discussion of the topic).

Manure management

GHG emissions from manure depend mainly on collection and storage practices. Across continents, the fate of manure excreted in housing facilities differs. In Europe, strong environmental regulations require that much of excreted manure be recycled, partly in grassland and cropland and partly for biogas production (Oenema and others, 2007). In extensive rangelands of Africa, manure is not collected or stored. In mixed smallholder systems across the tropics, most manure is not returned to grazing land. In intensive livestock systems, composted manure may be applied to fodder crops, but the large majority is applied to food and high-value crops (e.g. coffee, tea, tobacco).

In highly populated areas of Asia, most manure is destined for different and competing uses such as organic fertilizer, feed for fish ponds, biogas production, and biofuel (i.e. burned for cooking). In the mixed intensive systems of North America, manure is not yet fully recycled. There are places where manure is indirectly discharged into waterbodies (Centner, 2011) or accumulated in constructed wetlands (Knight et al., 2000). Use of manure for biogas production is increasingly gaining attention, but it is not yet widespread throughout the world (Cuellar and others, 2008).

In Latin America, recycling of manure is uncommon (Leon-Velarde and Quiroz, 2004). This can be explained by the following facts: (i) fertilizer is cheaper in Latin America; (ii) soils are more fertile; (iii) expansion of farmland can still counteract low soil fertility. Exceptions are urban and peri-urban areas (e.g. southern Brazil) where recycling of wastes into agricultural land, treatment of slurries, and biogas production have resulted more from environmental concerns and the disconnect between livestock and the land than from the demand for organic resources as soil amendments (Kunz and others, 2009).

Table 4 - Ranges of N cycling efficiencies (NCE) in mixed crop and livestock systems

	NCE through livestock	NCE for manure collection	NCE for manure storage	NCE for cropping	NCE for mixed systems
Developed world					
Europe[1]	0.55-0.95	0.50-0.90	0.50-0.90	0.40-0.60	0.11-0.51
United States[2]	0.65-0.85	0.10-1.00	0.50-0.80	0.20-0.50	0.01-0.34
Developing world					
Africa[2]	0.46-1.00	0.05-0.95	0.37-0.87	0.10-0.47	0.01-0.39

Sources: [1]Oenema (2006), [2]Gourley and others (2011), Gourley and others (2010), [3]Rufino and others (2006). The numbers show the fraction of N recovered and recycled in the next step.

Payment for environmental services

The negative environmental impact of livestock could increase with the growth of demand for animal proteins in the developing world (FAO, 2007). As a result, there is increasing interest in incentive systems to promote livestock production at lower environmental costs.

One possible incentive system is the payment for environmental services (PES). Most PES projects have focused on climate regulation, water management, landscape preservation, and conservation and management of biodiversity or as a bundle of these services (Landell-Mills and Porras, 2002; Wunder, 2005).

Despite the fact that livestock is widely distributed in virtually all agro-ecosystems of the developing world, there are few examples of PES targeting livestock keepers. An important question is, therefore, to what extent can PES be targeted to livestock systems in developing countries? Table 5 shows the opportunities for pastoral/grazing systems and for mixed crop-livestock systems to access PES schemes: climate regulation, biodiversity conservation and water conservation and hydrological services. Opportunities in PES schemes for livestock systems are mainly driven by the carbon market.

Table 5 - Potential for PES in livestock systems

Production systems	Climate regulation	Biodiversity conservation	Water conservation and hydrological services
Pastoral or grazing systems	Access to PES can be driven by restoration of degraded lands and implementation of sustainable grazing land management, which also presents great potential for stocking carbon (Naie and others, 2009). On optimally grazed lands, carbon accrual is greater than on ungrazed or overgrazed lands (Conant and Paustian, 2002). Also, greater livestock density reduces biomass removal through fires	Positive biodiversity effects are achievable by: reducing stocking density; protecting migration corridors; maintaining seasonal dispersal areas; refraining from poaching wildlife and reporting poaching by others; protecting natural vegetation on land and avoiding fencing or sub-dividing land; restricted grazing	PES schemes for water for livestock are in general designed to target the reduction of land-use change caused, for example, by extensive cattle grazing in forests (forest degradation diminishes water quality and quantity and increases risks associated with landslides and flooding)
Mixed crop-livestock systems	Access to PES schemes can be driven by: adoption of improved feed supplements that can lead to an emissions reduction; adoption of improved pastures with high-density trees and fodder banks that reduce land degradation; switching to organic fertilizer to increase the capacity for stocking carbon; integrated livestock and manure management	Positive biodiversity impacts achievable by: reducing stocking densities; application of sustainable management practices to reduce environmental degradation and protecting natural vegetation on land; planting trees and sustainable soil management (zero grazing and fodder and manure production)	PES schemes are in general designed to target the reduction of land-use change caused, for example, by extensive cattle ranching in the upper part of a catchment (a cloud forest may be threatened and a downstream dam may run the risk of siltation, reducing its useful lifespan). Participants can be paid to not cut trees or clear forest on enrolled land. In more intensive livestock systems, participants may be paid to limit livestock contamination (mainly determined by nutrient loadings)

Source: Adapted from Silvestri and others (2012)

The implementation of PES in livestock production can be favoured by the growing potential of the carbon market, the emerging efforts for the inclusion of PES in national policy frameworks, and by research institutes together with the private sector and farmers. PES can be an incentive to apply agricultural practices that mitigate GHG and that implement sustainable land management practices to conserve biodiversity, protect wildlife and ensure the equitable use of natural resources. Especially in the context of the developing world, where future trends foresee an intensification of the livestock sector, PES schemes may contribute to facilitating agricultural transitions (Silvestri and others, 2012) by reducing conflicts between market goods and environmental goods.

PES can benefit the poor directly through the provision of increased cash flows and as a means of promoting household income diversification, and indirectly through social and cultural benefits (Grieg-Gran and others, 2005; Pagiola, Arcenas and Platais, 2005; Pagiola and others, 2008; Turpie and others, 2008). On the other hand, there are important barriers to PES: (i) high transaction and investment costs; (ii) weak co-operative institutions among poor providers; (iii) a low degree of awareness, education and technical capacity; and (iv) poorly-defined property rights.

For most PES programmes that involve crop and livestock producers, the income generated from the environmental benefit will only be a small share of household income compared to the profits from farm production (FAO, 2007). In Africa, where close to half of the pastoralists earn less than $1/day, modest improvements in dryland natural resource management may yield gains of 0.5 t C/ha/yr[1], which translates into $50/yr, which can bring about a 14 per cent increase in income for poor pastoralists (Reid and others, 2004). Benefits from carbon PES schemes might also be associated with increases in production, creating a double benefit (Steinfeld and others, 2006). However, carbon markets will not automatically generate benefits for farmers and pastoralists without institutions to support the participation of poor households.

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[1] Considering carbon valued at $10 per ton.

Livestock in Global Development Scenarios

3

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This section presents scenarios of global development, known as Shared Socioeconomic Pathways (SSPs),

as recently developed for the Intergovernmental Panel on Climate Change (O'Neil and others, 2012). This section is largely based on Havlík and others, 2012.

The SSPs contain specified narratives developed by hundreds of stakeholders and are a set of quantified measures of how economies are likely to evolve under different socioeconomic conditions over the 21st century. This formulation allows an SSP to be designed independently of a climate-change projection.

For this study, we present three scenarios: a global baseline and two variants selected from the five SSP scenarios. The advantages of using these scenarios are:

- They represent plausible consensus estimates of global futures;

- The information base of the scenarios is broad because they represent inputs of the leading global modelling teams in many specialized fields, including agriculture, the environment, climate change and international trade;

- The modelling approach permits quantitative analysis of land use in crop farming and livestock;

- Although the SSPs represent changes in socioeconomic conditions, they can be linked to climate-change scenarios in a consistent manner for future studies.

Figure 3 shows five SSPs presenting challenges to mitigation and adaptation, across possible development pathways. SSP 1 in the lower left corner, for example, indicates a future in which challenges to both mitigation and adaptation are low. By contrast, SSP 3 indicates a future in which challenges to both are high. The world can have a low capacity to mitigate for many – unrelated – reasons (e.g. low institutional capacity or high availability of low-price fossil fuels). The same is true for adaptive capacity (e.g. low institutional capacity or slow reduction of extreme poverty in developing countries).

Figure 3 - Scenarios for Five Shared Socioeconomic Pathways

Each SSP provides a brief narrative of the main characteristics of a future development path (see O'Neill and others, 2012). As a first step, narratives are developed based on three out of the total five SSPs (SSP1 to SSP3, circled in Figure 1) by the ANIMALCHANGE EU FP7 project (see Havlík and others, 2012). We focus on three narratives that cover a wide range of plausible future developments and that, at the same time, prevent inflation in the number of scenarios under different assumptions on future climate (Representative Concentration Pathways – RCPs) and different Global Circulation Models (GCMs).

SSP1 is a sustainability scenario

with strong progress towards reducing fossil-fuel dependency and with rapid technological changes that lower the environmental costs of growth[2]. Under SSP3, the world is reducing resource intensity and fossil-fuel dependency. Low-income countries grow more rapidly, inequality between and within economies falls, technology spreads, and there is more action to reduce the environmental costs of growth. The Millennium Development Goals are achieved by 2030, resulting in educated populations with access to safe water, improved sanitation and medical care. Rapid economic growth in low-income countries reduces the number of those living in poverty. The world has an open trade economy, with rapid technological change directed towards lower environmental costs, including clean-energy technologies and land-saving technologies. Consumption is oriented towards low material growth and energy intensity, with a relatively low level of consumption of animal products. Investments in education help cut population growth. Other factors that reduce vulnerability to climate and other global changes include, for example, the successful implementation of stringent policies to control air pollutants and rapid shifts towards universal access to clean and modern energy in the developing world.

SSP2 is a continuation of current trends,[3]

with some effort to reach development goals and reductions in resource and energy intensity. On the demand side, investments in education are not sufficient to slow rapid population growth. In SSP2, there is only intermediate success in addressing vulnerability to climate change. In this world, trends typical of recent decades continue, with some progress towards achieving development goals, reductions in resource and energy intensity at historic rates, and slowly decreasing fossil-fuel dependency. The development of low-income countries proceeds unevenly, with some countries making relatively good progress while others are left behind. Most economies are politically stable with partially functioning and globally connected markets. A limited number of comparatively weak global institutions exist. Per capita income levels grow at a medium pace on the global average, with slowly converging income levels between developing and industrialized countries. Intra-regional income distributions improve slightly, with increasing national income, but disparities remain high in some regions.

[2] The scenarios have been reordered from the Inception Report. The first scenario in Inception Report was the Baseline Scenario, which is SSP2 here; the second was the Sustainability Scenario (which is SSP1 here); and the third was the Degradation Scenario (which is SSP3 here).
[3] The continuation of current trends mimics, on the demand side, the FAO projections (Alexandratos and Bruinsma 2012).

Educational investments are not high enough to rapidly slow population growth, particularly in low-income countries. Achievement of the Millennium Development Goals is delayed by several decades, leaving populations without access to safe water, improved sanitation, and medical care. Similarly, there is only intermediate success in addressing air pollution or improving energy access for the poor, as well as other factors that reduce vulnerability to climate and other global changes.

SSP3 is a degradation scenario

characterized by high population growth rates and important regional differences in wealth, with pockets of wealth and regions of high poverty. Unmitigated emissions are high, and there is low adaptive capacity and a large number of people vulnerable to climate change. The impact on ecosystems is severe. The world is separated into regions of extreme poverty, moderate wealth and a middle group that is struggling to maintain living standards among a rapidly growing population. This is a world failing to achieve global development goals, and with little progress in reducing resource intensity, fossil-fuel dependency or addressing local environmental concerns such as air pollution.

Countries focus on achieving energy and food security goals within their own region. The world has deglobalized, and international trade, including energy-resource and agricultural markets, is severely restricted. Little international cooperation and poor investments in technology development and education slow down economic growth in high-, middle-, and low-income regions. Population growth in this scenario is high because of the adverse education and per income growth trends. Urban growth mainly involves unplanned settlements, aggravating the risks of zoonoses. Unmitigated emissions are high, driven by population growth, the burning of biomass and slow technical change in energy use. Governance and institutions show weakness and a lack of cooperation and consensus; effective leadership and capacities for problem solving are lacking. Investments in human capital are low, and inequality is high. Policies are oriented towards security, including barriers to trade.

The above narratives are currently developed for all sectors, including agriculture. The ANIMALCHANGE project contributes to this initiative by refining these narratives and developing them for the livestock sector (Soussana and others, 2012). These narratives will be used for running GLOBIOM (a global model to assess competition for land use between agriculture, bioenergy, and forestry), developed by IIASA, and coupling biophysical and socioeconomic processes on a global scale.

The GLOBIOM model[4]

The Global Biosphere Management Model (GLOBIOM) (Havlík and others, 2011) is a partial equilibrium model that covers agriculture and forestry, including bioenergy. It is used for analysing land-use scenarios over many years. In GLOBIOM, the world is divided into 30 economic regions, in which consumer behaviour is modelled through isoelastic demand functions. Commodity uses "Simulation Units", which are aggregates of 5 to 30 arcmin pixels belonging to the same altitude, slope, and soil class in the same country. For crops, grass, and forest products, Leontief production functions covering alternative production systems are calibrated from biophysical models such as EPIC (Williams and others, 1995). For the present study, the supply-side spatial resolution was aggregated to 120 arcmin (about 200 x 200 km at the equator).

Economic optimization is based on the spatial equilibrium approach of Takayama and Judge (1971). Regional price-quantity equilibria are computed using the method of McCarl and Spreen (1980). The model is calibrated to year 2000 activity levels and then recursively solved in 10-year time steps from 2000 to 2050.

Livestock in GLOBIOM

GLOBIOM incorporates a detailed representation of the global livestock sector (Havlík and others, 2014). Distinctions are made among dairy and other bovines, dairy and other sheep and goats, laying hens and broilers, and pigs. Livestock production activities are defined by production systems (Herrero and others, 2013): for ruminants, grass-based (arid, humid, and temperate/highlands), mixed crop-livestock (arid, humid, and temperate/highlands), and other; for monogastrics, smallholders and industrial. For each species, production system and region, a set of input-output parameters is calculated based on the approach in Herrero and others (2013). Feeds consist of grass, crop residues, grain concentrates, and other feedstuffs. Outputs include four meat types (beef, sheep and goat meat, poultry and pork), milk, and eggs, and environmental factors (manure production, N excretion, and GHG emissions). Switches among production systems allow for feed substitution and for intensification or extensification of livestock production.

Land use

GLOBIOM defines six land types: cropland (arable and perennial), grassland, short-rotation tree plantations, managed forest, unmanaged forest and other natural vegetation (Havlík and others, 2011, and Mosnier and others, 2012). Depending on the profitability of activities by land type, land can move from one type to another subject to boundary conditions. Comprehensive greenhouse gas quantities are calculated for each land type by activity.

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[4] www.globiom.org.

Crop yields

For the three SPPs, projected yields for 2010-2100 (IIASA) are already implemented in the GLOBIOM model through collaboration with the ISI-MIP framework. In GLOBIOM, spatial expansion of crops goes into less productive land. Moreover, cities take away the best land and push agriculture towards more marginal land. Spatial results from the biophysical crop simulation model EPIC are modified by an exogenous technological factor, which is calibrated to GDP growth. This calibration allows yield increases as a function of the change from good cropland to marginal cropland.[5]

Nitrogen fertilizers

The use of nitrogen fertilizers is derived from crop input-output tables that are quantified in the narratives. Recent studies show that no major change in mineral N use efficiency can be evidenced at the global scale and for the main annual crops (J.-F. Soussana, personal communication). For N fertilizer, SSP factors affect the ratio of N fertilizer-supply increase to crop grain DM yield increase in relative units. The following values were set by SSP: SSP1: 0.75; SSP2: 1.00; and SSP3: 1.25. These modifiers are applied initially in the same way for all regions.

Pasture productivity

GLOBIOM defines pasture productivity from the EPIC model and from the CENTURY model. Initial values of pasture productivity are calibrated from survey data. Feed ratios are standardized by system and by region.

Human diets

GDP is the main driver for calorie intake per capita and for the fraction of animal products in the total diet. Projections for the three SSPs in terms of food habits were incorporated into the SSPs (Havlík and others, 2012) in the following way.

- In SSP1, a convergence (driven by elasticities) towards nutritional targets is considered, using both the IIASA definition and the WHO definition. Income elasticity for calories and animal products rises in developing countries and falls in the United States;

- The same rising and falling pattern of elasticities would occur in SSP2 but at a slower pace. GDP convergence tends to make regions converge on diet patterns. This also matches the FAO 2030 projections (Alexandratos and Bruinsma, 2012);

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[5] CropYieldAnnex.

- In SSP3, no convergence to nutritional targets was found, current trends are reinforced by GDP changes with less consumption in developing regions, but higher or stable consumptions in developed regions (same elasticities as in SSP2).

Food wastes and agricultural losses

The three SSPs are based on FAO (2011), which includes four categories of farm product losses. Post-harvest losses are functions of GDP growth under the assumption that waste-saving technologies are cheaper and more widely available in high-income nations.

- Agricultural production: loss during harvest, for animal products this includes deaths of animals. This should be neglected because it is already included in production statistics and in GLOBIOM. High losses at harvest or during production for animals are recorded especially for roots, tubers, fruits and vegetables and fish (also for animal products in some regions like sub-Saharan Africa);

- Post-harvest losses (e.g. conservation in silos). This is lower than 10 per cent except for roots and tubers;

- Losses post-harvest and during processing, packaging, transport and retailing are summed up in one variable that falls as a share of production with GDP growth. Market forces make the loss rates converge during GDP growth, and there is no reason at this stage to differentiate across SSPs; and

- Consumption wastes will be included indirectly in changes of consumption. So, when consumption goes down, this can be through waste reduction. This is included (but then indirectly across SSPs).

Macro drivers

The SSPs project two socioeconomic drivers – national population and GDP per capita. The world's population in 2050 is projected to increase from the 2010 figure of 6.8 billion to 8, 9 and 10 billion for SSP1, SSP2, and SSP3, respectively (Figure 4). In Africa and Latin America, the increases match global increases, the greatest being in SSP3 and the smallest in SSP1. In Europe, population is the highest under SSP1, where the slow increases observed over recent decades continue, and it is the lowest under SSP3, where it falls to levels near those observed in the middle of the past century.

The SSPs differ substantially in the levels of projected economic growth (Figure 5). Global GDP reaches $20,000 per capita by 2050 under SSP1, but does not exceed $10,000 per capita under SSP3. The differences in the growth rates between the scenarios are higher in developing regions (Africa, Latin America), and lower in industrialized regions (Europe).

Figure 4 - Population projections in millions (world and Asia population numbers on the secondary axis).
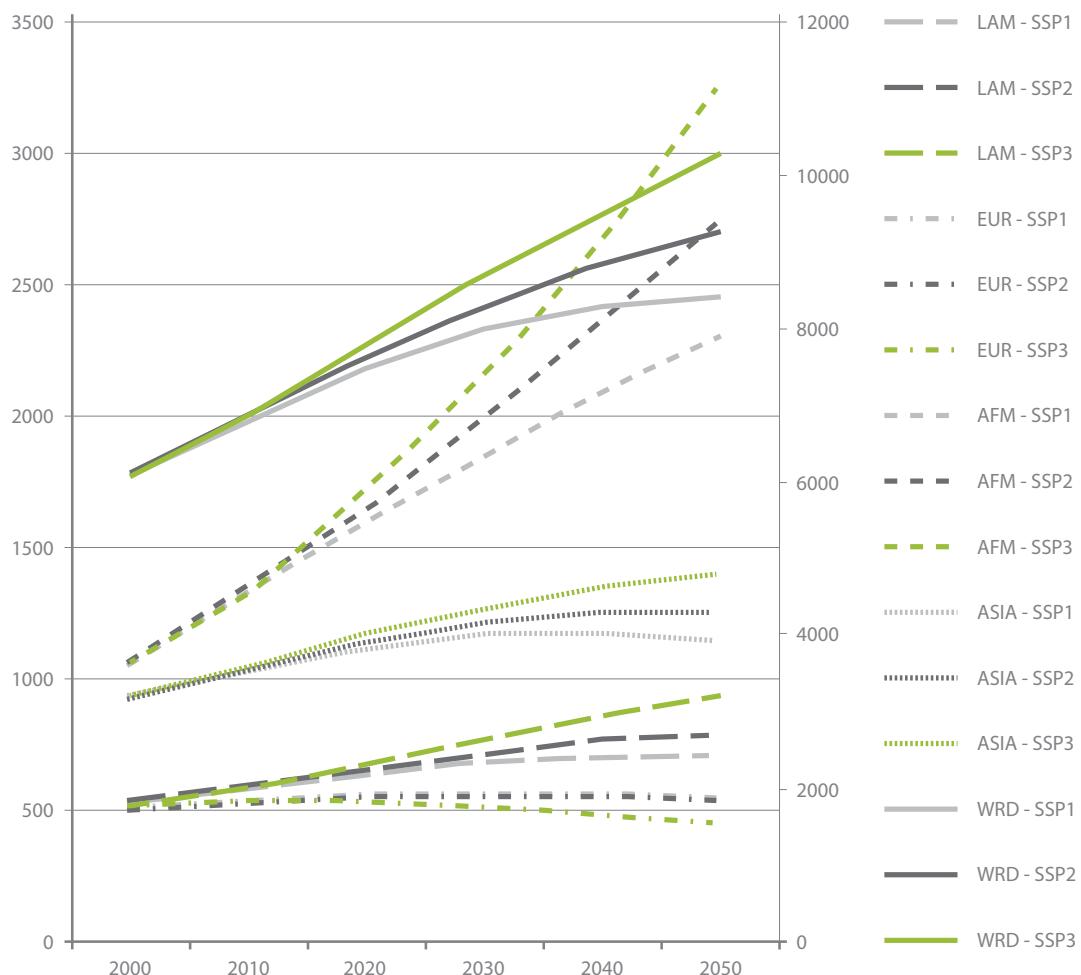
Source: https://secure.iiasa.ac.at/webapps/ene/SspDb/dsd?Action=htmlpage&page=welcome

Note: The following countries have been aggregated into the region of Asia: Afghanistan, Bangladesh, Bhutan, Brunei Darussalam, Cambodia, China, DPR of Korea, East Timor, India, Indonesia, Laos, Malaysia, Mongolia, Myanmar, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Thailand, Vietnam.

Both population and GDP growth are important drivers of future demand for agricultural commodities in general and livestock products in particular. Since, in the developing regions, they are moving in opposite directions – higher GDP growth is accompanied by lower population growth – the overall impact on demand is ambiguous.

Figure 5 - Projected GDP per capita, $2005 at MER (EUR on secondary axis).
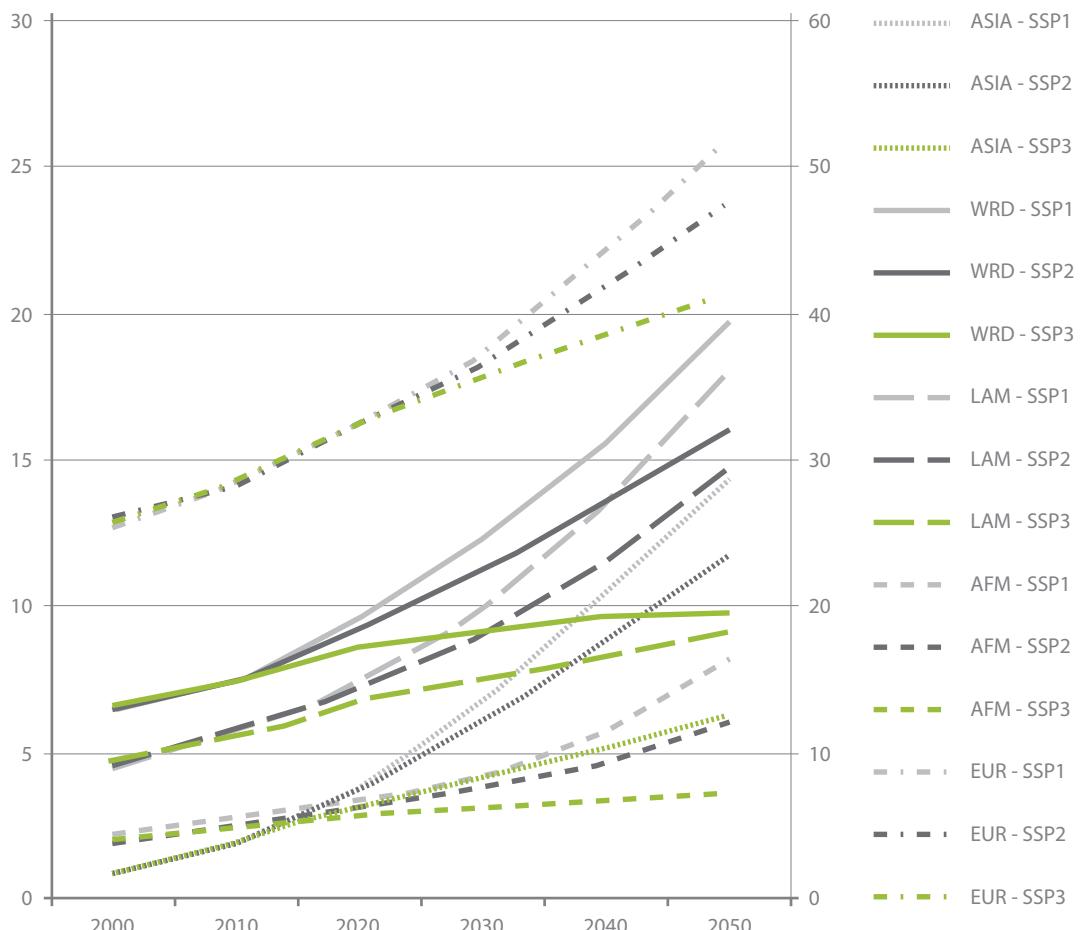
Source: https://secure.iiasa.ac.at/web apps/ene/SspDb/dsd?Action=htmlpage&page=welcome

Agriculture and land-use drivers

The SSPs provide semi-quantitative guidance about agricultural and land-use parameters. On the demand side, assumptions are provided about developments of human diet preferences beyond the conventional relationship between diets and income.

On the supply side, assumptions about technological progress and its sources are of particular interest. Between the two, there is the issue of losses and wastes, which currently represent some 30 per cent of agricultural production (FAO, 2011) and hence could play an important role in increasing the efficiency of natural-resource use.

Food demand

Food demand in GLOBIOM has three drivers: (i) population growth, (ii) income per capita growth, and (iii) response to prices.

Drivers (i) and (ii) are exogenously in the model baseline. Demand per capita increases linearly with population in each of the 30 GLOBIOM regions. GDP per capita changes determine demand according to the income elasticity values posited for each scenario. Prices (driver iii) are endogenous to each SSP scenario, and they are influenced by assumptions about technology, natural resources, and consumer preferences.

Income effects in GLOBIOM capture the pure effect of income plus the impact of other structural changes (urbanization, consumer changes with globalization, etc.) that occur with income growth. Income elasticities in GLOBIOM have two sources: the USDA elasticity dataset (Muhammad and others, 2011) and the food balance sheets (FBS) from the FAO. Indeed, although the USDA database provides a convenient ready-to-use set of elasticities, their values have been criticized, in particular in the case of Europe (see Abler, 2010). To complement this dataset with more accurate information, we performed regressions on the FAO FBS versus the change in income per capita during the period 1995-2005. When a robust trend was observed, the corresponding income elasticity was preferred to calibrate the initial year of GLOBIOM. This approach allows better use of recent trends (such as the relative decrease of cereals in consumption in several regions such as Europe or China, which are not reflected in the positive elasticities estimated by the USDA).

The food-consumption projections require assumptions about the trend of income elasticities by national income levels. To derive these elasticities, we built scenarios for future diets mainly based on FAO projections (Alexandratos and others, 2006). These scenarios are adapted to the different narratives for each modelling exercise.

The rule for developed countries is that consumption does not exceed 3600 kcal/c/d, which is slightly higher than the level of Western Europe. The only exception is the United States, which projects consumption of 4000 kcal/c/d.

It is important to note that these levels are much higher than the nutrient guidelines (usually around 2,800 kcal/c/day for a strong and active adult, see USDA, 2010), because FAO data correspond to food available for final consumption, including domestic waste.

For SSP1, future diets are considered to be more sustainable than in the FAO baseline. Therefore, some alternative assumptions are made about total consumption per capita and demand for some specific products. First, to reflect the better management of domestic waste in developed countries, consumption per capita is, in each region, assumed to be almost constant, whereas it could increase in SSP2 for some developed regions (North America, for example). Second, animal protein demand is reduced in regions where more than 75 g protein/cap/day are consumed for animal and vegetal products. A minimum consumption of 25 g protein/cap/day of animal calories is ensured, but red meat consumption is reduced to 5 g protein/cap/day (target remains possible through non-ruminant meat, eggs and milk). For developing regions, more nutritious diets are assumed, and this is materialized through an increase in protein intake at 75 g protein/cap/day and a reduction of root consumption at a level of 100 kcal/cap/day.

For SSP2, these future diets follow the projections from the FAO at projected to 2050. For SSP3, as economic growth is much lower in developing regions, the income effects alone lead to a significantly lower demand per capita in these regions.

Figure 6 - Per capita calorie availability, without price effects (kcal/capita/day)
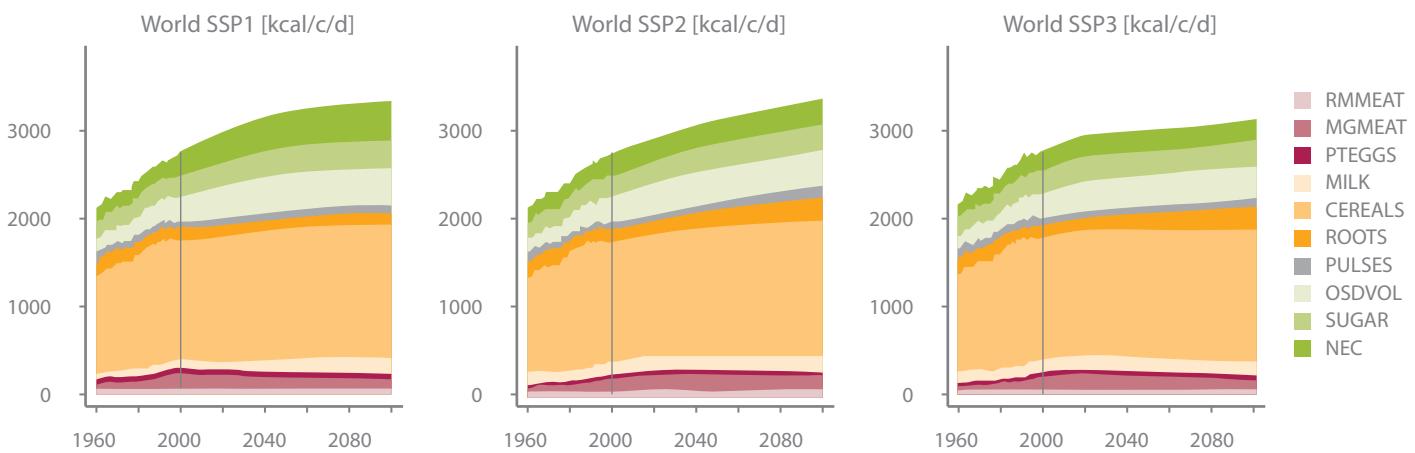
Figure 6 illustrates the differences in future consumption patterns at the global level depending on the different GDP per capita scenarios from the SSPs. Figure 7 shows the different nutrition transitions at the global level for animal products underlying the SSP scenarios, following the IIASA interpretation of the narratives.

Figure 7 - Animal food availability across SSPs without price effects (kcal/capita/day)

Legend:
- MGMEAT - SSP1
- MGMEAT - SSP2
- MGMEAT - SSP3
- MILK - SSP1
- MILK - SSP2
- MILK - SSP3
- PTEGGS - SSP1
- PTEGGS - SSP2
- PTEGGS - SSP3
- RMMEAT - SSP1
- RMMEAT - SSP2
- RMMEAT - SSP3
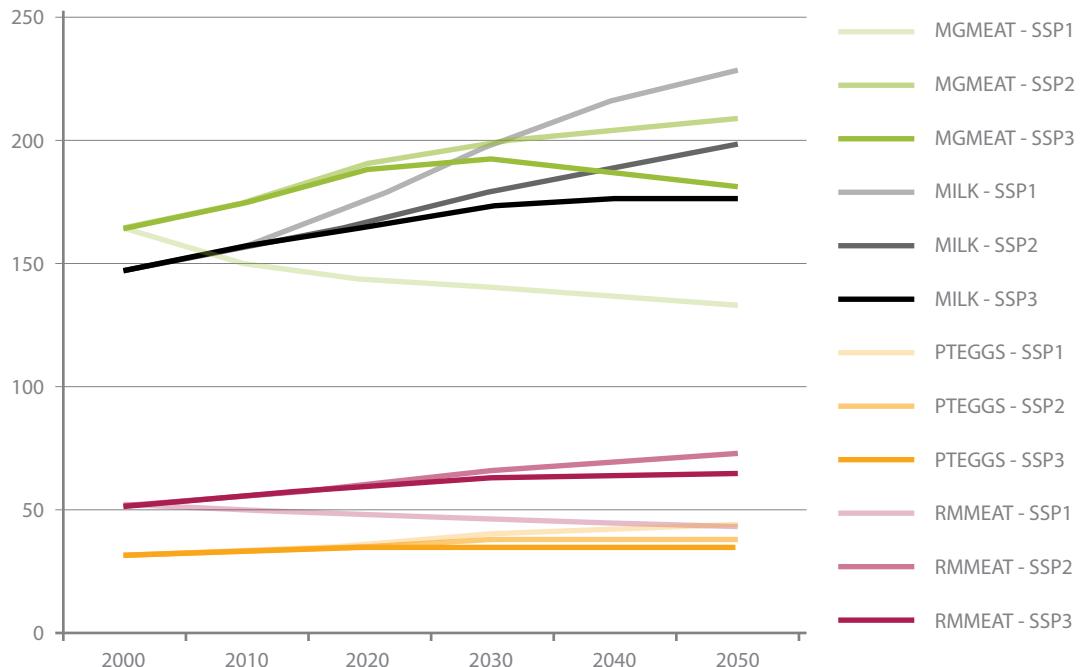
Technical progress in crop production

Technical progress in crop production is embodied in rising crop yields. Crop yields were projected based on econometric estimates of the relationship between crop yields and GDP per capita. Crop yields were fitted on national log GDP per capita over the period 1980-2009 in a fixed effects panel estimation. A separate rummy was created for country grouping by GDP category, using the World Bank's categories with slight changes in group thresholds to balance groups and to have enough observations in each group. A separate estimate was made for each of the 18 crops. Formally, the fixed effects model is:

$$y_{it}^c = \Sigma_j^M d_{ij} a_i + \Sigma_g^G g_{ig} \beta_g^c x_{it} + u_{it}$$

where y_{it}^c is the yield of country i in period t, d_{ij} denotes the fixed effects of country i with $d_{ij} = 1 \; \forall \; i = j$ and 0 otherwise; the fixed effects coefficient a_i captures the countries' individual time-invariant impact on yield; g_{ig} represents the GDP per capita group dummy with $g_{ig} = 1 \; \forall \; i \in g$ (i.e. if country belongs to GDP per capita group g), coefficient β_g^c captures the effect of GDP per capita of countries in group g, M is the number of countries in the sample, c is the crop index, and u_{it} denotes the unobserved error term.

The annual yield was forecast for each crop and country from its base yield, which is the five-year average centred on 2005. The increment in yield stemming from the GDP per capita increase of a given scenario was then added to a country's base-year yield. There is no need to account for countries' fixed effects coefficients, as it is supposed that individual country characteristics do not vary over time.

The forecast takes the following form:

$$y_{i, FORECASTYEAR}^c = y_{BASEYEAR}^c + \beta_g^c \left[(\text{In}(GDPPC_{FORECASTYEAR}^c) - \text{In}(GDPPC_{BASEYEAR}^c) \right]$$

As an example for the wheat yield forecast for the United States, the coefficient takes the value 1.785, which is the coefficient valid for all countries belonging to the high-income group. The US forecast for 2050 and projected GDP per capita in the SSP1 scenario is then calculated as

$$y_{U.S., 2050}^{Wheat} = 2.8 \left(\tfrac{t}{ha}\right) + 1.785 \left[(\text{In}(72338) - \text{In}(42600)] \left(\tfrac{t}{ha}\right) = 3.21 \left(\tfrac{t}{ha}\right)$$

In cases where the estimate was either not significant or the resulting elasticity deviated by more than 25 per cent from the historically observed elasticity at the level of GLOBIOM regions, these estimates were replaced by time series estimates, either at the country or region level.

Figure 8 shows the resulting yield projections in an aggregate over all modelled crops in terms of calories produced per hectare. In the initial ranking, the highest yields are observed in Europe, followed by Latin America and Asia, and Africa and the Middle East. This ranking is mostly preserved over the whole simulation period, although Latin America catches up with Europe under both the SSP1 and SSP2. Yields in Europe are still projected to grow by 35-50 per cent depending on the SSP. The relative yield growth in Latin America is similar to that of Africa and the Middle East: 123 per cent under SSP1, 106 per cent under SSP2, and 66 per cent under SSP3. For these preliminary scenarios, a simple assumption of the nitrogen intensity of future production was made, as reported in deliverable D2.1 – proportional increase of nitrogen utilization to yield growth (elasticity = 1) under SSP2, decreasing nitrogen intensity (elasticity = 0.75), and increasing nitrogen intensity (elasticity = 1.25). The yield projections were then used as exogenous variables in GLOBIOM.

Figure 8 - Aggregate crop yield projections by SSP (gigacalories per ha)
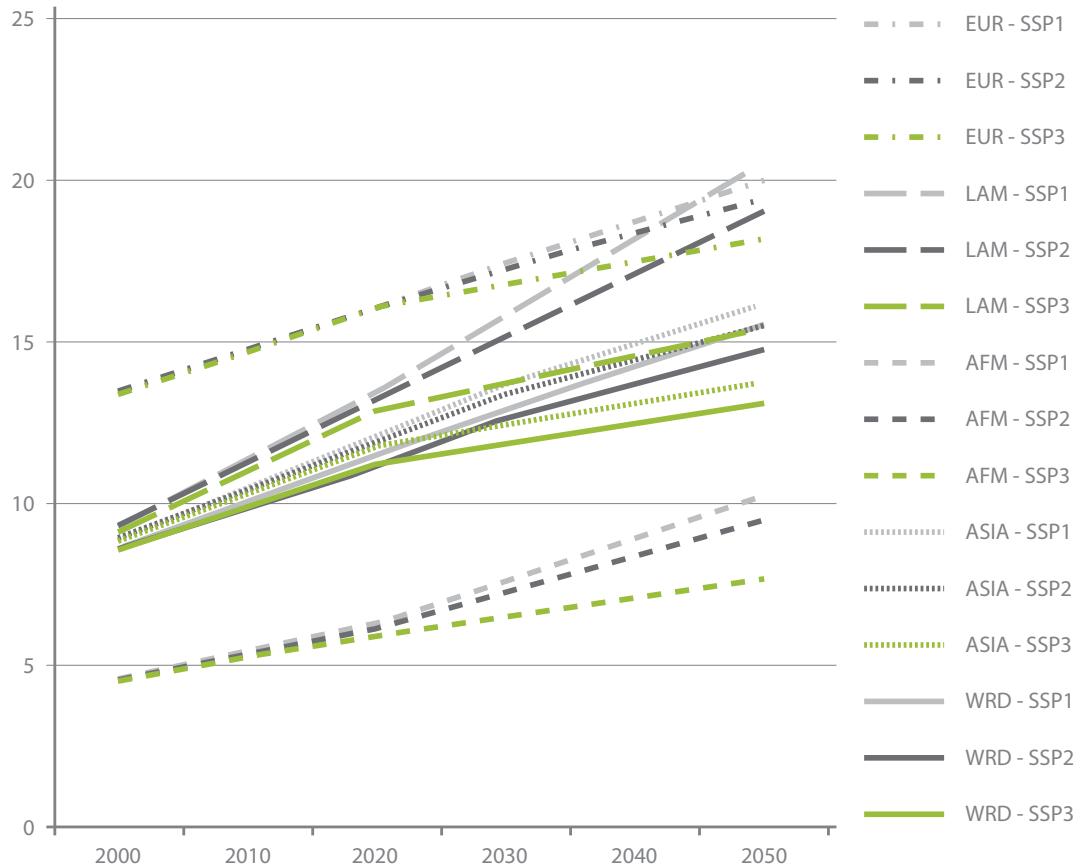
GLOBIOM has two other sources of potential yield change: (i) system changes - switches among cropping systems (intensive rainfed, extensive rainfed, and irrigated); and (ii) land changes - re-allocation of individual crops to more or less productive fields. In order to stay as close as possible to the projected yields, which already include both these effects, we have constrained the possibility of switching between the systems for the scenario runs. However, a re-allocation in space was allowed, which will lead to slight differences between the exogenous yield projections and the yields calculated as a result of GLOBIOM scenario runs.

Technical progress in livestock production

Livestock productivity can be specified in several ways. The simplest indicator is productivity per head, as shown in FAOSTAT. Unfortunately, this indicator does not account for land or feed use per head. A second indicator, the feed conversion efficiency unit of product per unit of feed, appears more relevant. However, since FAOSTAT does not report feed use by product or livestock category, and because feed coverage is not exhaustive in FAOSTAT, the feed conversion approach cannot be used here because of a lack of adequate data.

We assume that changes in the industrial organization of animal production are exogenous because we do not have reliable information in Africa that would permit an estimate of an industrial transition function, as has been done for parts of South and South-East Asia.

We applied a mixed approach to livestock productivity. First, global annual rates of the increase in feed conversion efficiency were estimated for livestock products from Soussana and others (2012) for SSP2; second, regional and SSP-specific annual rates of increase were calculated by scaling this central estimate by the rates of change estimated for crop yields as described above. Where necessary, a ceiling was fixed to avoid biologically infeasible values.

Figure 9 - Projected feed conversion efficiencies (kg protein product/kg protein feed)
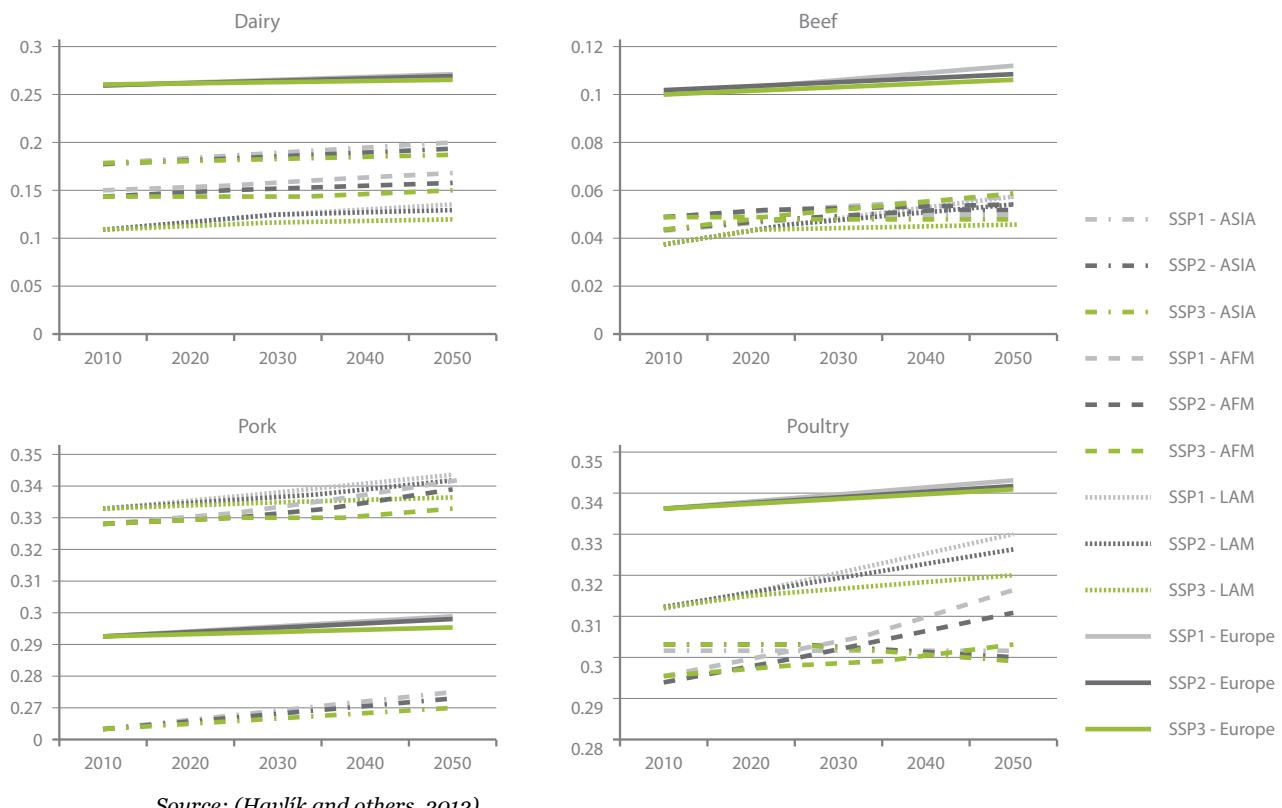
Source: (Havlík and others, 2012).

The feed conversion efficiency change for the period 2010-2050 reaches its highest value of 70 per cent in sub-Saharan Africa under SSP1 (Figure 9). Feed conversion efficiency improves by about 50 per cent under SSP2 in SSA, and similar growth is projected for Latin America for both SSP1 and SSP2. Dairy feed conversion efficiency improves in these two regions by about 20-30 per cent under SSP1 and SSP2. Pigs and poultry feed efficiencies, as well as efficiencies in Europe, usually increase by less than 5 per cent over the whole projection period given that they are already very high.

Depending on the SSP, we allow in GLOBIOM for more or less important switches between the livestock production systems. The production system structure is more or less frozen under SSP3 and fairly flexible under SSP1. This can be justified by the general assumption of better access to credit, public investment in infrastructure, capacity building etc. under SSP1 compared to SSP3. Hence, feed conversion efficiency change will be close to the projected values under SSP3, but it may differ under SSP1.

Losses and waste management

GLOBIOM does not account for agricultural losses and wastes. In order to consider losses and wastes, we used the analysis published by the FAO (2011). That study specifies three types of losses (pre-distribution) according to the phase of the production chain in which they happen (agricultural production, post-harvest handling and storage, processing) and two types of wastes (distribution/retail, consumption).

With respect to representation of these three categories in GLOBIOM and their projections in the future, we assume that "production" and hence yields as reported by FAOSTAT are net of losses during agricultural production. Hence, their developments are included already in the crop-yield projections based on historical FAOSTAT crop yields and do not require particular attention here. "Consumption" in the FAOSTAT food balance sheets is reported gross (before subtraction of the consumption wastes). Hence, assumptions about consumption wastes are implicitly included in the food demand projections.

Thus, for explicit losses and wastes (LW) analysis, we are left with three categories. For projections of future rates of these losses and wastes, we decided to investigate their relationship to GDP per capita in a cross-section approach for the regional aggregates reported by the FAO (2011). Five product categories were considered (cereals, oilseeds and pulses, roots and tubers, meat, and milk). However, only for oilseeds and pulses and milk were the losses and wastes to be covered in GLOBIOM both important enough and did a clear relationship between the GDP per capita and the LW rates exist. Thus, the LW narratives were quantified only for these two product categories.

Figure 10 - Losses and wastes of oilseeds and pulses (% of production)
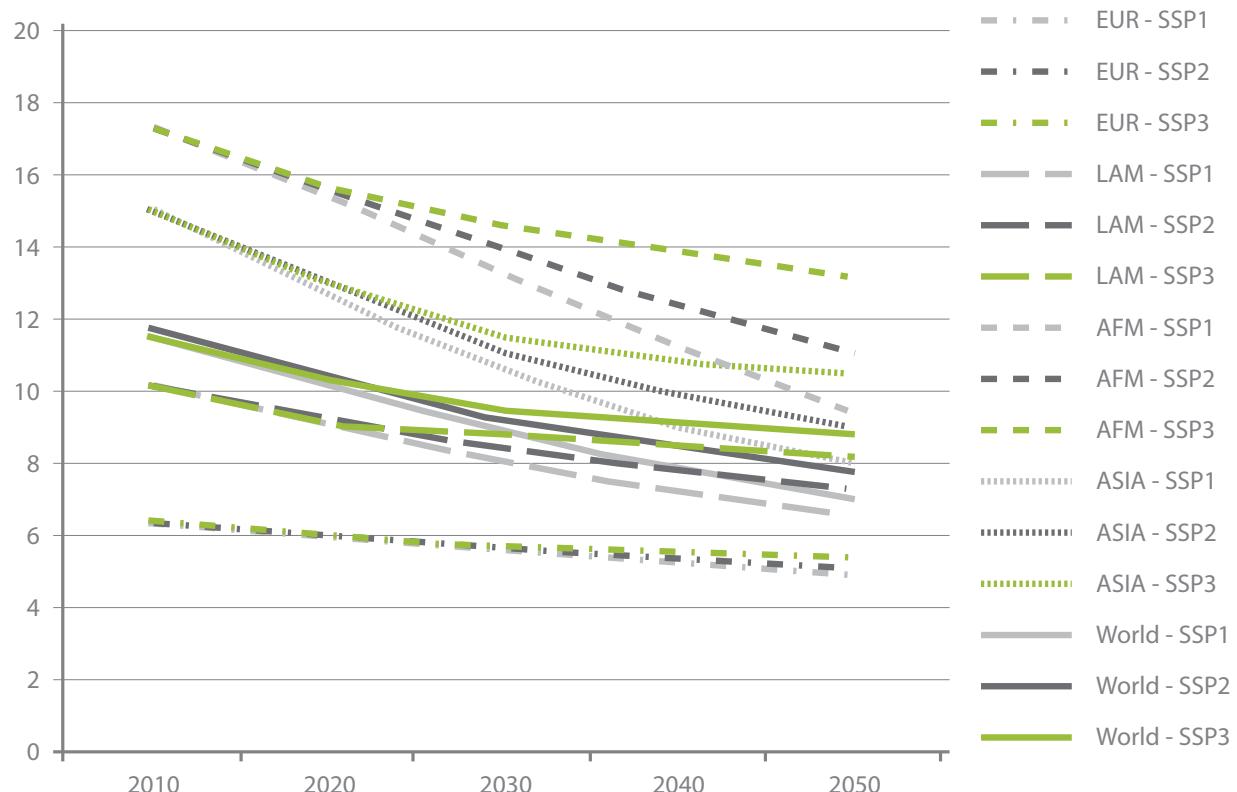
Globally, the gains from reducing losses and wastes could add 3-5 per cent to the milk supply. These effects are small compared to the crop yield and feed efficiency in dairying, but they can play some role in particular regions. The highest losses and wastes (LW) in the oilseeds and pulses sector were observed in Africa and the Middle East region, 17 per cent, and the lowest LW was in Europe, 6 per cent (Figure 10). Under SSP1, LW in Africa and the Middle East would go down 10 per cent. Globally, LW would go down from 12 per cent to 7-9 per cent depending on the SSP. In the dairy sector, the highest losses and wastes occurred in Asia, followed by Africa and the Middle East (Figure 11). In Africa and the Middle East, they are projected to go down from 12 per cent to 4-9 per cent depending on the scenario.

Figure 11 - Losses and wastes in dairying (% of production)
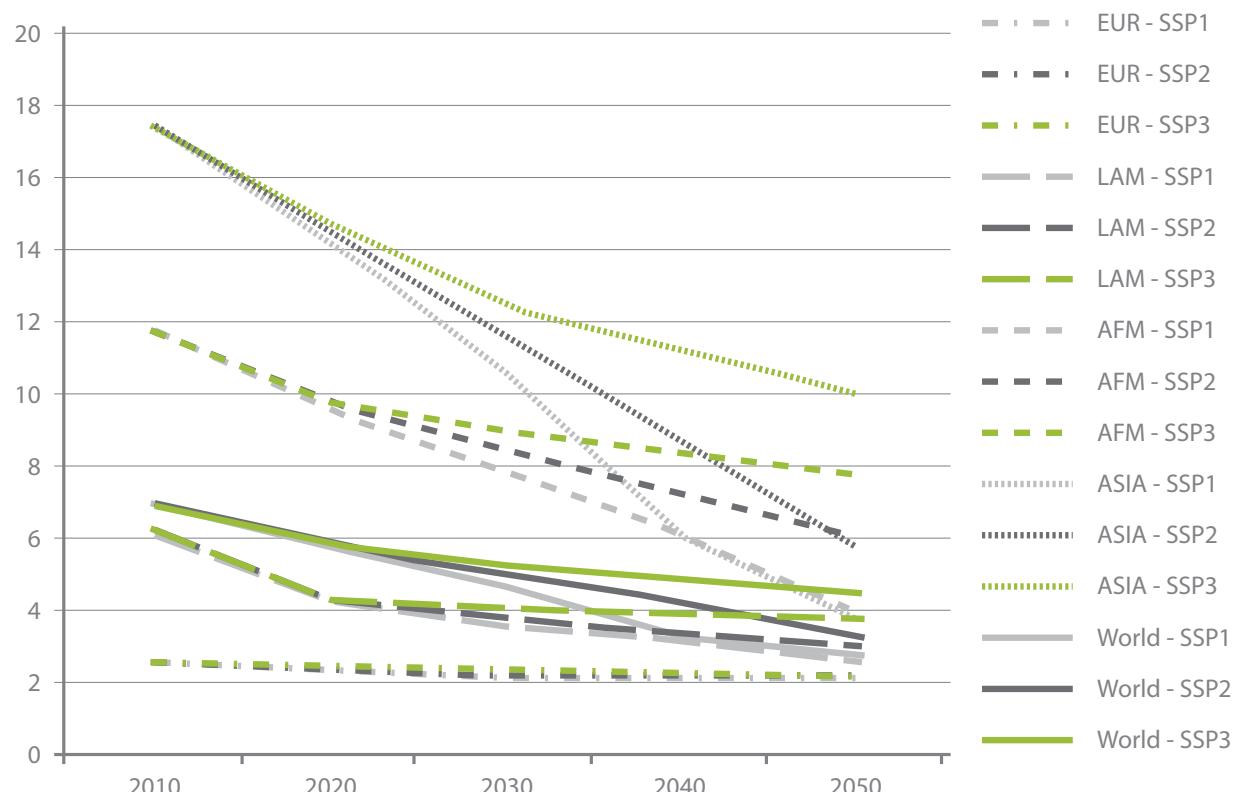
Livestock in Global Development Scenarios

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Results

African livestock futures
under the SSP scenarios to 2050

Consumption

Global calorie consumption per capita would increase the most under SSP2, where it would be 14 per cent higher in 2050 compared to 2000. Owing to lower GDP growth and to slower technical change leading to higher production costs, calorie consumption per capita would only increase by 3 per cent under SSP3. Total calorie consumption per capita under SSP1 would, on a global scale, reach similar levels as under SSP2, but both the regional and the commodity structure would exhibit significant differences (Figure 12). With respect to the commodity structure, crop product consumption would increase by 10 per cent and livestock product consumption by 37 per cent under SSP2, whereas it would be 12 per cent and 19 per cent under SSP1. The relative stagnation of per capita livestock product consumption hides a 2 per cent decrease in meat consumption and a 61 per cent increase in milk consumption.

Figure 12 -- World food consumption per capita (kcal/capita/day)
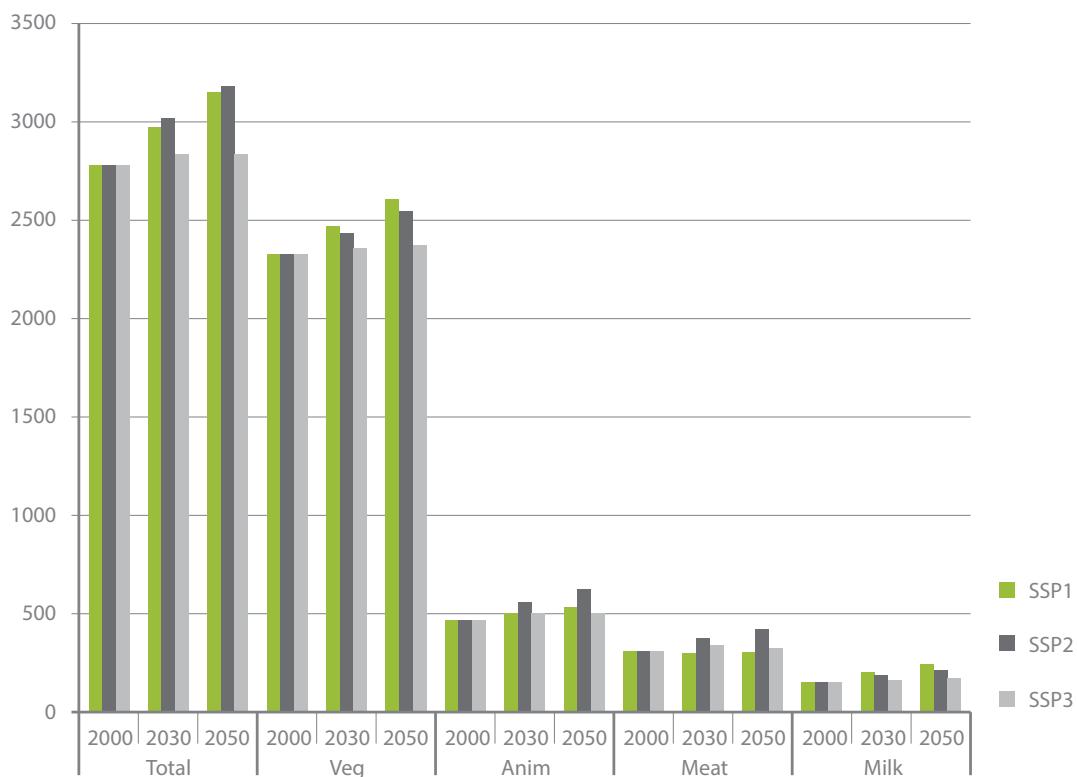
Regional differences in per capita consumption of animal products are striking in the base year of 2000. As shown, the global per capita consumption was about 450 kcal/cap/day, varying from about 200 kcal/cap/day in Africa and the Middle East (AFM) to 1,000 kcal/cap/day in Europe. Also, in Latin America (LAM), livestock product consumption was above average. In 2050, the highest per capita consumption would be reached under SSP2. Under SSP3, low economic growth and poor technological progress would lead to a relatively small (compared to SSP2) increase in Europe, Latin America and Asia and would result in quasi-stagnation in Africa and the Middle East. Under SSP1, more sustainable diets and better household waste management would lead to a decrease in livestock product consumption in Europe (-2 per cent), and to an increase of 43 per cent in Africa and the Middle East due to high economic growth and fast technological progress.

Figure 13 - Livestock product consumption per capita (kcal/capita/day)
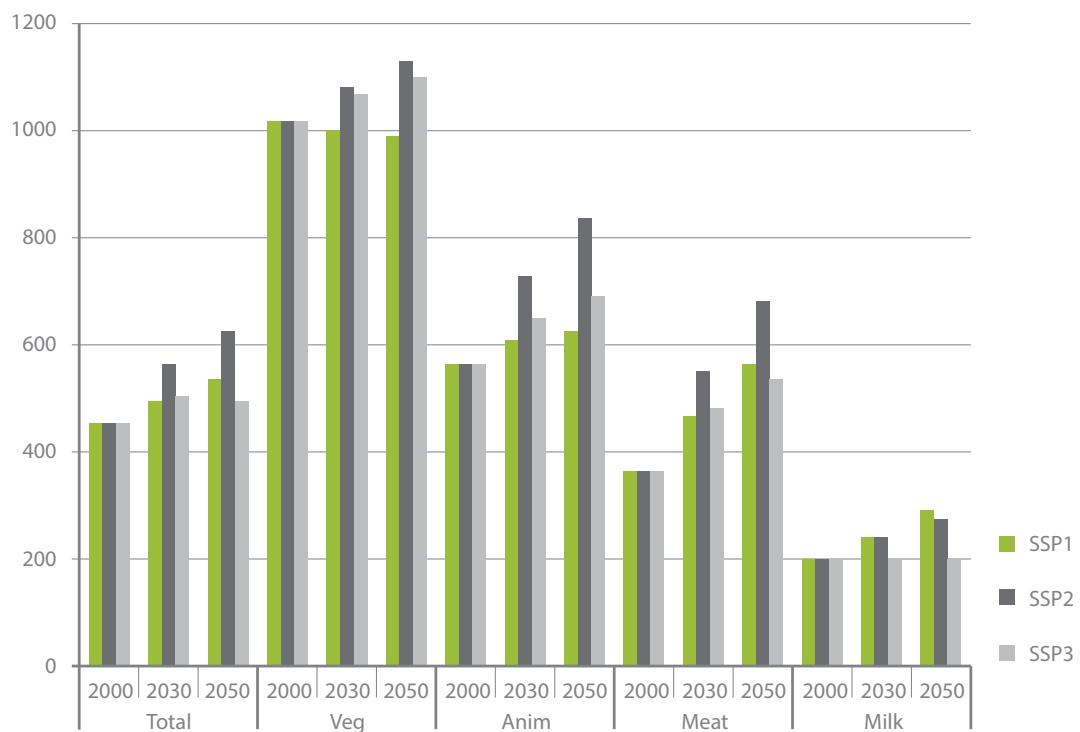
These per capita food consumption changes would translate globally to a 73 per cent increase in total calorie consumption under SSP2 by 2050, corresponding to a 66 per cent increase in crop product consumption and a 106 per cent increase in livestock product consumption (Figure 13).

Figure 14 - World food consumption - total (petacalories)
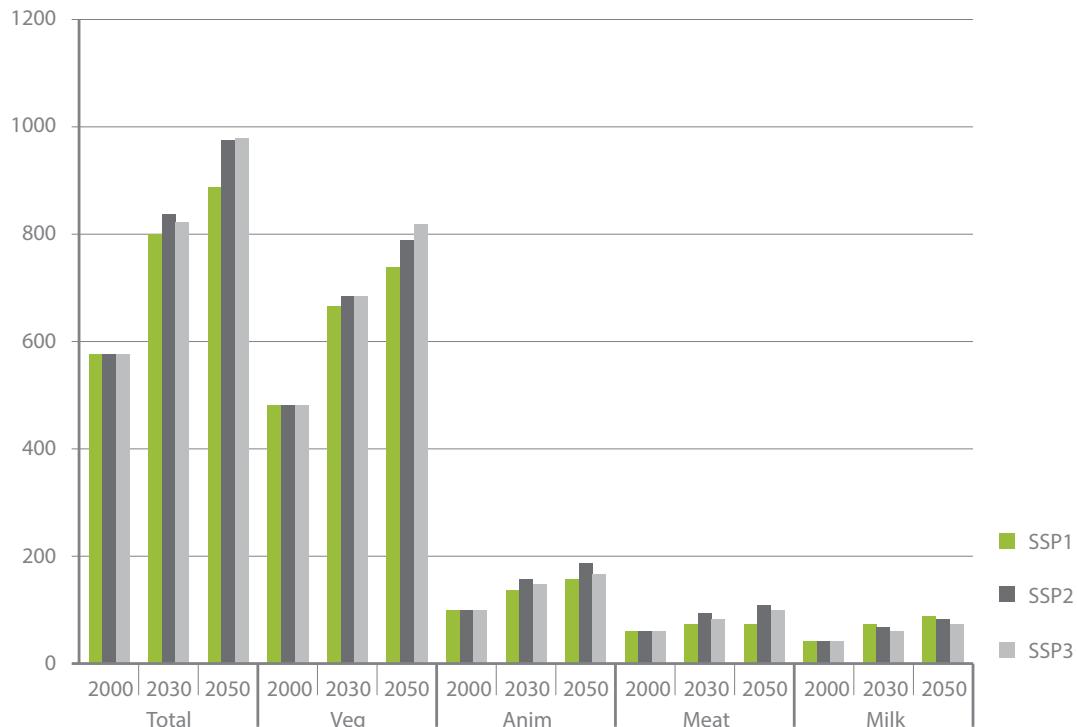
In 2000, about 30 per cent of global livestock consumption occurred in Asia (Figure 13). Latin America consumed about one-third and Africa and the Middle East about one-fifth of the livestock calories consumed in Asia. In 2050, under SSP2, Asia continues to dominate growth in consumption, followed by Africa and the Middle East and Latin America. In contrast, Europe roughly maintains the same level of consumption of animal products. Europe's share of total consumption would hence fall to 10-12 per cent.

Figure 15 --Livestock product consumption - total (petacalories)
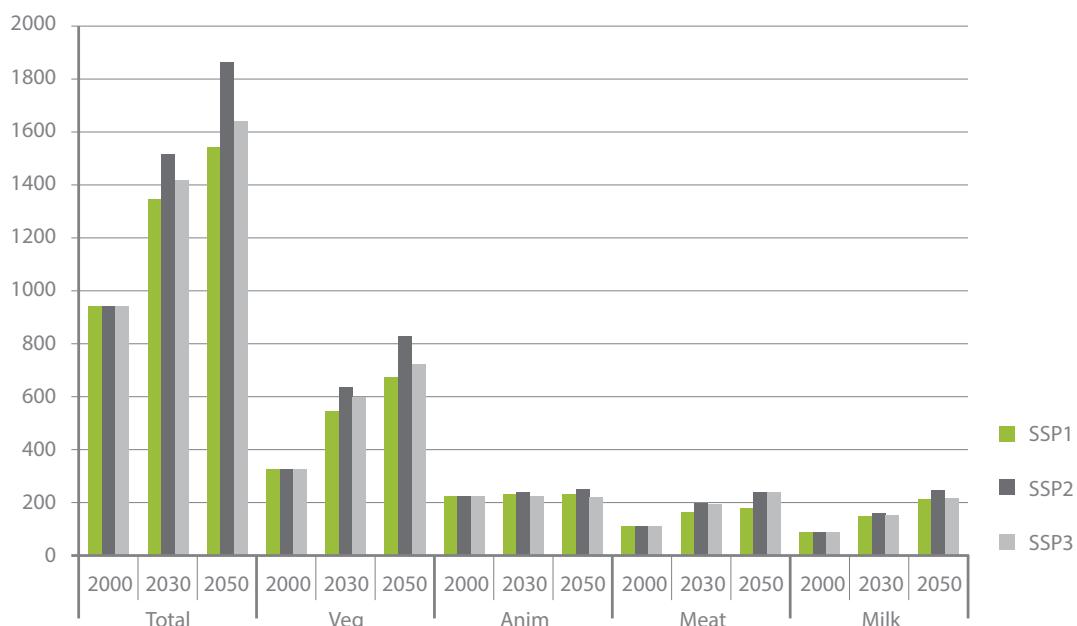
The only demand for livestock products in GLOBIOM is for human consumption. For crop products, GLOBIOM includes demands for feed and "process demand", the latter being attributed to biofuels.

Feed is the second-largest item after food in the total crop demand. It would peak at 44 per cent of total demand under SSP2. Process demand/demand for crops for first-generation biofuels would, in 2050, reach their largest share under SSP1 – 9 per cent of all crop production in terms of calories.

Figure 16 - World demands for crops in primary commodity equivalent (petacalories)
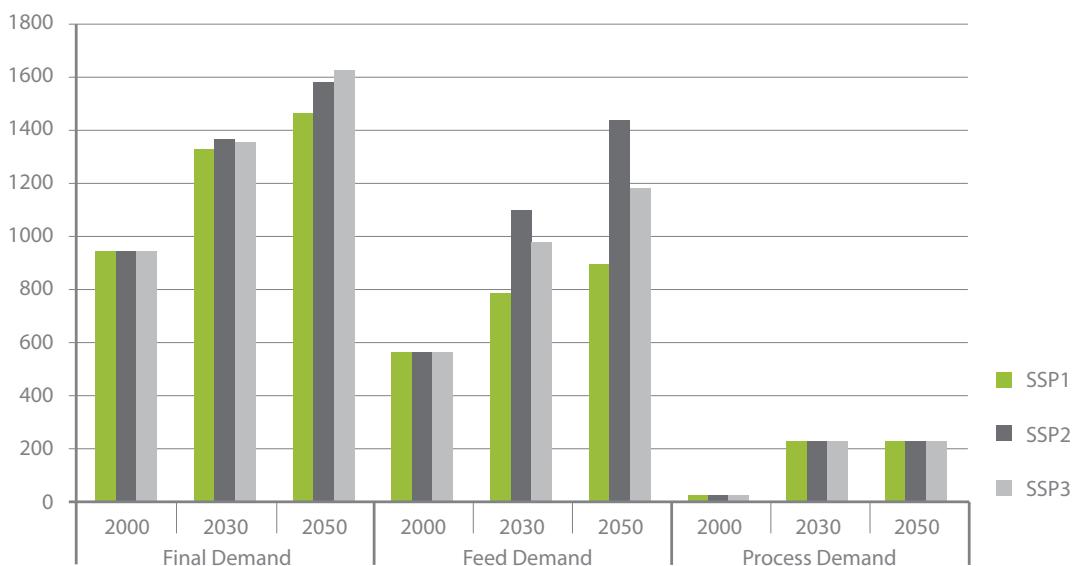
Crop feed demand distribution across the regions mimics livestock production in 2000. In 2050, the demand for feed crops is the highest in Asia for all scenarios. It is also the highest under SSP2 for all project regions. Under SSP1 and SSP3, it is stagnating in Europe. Apart from the Asian case, under SSP3, the feed demand is the highest in Latin America; under SSP1, it is the highest in Africa and the Middle East.

Figure 17 - Demand for feed crops by region (petacalories)
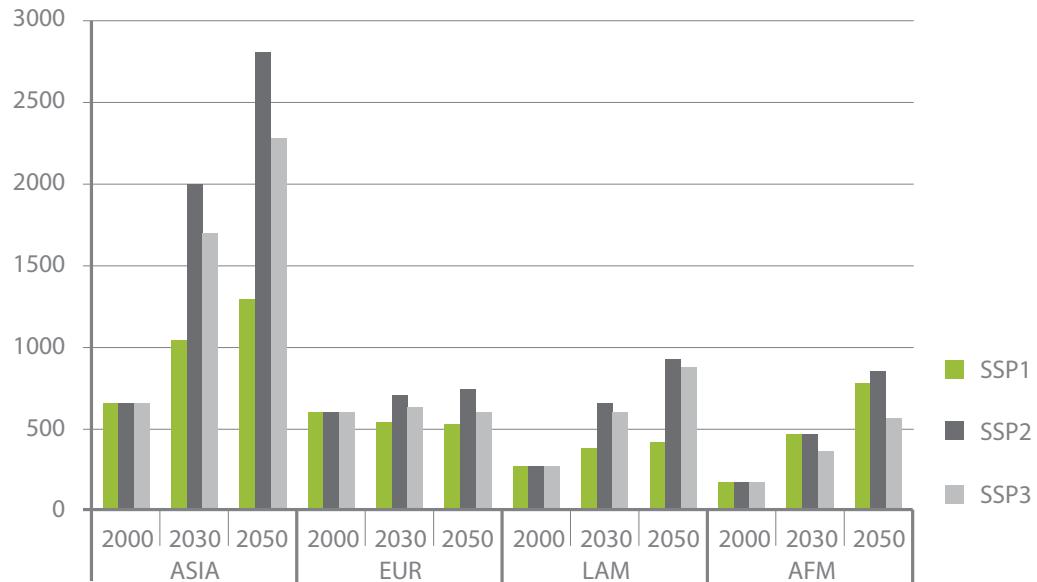
Production

Crop production would increase between 2000 and 2050 globally by 109 per cent under SSP2. The increase would be similar under SSP3, +95 per cent, and only under SSP1 would the increase be substantially lower, +66 per cent. Different regions are projected to contribute differently to this growth (Figure 18). While in Europe, crop production is projected to increase by 63 per cent under SSP2, it is projected to double in Asia, increase by almost 150 per cent in Latin America, and by 250 per cent in Africa and the Middle East. Under SSP3, the supply is expected to develop similarly in Europe, Asia and Latin America, but the lack of technological change will substantially reduce growth in supply in Africa and the Middle East, at +180 per cent.

Figure 18 - Supply of vegetal calories by region (petacalories)
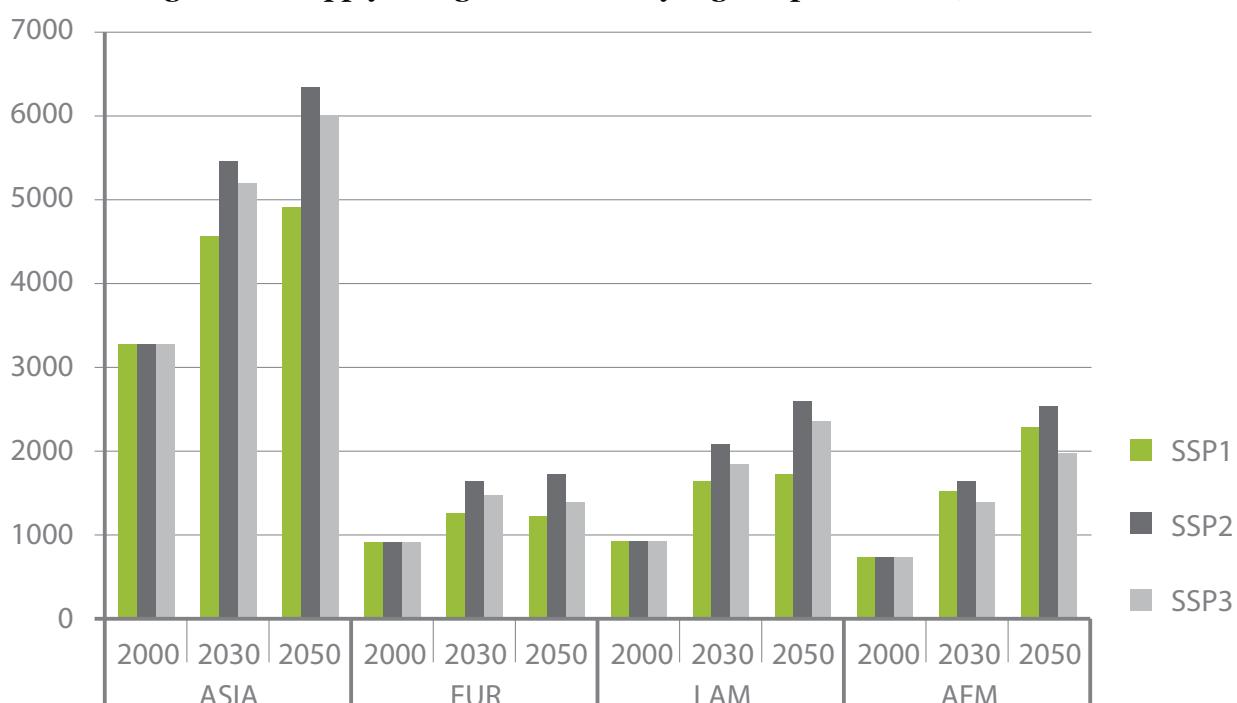
Livestock production is projected to nearly double under SSP2, growing by 92 per cent globally to 2050. The relative changes in production across regions are similar to those of crop production, with the exception of Europe, where livestock production is expected to be almost constant.

Figure 19 - Supply of animal calories by region (petacalories)
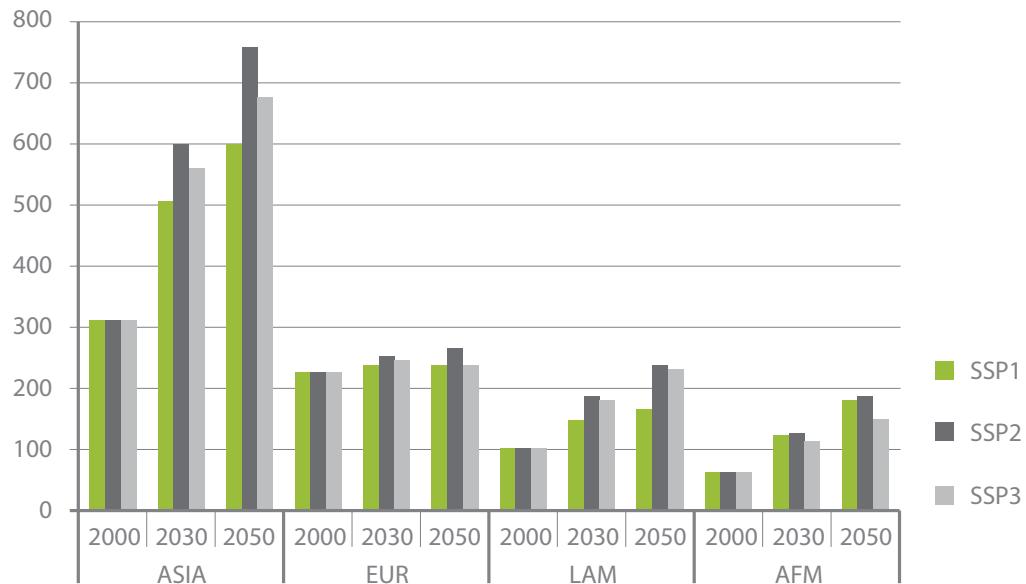
Prices

GLOBIOM projects relatively stable agricultural commodity prices. The crop price index is projected to remain between 1.01 and 1.04 compared to 2000 at the world level under SSP2, being slightly lower in Europe and Latin America, and higher in Africa and the Middle East (Figure 20). Asia is projected to follow the general global price trend across all scenarios to 2050. The livestock product price index is projected to reach about 1.06 under SSP2 both by 2030 and 2050, with again the lowest price increase in Europe, a slightly higher increase in Latin America and substantial increases, over 50 per cent, in Africa and the Middle East (Figure 21).

Figure 20 - Crop price index compared (2000 = 1)
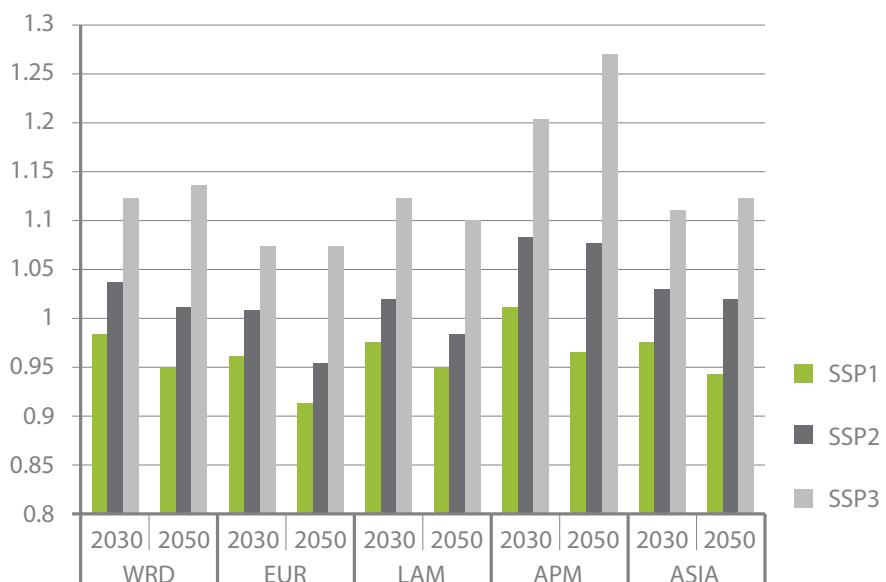
Both the crop price index and the livestock product price index calculated with respect to 2000 price levels take the highest values under SSP3 and the lowest values under SSP1, although the production tends to be highest under SSP2. This points to differences in the major drivers of these scenarios. Under SSP3, relatively high population growth and relatively low technological progress lead to high producer prices. Under SSP1, relatively low population growth, sustainability considerations in Western diets, and a fast rate of technological progress lead to low prices.

Figure 21 - Livestock product price index compared (2000 = 1)
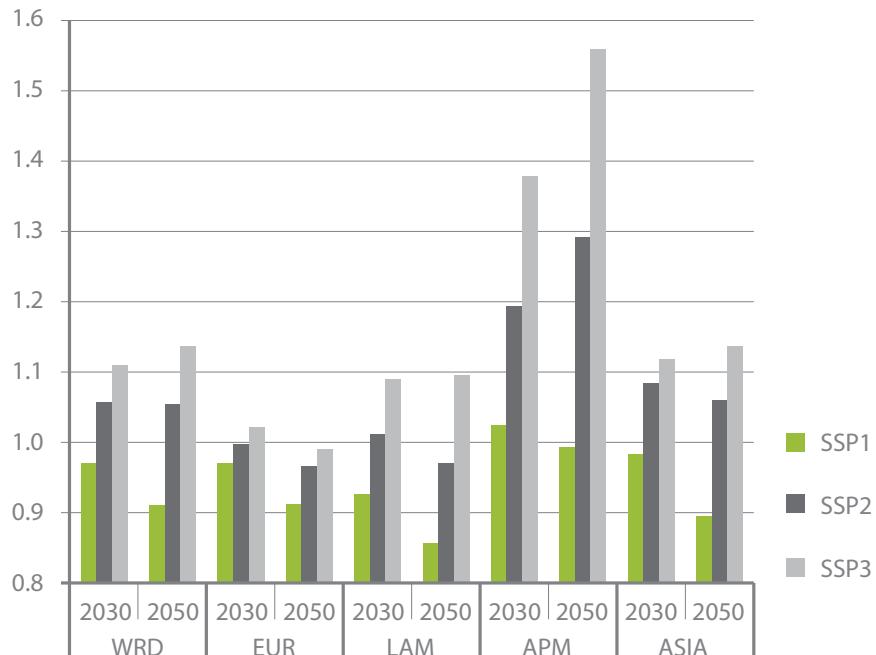
Land use

Increased production will come to some extent from intensification of production on existing agricultural land but will also require expansion of agricultural activities to other land cover types. We estimate that, under SSP2, 175 million ha of additional cropland and 300 million ha of additional grassland would enter production by 2050 compared to 2000 (Figure 22). These numbers compare fairly well with the FAOSTAT land-use statistics, which report that, between 1961 and 2009, the area of arable land and permanent crops increased by 162 million ha, and the area of permanent meadows and pastures increased by 269 million ha. Additional demand for about 150 million ha of land comes in our model from short-rotation tree plantations providing feedstock for bioenergy. The total expansion would hence reach 625 million ha covered, with 35 per cent from expansion in forests and 65 per cent from expansion in other natural land. This would mean, in absolute numbers, an average rate of deforestation of about 4.4 million ha per year. Recent rates of deforestation, as reported by FRA2010, were 8.3 million, 4.4 million and 5.6 million ha per year over the periods 1990-2000, 2000-2005, and 2005-2010, respectively.

Figure 22 - Cumulative land cover change over 2000-2050 (million hectares)
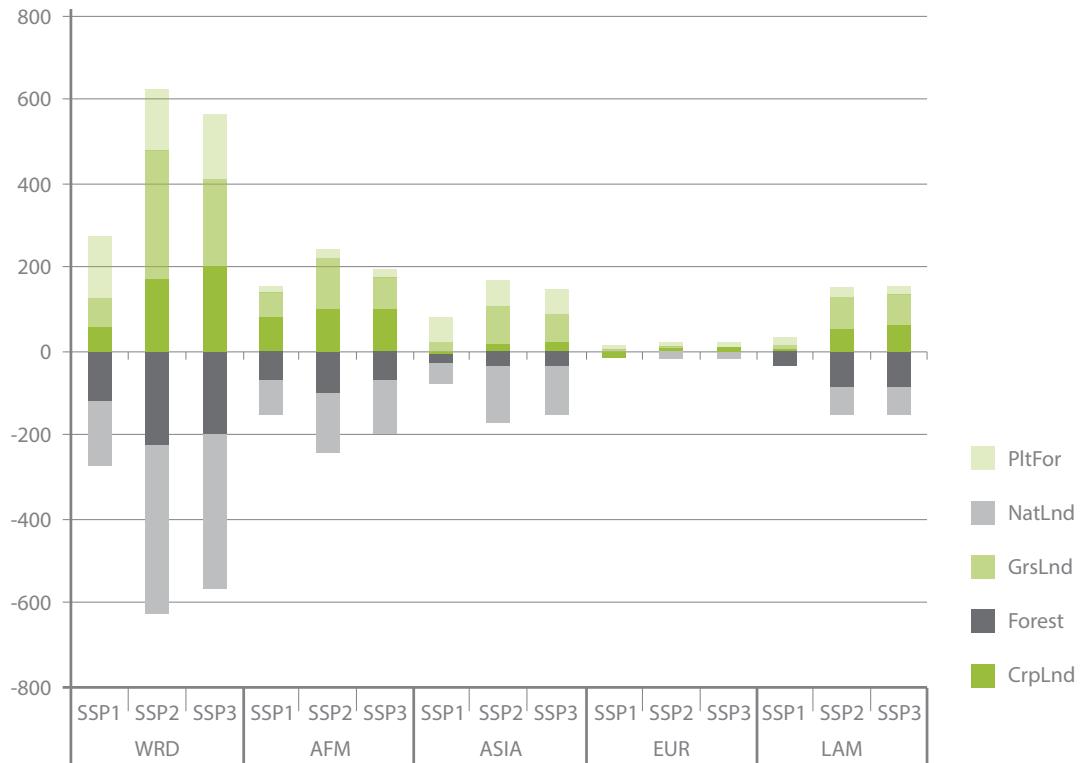
Land cover changes are not equally distributed across regions.

About 55 per cent of global cropland expansion is projected to occur in Africa and the Middle East, about 30 per cent in Latin America, and only 4 per cent in Europe. For grassland, 43 per cent of the expansion is projected in Africa and the Middle East, 27 per cent in Latin America, and less than 1 per cent in Europe. About 44 per cent of total deforestation is projected in Africa and the Middle East, and 37 per cent in Latin America.

SSP2 is the scenario with the highest demand for additional agricultural land because of the mix of sustained demand and moderate yield increases. Under SSP3, lower meat demand caused by lower economic growth and higher production prices leads to grassland expansion that is 30 per cent lower than under SSP2, which causes the total agricultural land expansion to be lower, albeit with slightly higher cropland expansion. Under SSP1, both cropland and grassland expansion represent less than 30 per cent of the expansion necessary under SSP2, leading to conversion of just 44 per cent of forests and other natural land.

Cropland management.

Exogenous crop yield increases are the highest under SSP1 and the lowest under SSP3 (IntsEf in Figure 21). However, this is only one source of yield change in GLOBIOM. The other one appears at higher spatial aggregates and is due to re-allocation of the production across the individual simulation units. This effect is negative under SSP1 and mostly positive under SSP3. One interpretation could be that since technological progress is assumed to be low and total demand relatively high because of the large population, which together lead to high agricultural prices, crop production seeks to, on the one hand, use the best available resources, and, on the other hand, is competitive in acquiring them. Another potential reason for this phenomenon could be that technological progress makes it possible to develop crop production also in regions that start from very low yields but improve rapidly. From this latter perspective, the positive aggregation effect would suggest that, with low crop-yield growth, production will seek the most productive regions. The sum of the two effects leads to the highest overall yield increase under SSP2 and not SSP1, as could be expected. The aggregate crop-yield increase over 2000-2050 reaches about 70 per cent globally under SSP2. It reaches some 40 per cent in Europe, and 90 to 115 per cent in Latin America and Africa and the Middle East.

Figure 23 - Total crop-yield change in terms of calories over 2000-2050 decomposed between intensification/exogenous and aggregation effects (%)

Figure 24 - Additional nitrogen consumption compared to 2000 (%).
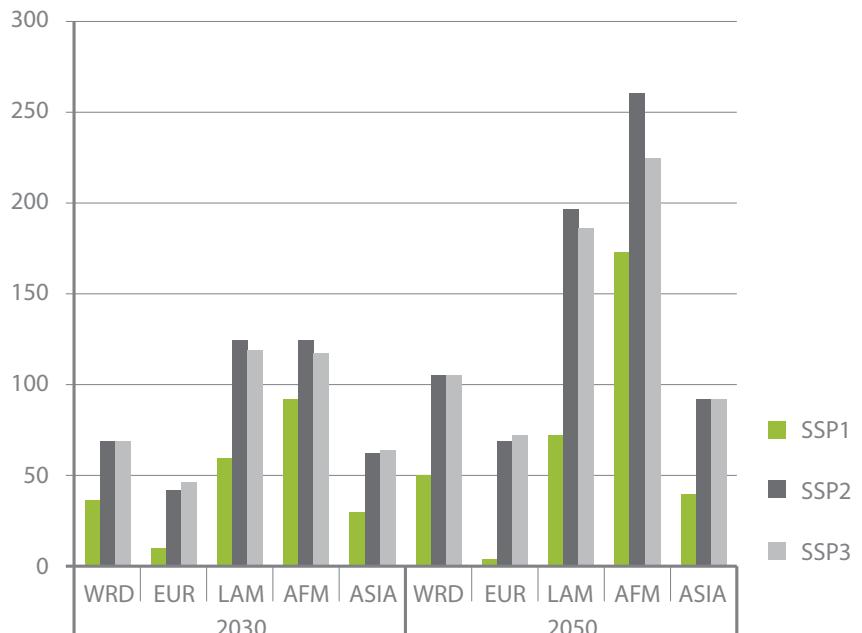
Increased yields would require additional inputs. We estimate that, globally, the use of nitrogen fertilizer would need to double under SSP2 by 2050 (Figure 24), and also 15 per cent more irrigation water would be required, especially in Africa and the Middle East (Figure 25).

Figure 25 - Additional irrigation water consumption compared to 2000 (%)
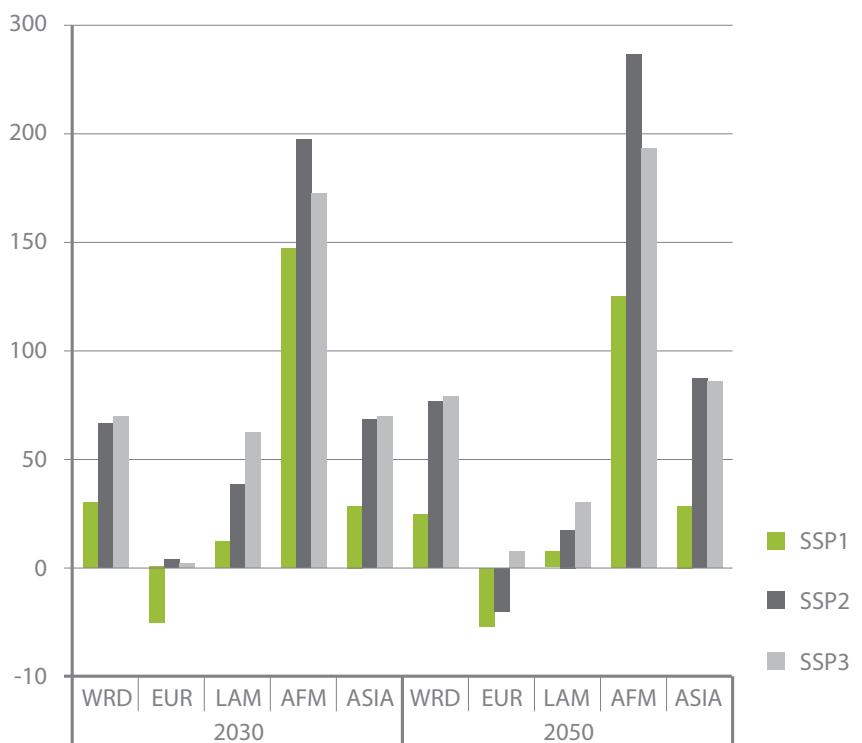
Livestock production

We have seen before that total livestock production is projected to increase by about 92 per cent (expressed in calories). Under SSP2, the growth in production of the different commodity aggregates is relatively equally distributed: +106 per cent for monogastric meat and eggs, +88 per cent for ruminant meat, and +85 per cent for milk. The model results are a good reflection of our assumptions about sustainable diets under SSP1, where the share of ruminant meat decreases substantially, whereas milk production is less restricted, and, overall, per capita food consumption is limited. This results in ruminant meat production increasing by 22 per cent only between 2000 and 2050, with the supply of monogastric products increasing by 45 per cent, about half of the growth under SSP2, and milk production growing even more than under SSP2, by +91 per cent (Figure 26).

Figure 26 - Global livestock production by product (million tons protein)
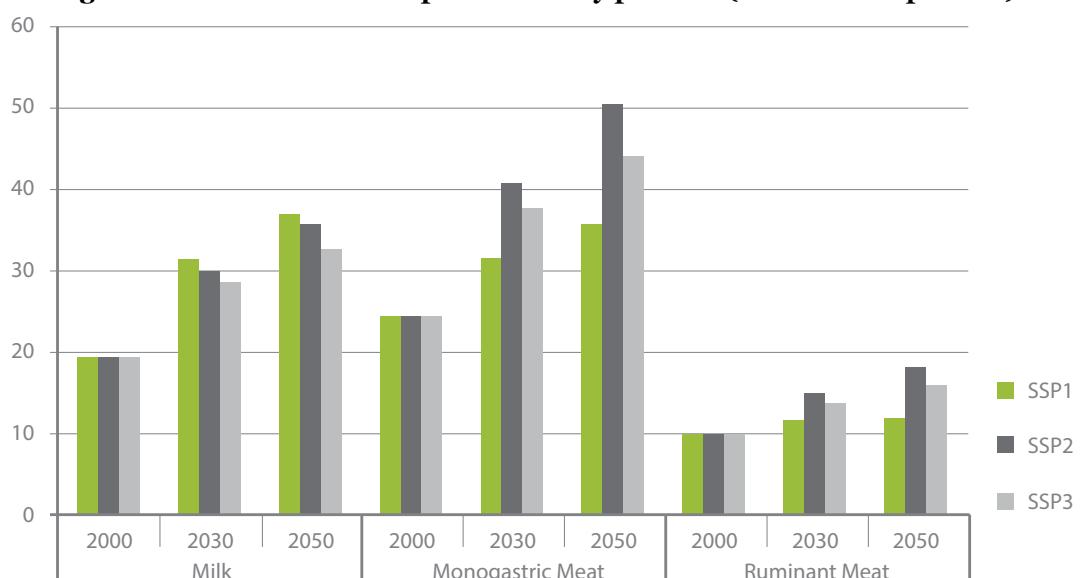
Monogastric production is likely to grow between 40 per cent (SSP1) and 125 per cent (SSP2) in Asia depending on the scenario. In Latin America, monogastric production is projected to increase by 170 per cent, and it is expected to increase nearly sixfold in Africa and the Middle East (Figure 27). It is still projected to grow in Europe under SSP2, +33 per cent by 2050. However, this growth looks like stagnation when compared with projected developments in the other regions.

Figure 27 - Global monogastric production by region (million tons protein)
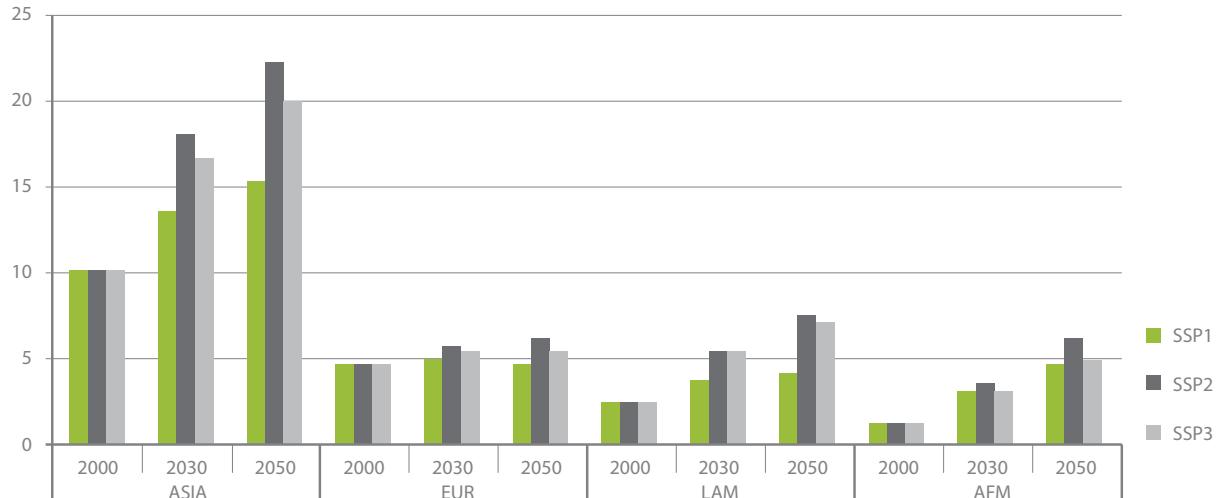
European ruminant meat production is projected to increase only by 15 per cent by 2050 under SSP2 (Figure 28). Ruminant meat production in Latin America and in Africa and the Middle East is projected to grow by 125 per cent and 160 per cent, respectively, but the different scenarios would have very different effects in these two regions. Under SSP3, the low economic and technological growth in Africa and the Middle East would lead to growth of 70 per cent only, while production would be similar to that of SSP2 in Latin America. On the other hand, under SSP1, lower global demand would push down production in Latin America (+21 per cent only), but the sustained demand in Africa and the Middle East together, with their improved competitiveness, would still lead to growth of 112 per cent compared to 2000.

Figure 28 - Global ruminant meat production by region (million tons protein)
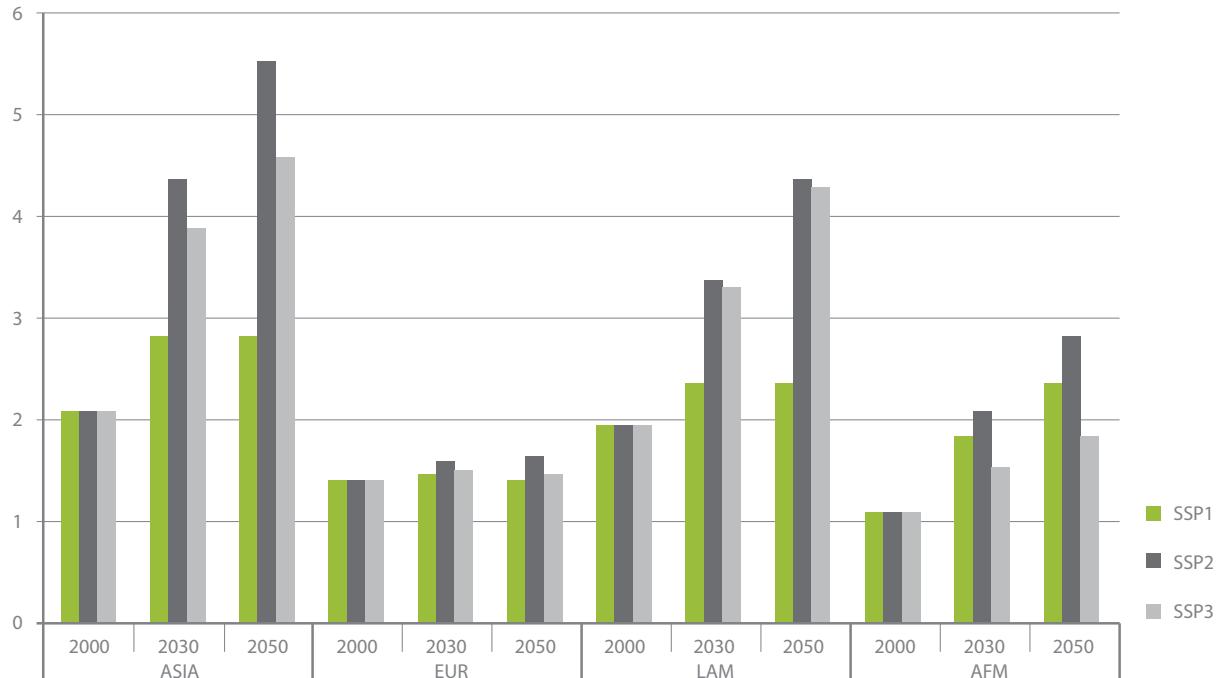
Unlike ruminant meat production, milk production is not negatively affected under SSP1. It is almost as high as under SSP2 in Latin America, and it is even the highest of the three scenarios for Asia and for Africa and the Middle East (Figure 29).

Figure 29 - Global raw milk production by region (million tons protein)
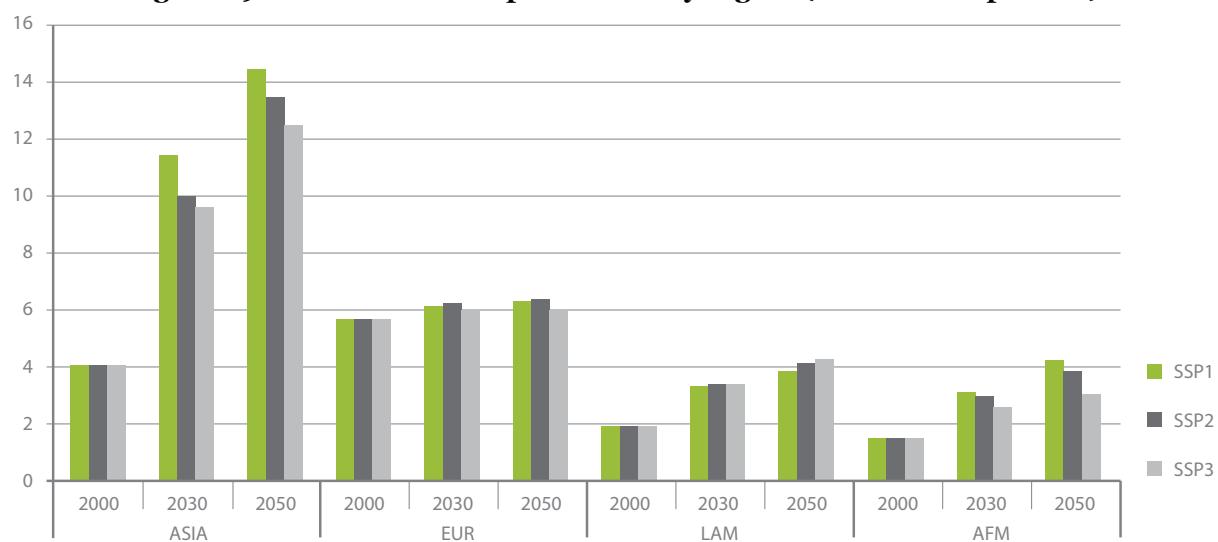
Livestock production by system

Livestock production will have different impacts on greenhouse gas emissions and other environmental variables depending on the production systems and their related productivity and feed use. In 2000, 88 per cent of global monogastric production came from industrial systems (Figure 30). While these systems were supplying 94 and 92 per cent of the production in Europe and Latin America, respectively, the majority (67 per cent) of the production in Africa and the Middle East still came from smallholder systems (Herrero and others, 2013). We do not expect further substantial increases in industrialization in Europe and in Latin America; in Africa and the Middle East, however, their share is projected to increase from 33 per cent to about 80 per cent by 2050, regardless of the scenario chosen.

**Figure 30 - Monogastric production by system
(percentages of system total)**
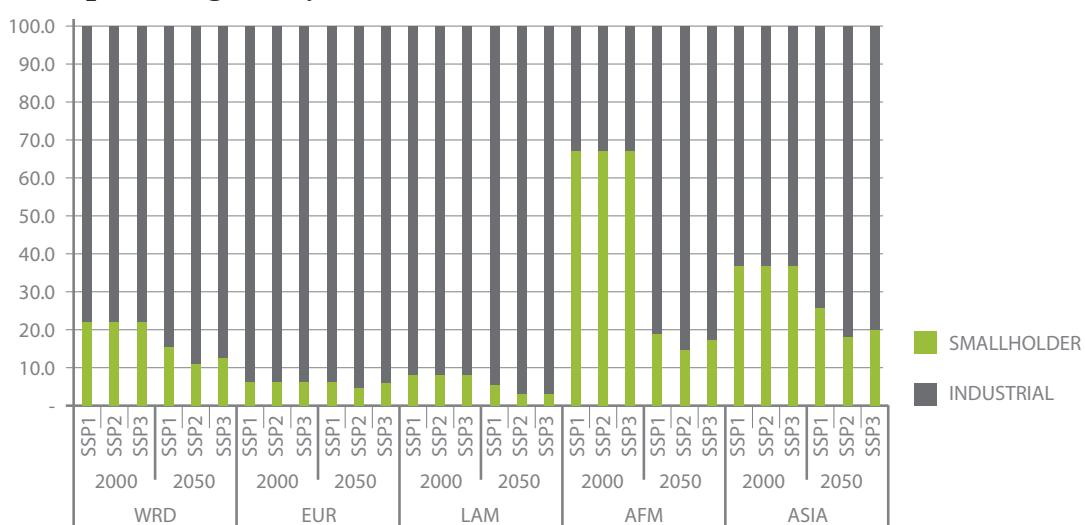
For ruminants, we distinguish eight production systems: grassland-based – arid (LGA), humid (LGH), temperate/highlands (LGT); and mixed crop-livestock systems – arid (MRA), humid (MRH), temperate/highlands (MRT), urban and other. Some 31 per cent of ruminant meat in 2000 was produced in mixed temperate systems followed by mixed humid (17 per cent), other (16 per cent), and mixed arid (14 per cent) systems (Figure 31). Most of the production in Europe came from mixed temperate systems (42 per cent), in Latin America from mixed humid systems (48 per cent), and in Africa and the Middle East from mixed arid systems (38 per cent). Under SSP2, the major change would be an increase in the share of production coming from grassland-based humid systems. Under SSP3, also according to the scenario's assumptions, production distribution across the systems would remain similar to that observed in 2000.

Figure 31 - Ruminant meat production by system (percentages of system totals)
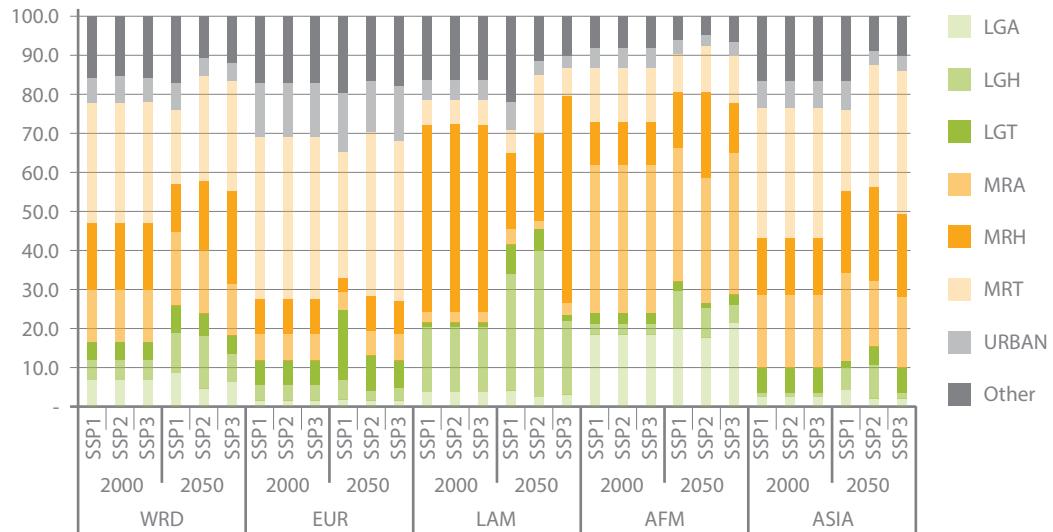
Most of the milk production in 2000 was coming from mixed temperate systems (35 per cent), followed by mixed arid (20 per cent), other (17 per cent), and mixed humid (14 per cent). In Europe and Latin America, up to 56 per cent and 52 per cent of total production was coming from the mixed temperate and humid systems, respectively. In Africa and Asia, mixed arid systems were delivering 42 per cent and 55 per cent of milk production, respectively. Globally, the most robust change in the production structure relates to the increase in the share of production coming from mixed arid systems going from 20 per cent in 2000 to up to 34 per cent in 2050. This is mostly due to the developments in Africa and the Middle East, and in Asia (Figure 32).

Figure 32 - Raw milk production by system (%)
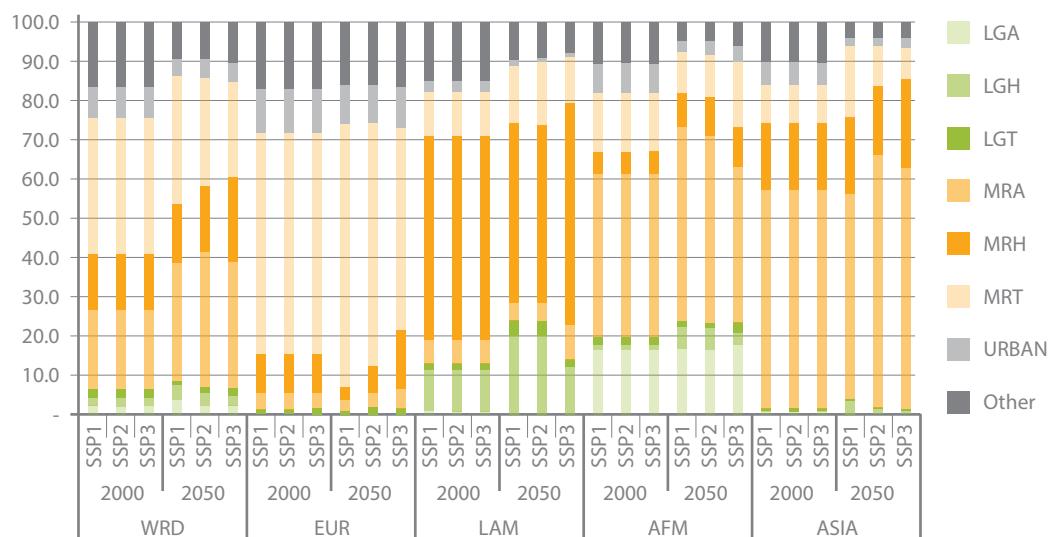
Greenhouse gas emissions

The three most important sources of greenhouse gas emissions in the agricultural and land-use sectors are soil N2O, CH4 from enteric fermentation, and CO2 from deforestation.[6] In terms of regional distribution, three regions were responsible for 57 per cent of the global emissions: Latin America emitted 32 per cent of the total emissions, Africa and the Middle East 24 per cent, and Europe only 1 per cent. Total agricultural emissions were with 542, 776, and 818 MtCO2eq for Europe, Africa and the Middle East, with Latin America being fairly comparable, the major difference coming from the land-use change emissions. These emissions were negative in Europe, and almost cancelled out the positive emissions from agriculture there, but with 845 in Africa and the Middle East, and 1,312 MtCO2eq in Latin America, they more than doubled the agricultural emissions in these regions (Figure 33).

The amount of future emissions depends substantially on the scenario assumptions. Our projections result in an increase of 34 per cent in 2050 under SSP2, and a decrease by 14 per cent under SSP1. While agricultural emissions would increase by 13 per cent and land-use change emissions by 29 per cent under SSP2, they would decrease by 14 per cent and 49 per cent, respectively, under SSP1.

Figure 33 - Global greenhouse gas emissions (million tons CO2eq)

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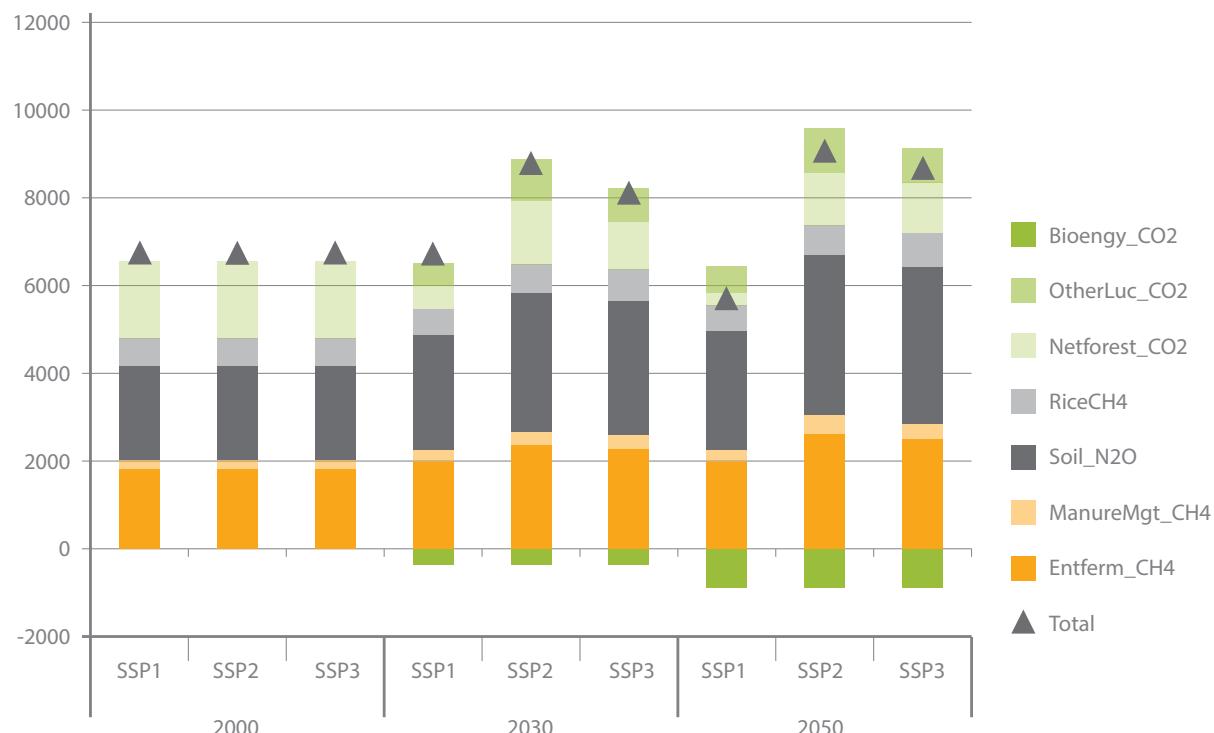
[6] These numbers are taken from FRA2010 since GLOBIOM starts from equilibrium in 2000, and hence cannot report emissions from land-use change from the preceding period.

In Europe, the most important contributor to agricultural emissions is enteric fermentation, with 177 MtCO2eq, and soil N2O emissions, with 251 MtCO2eq (Figure 34). The emissions from enteric fermentation are expected to increase by, at most, 7 per cent by 2050 under SSP2, but the emissions from soil N2O are projected to still increase by about 40 per cent both under SSP2 and SSP3.[7]

Figure 34 - Greenhouse gas emissions - Europe (million tonnes CO2eq)
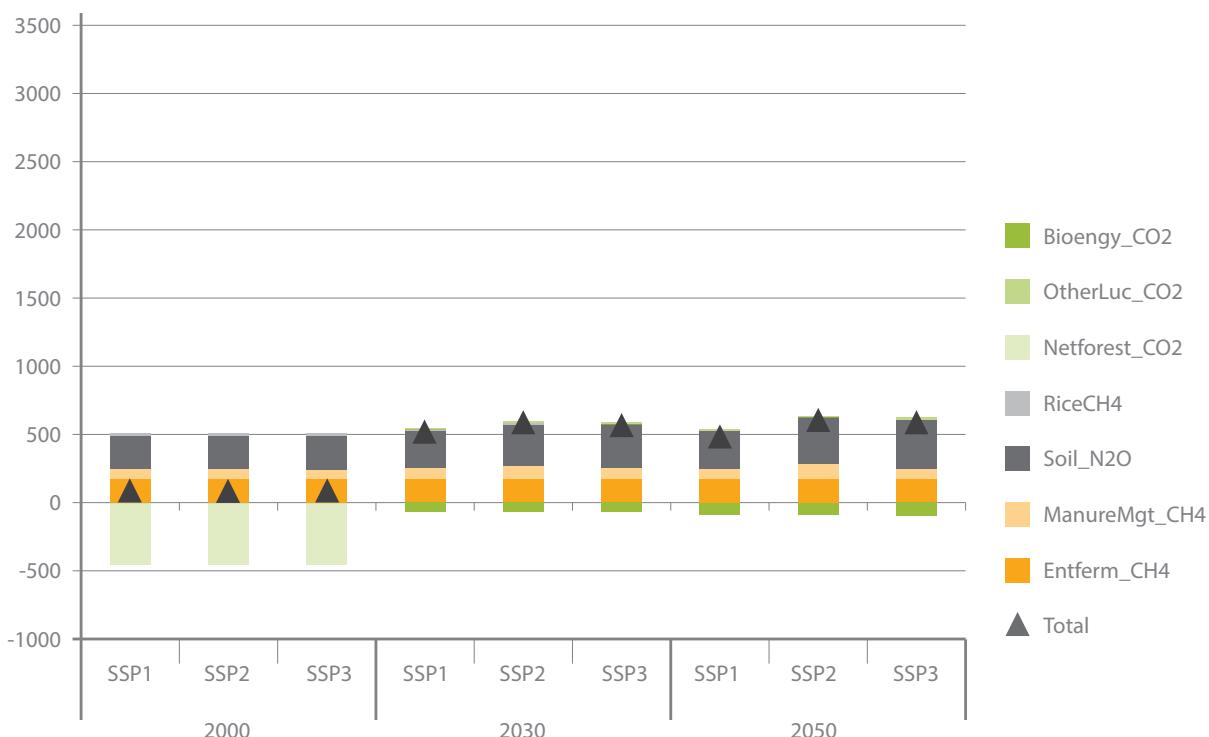
In Latin America, 62 per cent of 2000 emissions came from land-use change, followed by enteric fermentation and soil N2O. Under SSP1, the total emissions in 2050 could be 36 per cent of those in 2000, and also under SSP2 and SSP3, they would not exceed the 2000 levels. This positive development comes from the reduction of emissions from land-use change, -46 per cent under SSP2, and -90 per cent under SSP1. This will make it possible to buffer the non-negligible increases in agricultural emissions, e.g. 41 per cent for enteric fermentation and 85 per cent for soil N2O under SSP2 (Figure 35).

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[7] This version of the model does not consider net afforestation in traditional forests. This is a potential limitation of our results for regions with substantial net afforestation, which is the case of Europe.

Figure 35 - Greenhouse gas emissions – Latin America (million tons CO2eq)

Legend:
- Bioengy_CO2
- OtherLuc_CO2
- Netforest_CO2
- RiceCH4
- Soil_N2O
- ManureMgt_CH4
- Entferm_CH4
- ▲ Total

Figure 36 - Greenhouse gas emissions –Asia (million tons CO2eq)

Legend:
- Bioengy_CO2
- OtherLuc_CO2
- Netforest_CO2
- RiceCH4
- Soil_N2O
- ManureMgt_CH4
- Entferm_CH4
- ▲ Total
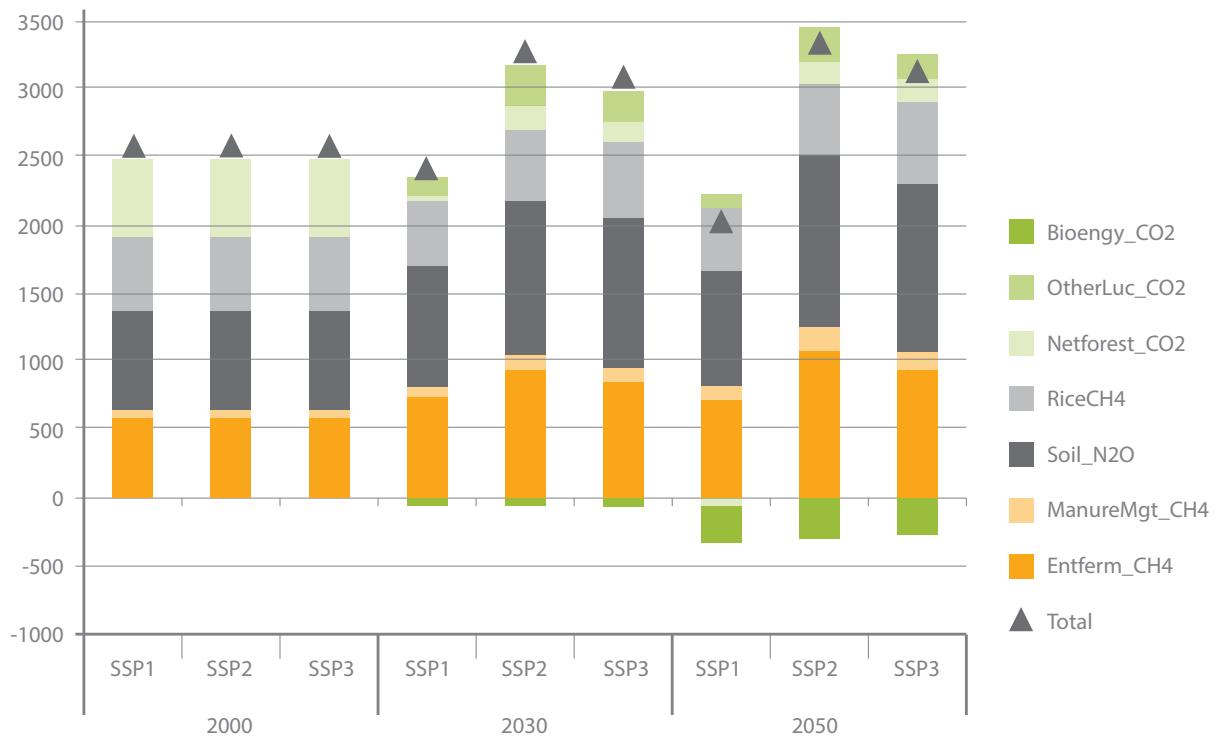
Figure 37 - Greenhouse gas emissions – AFM (million tons CO2eq)
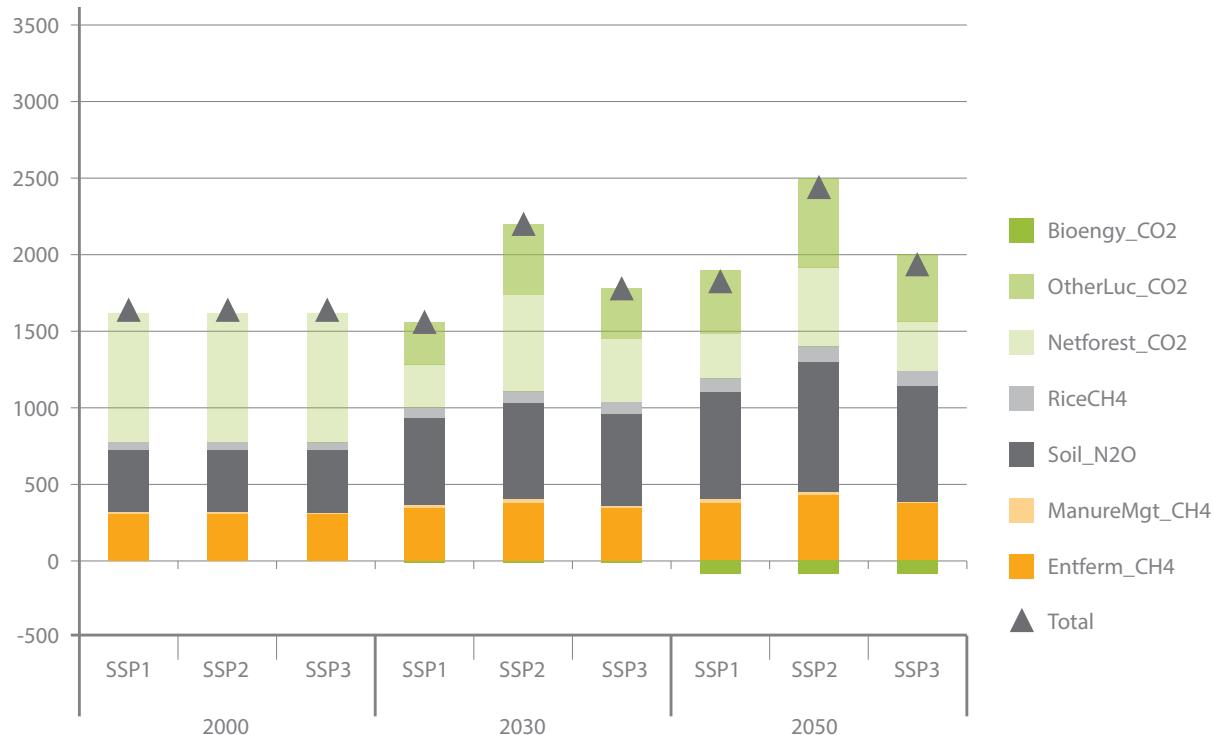
Potentially the greatest increase in emissions from agriculture and land-use change would occur in Africa and the Middle East, +50 per cent by 2050 under SSP2. In this region, about half of the 2000 emissions came from land-use change and half from agriculture. Soil N2O and enteric fermentation are the most important sources of agricultural emissions. Soil N2O is projected to more than double by 2050 under SSP2, and also emissions from enteric fermentation would increase by 42 per cent. SSP1 and SSP3 would lead to lower emissions but still 12 per cent and 18 per cent above the 2000 level (Figure 37).

Sub-Saharan Africa in the SSP Scenarios

4

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A Sub-regional Analysis

Production, consumption and trade

Figure 38 presents the consumption of animal products for different regions in SSA by SSP scenario to 2030 and 2050. The following observations can be made about the results.

Milk consumption: milk consumption is likely to triple under most scenarios in all SSA regions, with East Africa, traditionally the largest consumer of milk, dominating the growth in consumption. Under SSP1 (high technological change, high GDP, low population growth), milk consumption increases more than under the other scenarios due to its higher resource-use efficiency and due to preferential consumption of milk vs. meat in this scenario (Figure 39). The effects are more marked in West Africa, where greater improvements in resource-use efficiency of milk production can be attained under this scenario. Under SSP3, the increases in consumption mostly follow population growth, as income and efficiency effects do not play a large part in this scenario due to their slow growth.

Figure 38 - The total consumption of livestock products (tons 000s) in different regions of sub-Saharan Africa to 2050 by SSP scenario.

a. Milk

b. Monogastric meat

c. Ruminant meat
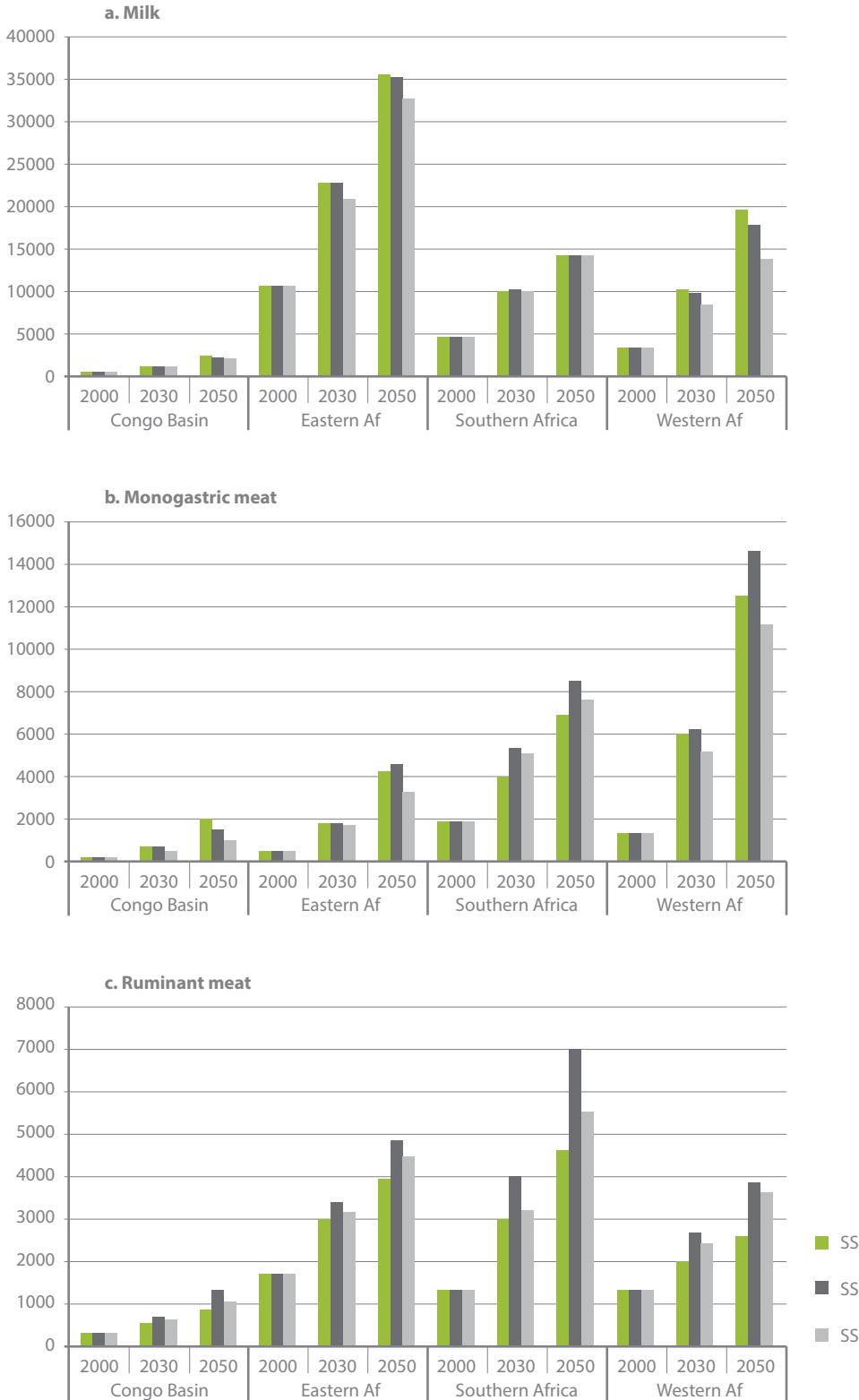
Monogastric consumption: together with milk, the consumption of meat and eggs from poultry and pork exhibit the highest projected rates of growth across SSA. West Africa is projected to have a six- to sevenfold increase in the consumption of monogastric products (mostly poultry), followed by Southern and East Africa (fourfold increases). All scenarios show high growth, but in general terms SSP1 shows lower growth than the baseline scenario (SSP2) due to lower population growth and a slight diet preference shift. These preferences lead to increasing ratios of milk to meat consumption across all SSA for SSP1, relative to the other scenarios (Figure 39).

Figure 39 - The ratios of red to white meat, and milk to meat consumption by SSA sub-region and SSP scenario to 2030 and 2050.
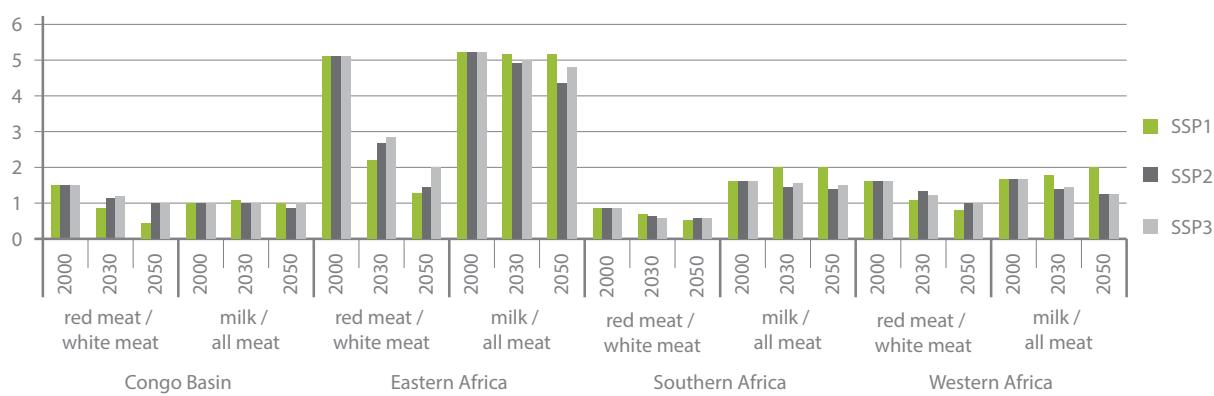
Ruminant meat consumption: Ruminant meat consumption is also projected to grow in all scenarios, but at lower rates than milk and monogastric meats. Ruminant meat consumption increases the most under SSP2 due to high population growth, sustained economic growth, and the lack of strong sustainability considerations with respect to diets, and average projected increases in the technical efficiency of crop and livestock yields. Clearly, under SSP1, ruminant meat is substituted by increases in milk and monogastric meats. Lower population growth also plays an important part in reducing the demand in this scenario, while lower GDP per capita growth would explain the lower demand growth of SSP3 relative to SSP2.

The production response

The projected production of livestock products in different regions of SSA is shown by the SSP scenario in Figure 40. Significant production growth can be observed across scenarios for all livestock products, with SSP1 and SSP2 showing, in general terms, the highest increases in production. The increases in production in these two scenarios are mediated via different processes. In SSP1, the high degree of technological change and the projected reduction in average production costs triggers significant increases in production, with less land expansion for the production of feed (cropland and grassland) (see land-use section). In general terms, we see this largely as an intensification effect, while in SSP2 some technological change occurs as well, but at a higher economic and environmental cost. In this scenario, there is significantly more land expansion than in the other scenarios, and this is the main effect behind the production growth.

The conditions for effecting production growth (high technological change potential in livestock and crop yields, lower costs, and adequate product prices) are highest for milk in East and West Africa, for monogastrics in West Africa and for ruminant meat in East Africa. In SSP3, the lower demand caused by the low GDP growth rate, and the slow improvements in resource-use efficiency and high costs lead to a reduced production response across all animal products.

Figure 40 - Total production (000s tons) of livestock products (a. milk, b. monogastric meat, c. ruminant meat) to 2030 and 2050 by region and by scenario in sub-Saharan Africa.

a. Milk

b. Monogastric meat

c. Ruminant meat
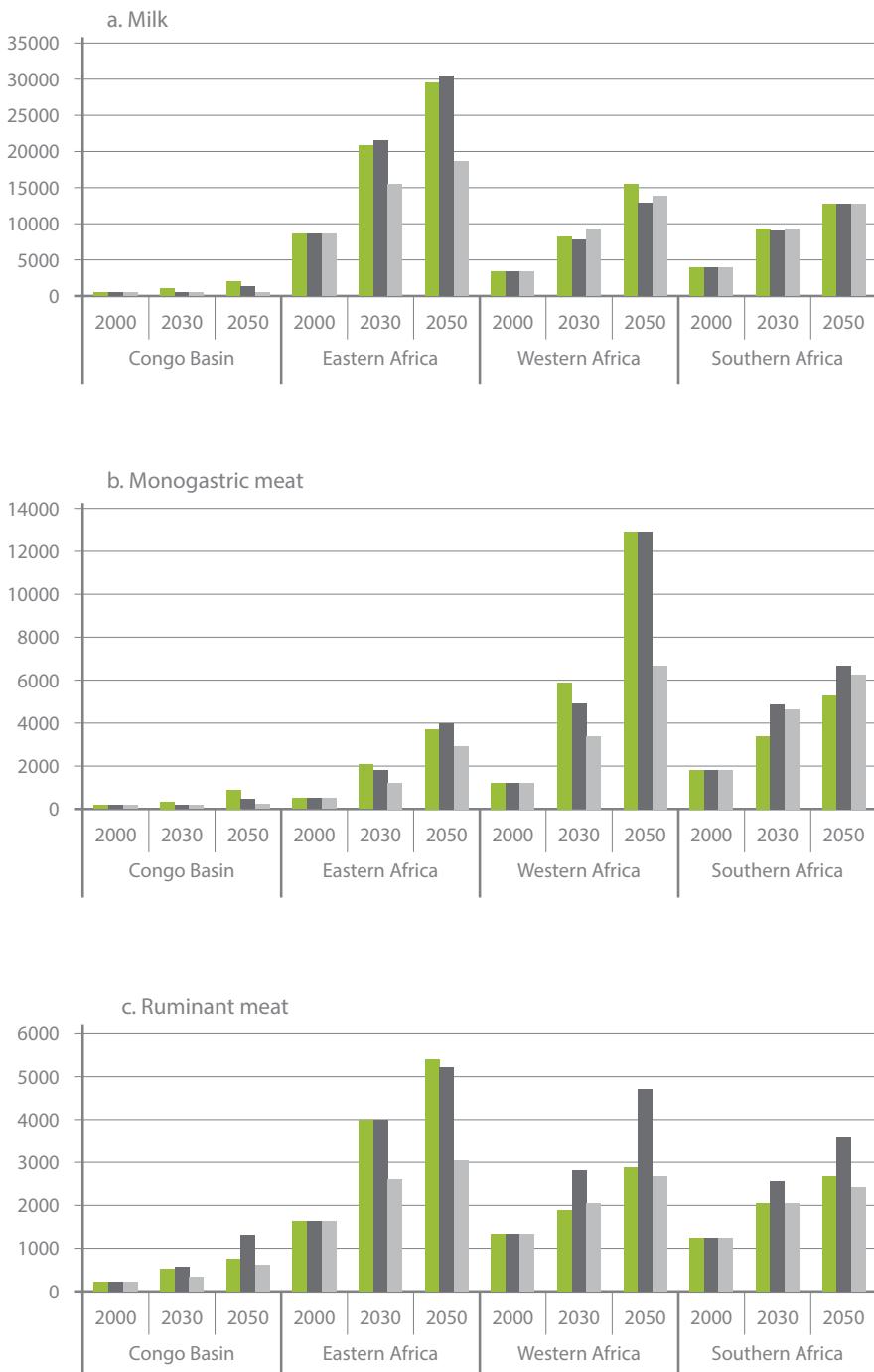
Livestock product prices under the SSP scenarios

Baseline prices and their projections for selected livestock products are shown by scenario in Figure 41. Baseline prices of pork and poultry meat in SSA relative to global prices are at least twice as high, thus rendering these sectors uncompetitive at the local level, especially under the baseline productivity and production levels. Of all the prices, only baseline ruminant and small ruminant meat prices are comparable to global prices. SSP 1, in general terms, shows a decreasing trend in prices that partly explains the increases in the production of these commodities. For the other two scenarios, large variability exists in the projected prices of ruminant meats, and this is partly a reflection of the changing supply and demand terms in the scenarios (vast differences in resource-use efficiency, technological change assumptions and elasticities that determine consumption and production), with SSP2 and SSP3 showing increases in prices, especially of the ruminant meats, where larger variation in productivity parameters exists.

Figure 41 - World and sub-Saharan African prices for selected livestock products to 2050 by SSP scenario.
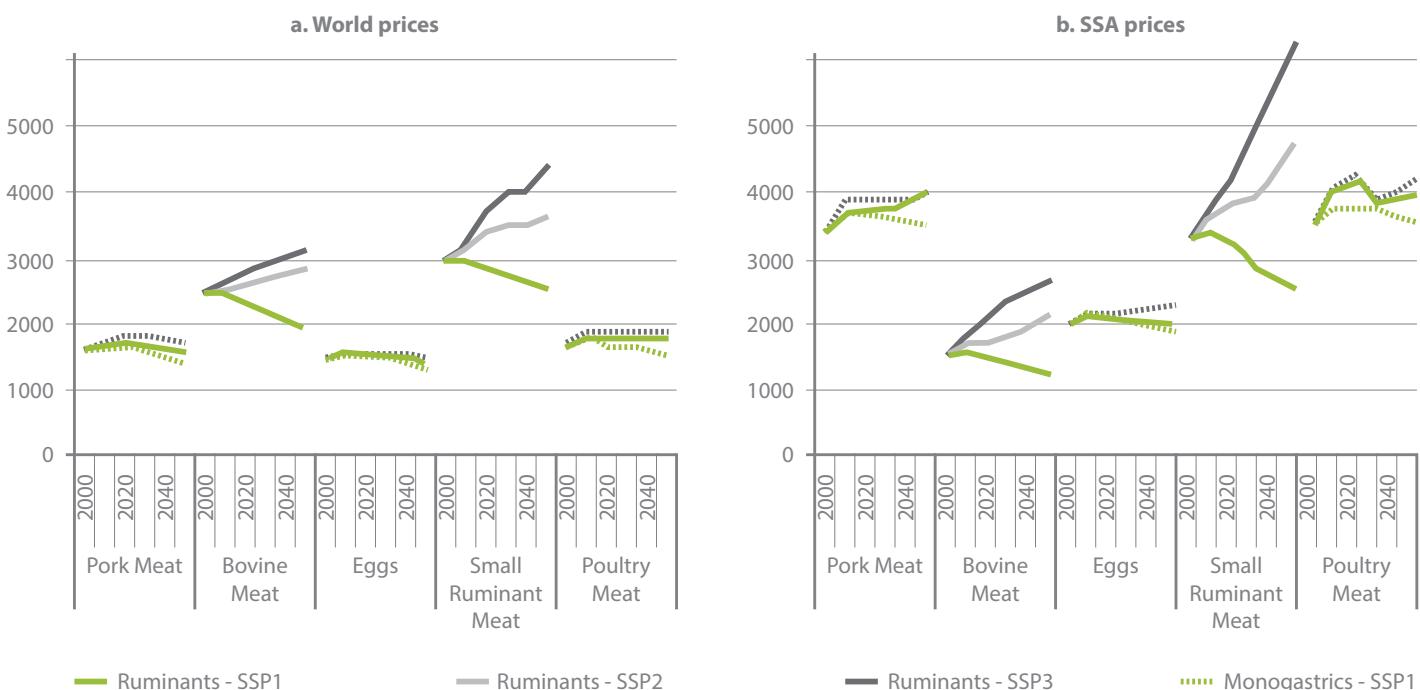
Trade and competitiveness

The proportion of traded livestock products as a percentage of production is shown in Figure 42 for different products and scenarios. Only under SSP1, with the highest crop and livestock yield increases, the highest resource use efficiencies and the lowest production costs, can the low trade-deficit conditions prevailing until 2000 for all animal products (around 10 per cent of national production) be maintained to 2050. Population increases and lower economic growth in SSP2 and SSP3, combined with lower resource-use efficiencies and technological change, and generally less competitive livestock sectors, would force sub-Saharan Africa towards a greater trade dependency to fill the product demand gaps. Maintaining business-as-usual trends (SSP2) would lead to a doubling of imports of milk and monogastric products (poultry mostly) relative to production by 2050. This would result, both for dairy and monogastric products, in an increase in imports compared to production from 10 per cent to 20 per cent. Even in ruminant meat, where sub-Saharan Africa was almost self-sufficient, the imports would increase to an equivalent of 16 per cent of local production. More worryingly is the fact that any negative deviation from the current trend in terms of production efficiency, prices and GDP growth (SSP3), such as potential impacts of climate change on productivity, would make the SSA livestock sector largely uncompetitive, particularly for products like red meats, with substantially lower resource-use efficiencies and high production costs.

These numbers, while extremely important, hide significant regional heterogeneity. For example, for milk under SSP1, the share of traded products will significantly decrease in the Congo Basin to 2050 (from over 60 per cent to under 20 per cent), while these would be maintained in East and Southern Africa at historical levels (approx. 10-15 per cent). In West Africa, the favourable production conditions modelled in this scenario (crop and livestock yield increases and prices) will not be enough to prevent increases in the percentage of traded milk (from slight surpluses in 2000 to over 30 per cent of imports). Under SSP3, the response of different regions is also very different, with East and Central Africa being very susceptible to reductions in technological change and demand pull factors (traded volumes would increase to over 60 per cent in both cases), in contrast to West and Southern Africa, where these volumes will remain close to historical levels due mainly to a demand contraction. For ruminant meats, the sustainable intensification scenario (SSP1) could turn East Africa into a potential exporter of ruminant meat by 2050 (20 per cent of exports as a percentage of production), while in other regions, like West Africa, the modelled improved productivities will not be enough to cope with the demands of a growing population (over 40 per cent of red meat imports by 2050, even in the best-case scenario, SSP1). The Congo Basin will likely remain a net importer of chicken and pork to 2050, as all scenarios show imports that are 1 ½ to four times greater than production. The story is different for the other regions. East and Southern Africa, while being able to triple the production of monogastrics to 2050, will likely remain net importers of these products (10-30 per cent of imports). West Africa, with its vast projected increase in production (six- to sevenfold) could become self-sufficient in monogastric products by 2050 under SSP1, while it would remain at 2000 import rates under SSP2 and SSP3 (10-15 per cent of imports).

Figure 42 - Trade deficit in edible livestock products (milk, monogastric meats + eggs, and ruminant meats) in sub-Saharan Africa to 2030 and 2050 by SSP scenario
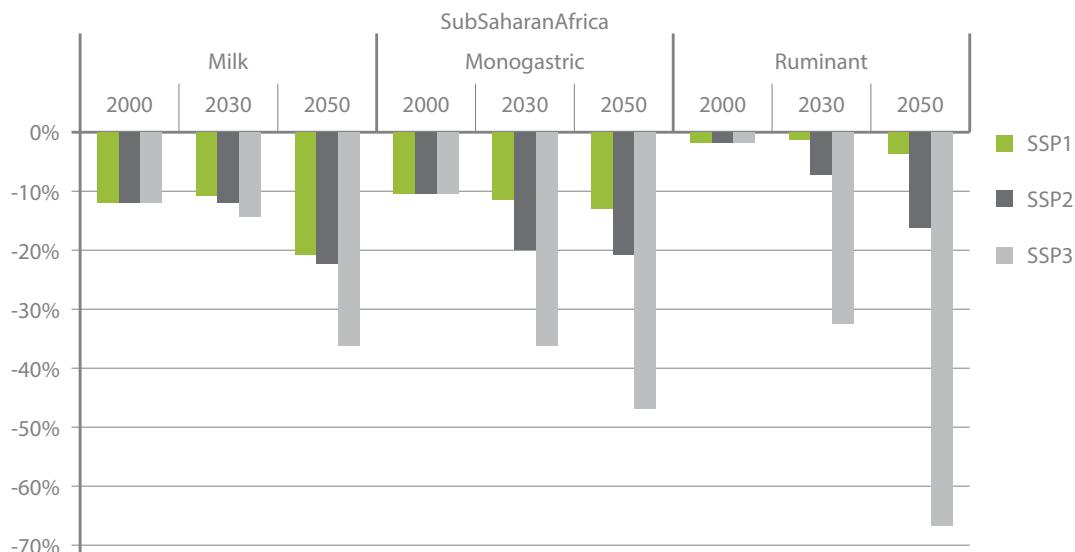
Which production systems are likely to be the engines of production growth in sub-Saharan Africa?

The contribution of different production systems to future milk, beef and small ruminant production projected in the different scenarios is presented in Figure 39.

Smallholder mixed crop-livestock systems are, and will remain, the main producers of ruminant products to 2050, under all scenarios. Under SSP1 and SSP2, however, pastoral systems and the mixed crop-livestock systems in more humid areas are likely to increase the production of meat and milk by four- to eight times relative to 2000 production. This is because, in these areas, the favourable yield increases in livestock and crops projected in these systems are high (SSP1) and also, significant grassland and cropland expansion is likely to happen to support the additional production (larger impact in SSP2, business as usual). Pastoral, agro-pastoral and smallholder mixed systems in arid regions are likely to contribute large increases in the production of milk under SSP1. This demonstrates that it is in those systems that have a low baseline production where significant improvements in productivity, resource-use efficiency and GHG intensities can be made at low cost through improved technology. Our study demonstrates that, given the right socioeconomic conditions and technology to reduce costs and increase productivity, with modest expansion to guarantee feed sources, pastoral systems in arid regions could triple production of cow's milk and increase small ruminant milk and meat production by a factor of five or six relative to the production levels of 2000. These products are less resource-use-intensive than beef production, which will also grow, but only slightly.

In the case of monogastrics, as discussed in Figure 30, most expansion of production in all scenarios will be through industrial production systems, which is consistent with the findings of Bruinsma (2003).

Figure 43 - The contribution of different ruminant livestock production systems to the projected production growth in sub-Saharan Africa to 2050 by SSP scenario

Systems differences in production

(million metric tons) (LG= grazing system, MR = mixed crop-livestock system, A = arid, H = humid, T = highland/temperate)
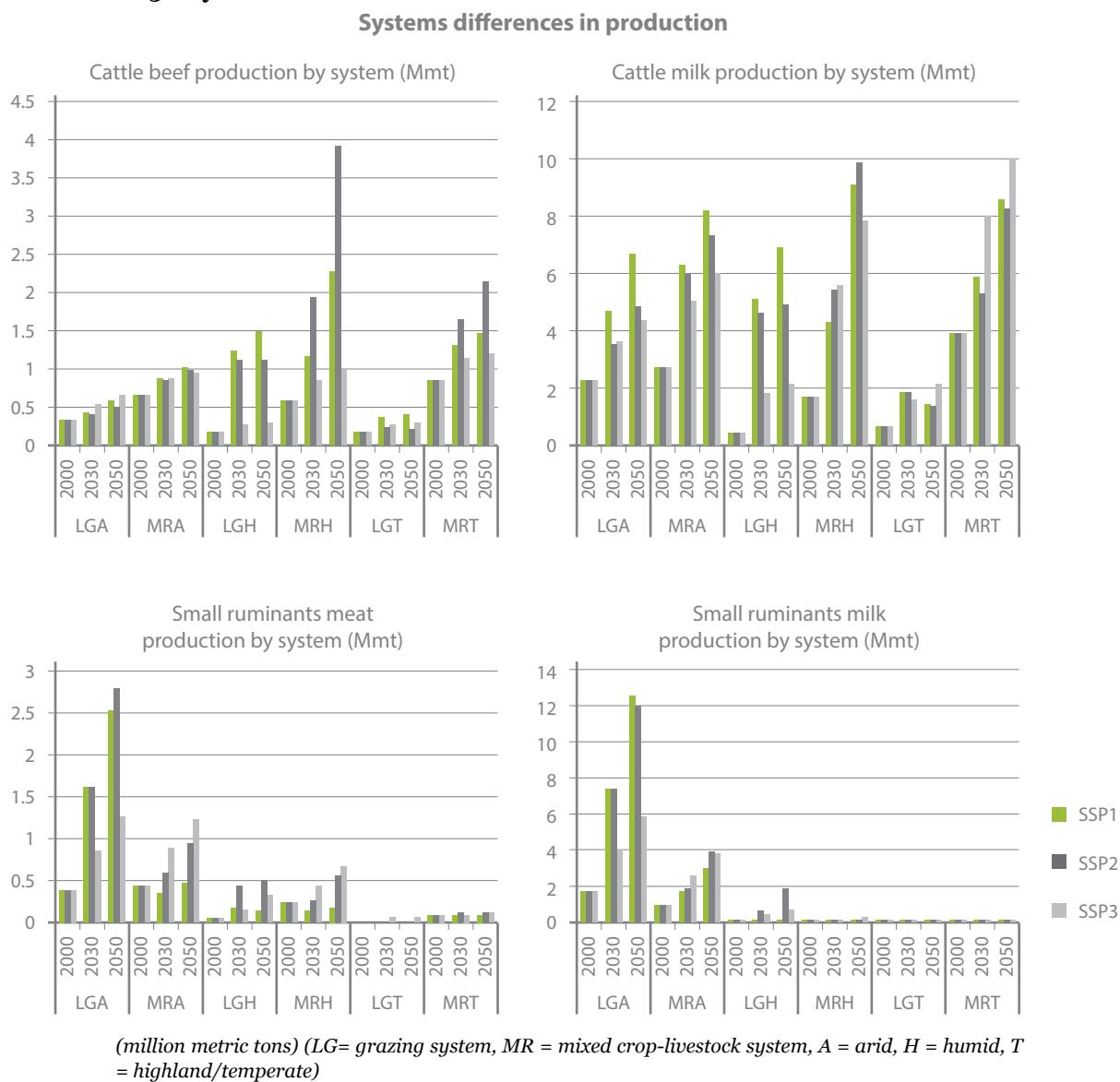
Land use and its change

Cropland and grassland expansion are needed in all scenarios to increase the production of livestock products to 2050. This suggests that intensification of livestock production alone (SSP1) is not enough to meet the increasing demand for livestock products. Figure 44 shows the land-use change projections under the different scenarios. SSP2 (business as usual) has the highest level of land-use change (LUC) due to intermediate technical change that prevents large-scale intensification of production, and high demand for animal products due to high population growth and intermediate GDP growth.

Land-use change diminishes under SSP1 (sustainability) due to high technical change, shifts in diets to more resource-use-efficient livestock products and lower population growth, while LUC also diminishes in SSP3 due mostly to demand contractions due to low GDP growth and inefficient production that limits production growth.

Figure 44 - Land-use change projections to 2050 by SSP scenario (000 ha)
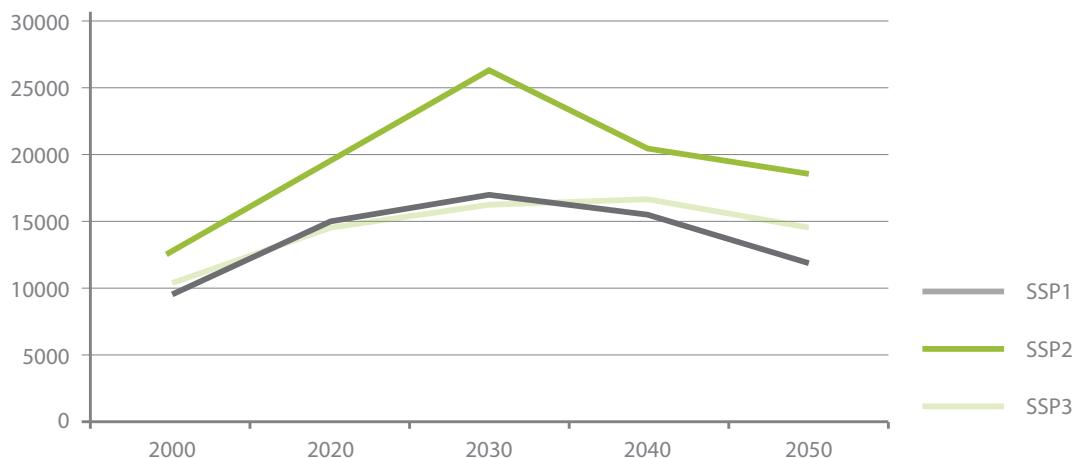
The most common source of land for increasing cropland production in SSA has been, in order of importance, grasslands in relatively high-rainfall areas, followed by wooded savannahs and primary forests (Figure 45). This pattern is likely to continue to 2050 with continuous land conversion in grasslands and natural land and a stabilization of the rate of reduction of primary forests across all scenarios. The main differences in the scenarios are that in SSP1 there is a reduction in the conversion of grasslands and natural land to croplands, while grassland conversion is reduced in SSP3 at the expense of increases in land-use conversion of natural lands.

Figure 45 - Source of land to cropland to 2050 for different SSP scenarios. GrsLnd = grasslands, NatLnd = natural land, PriFor = unmanaged forests.

SSA sources of land to cropland
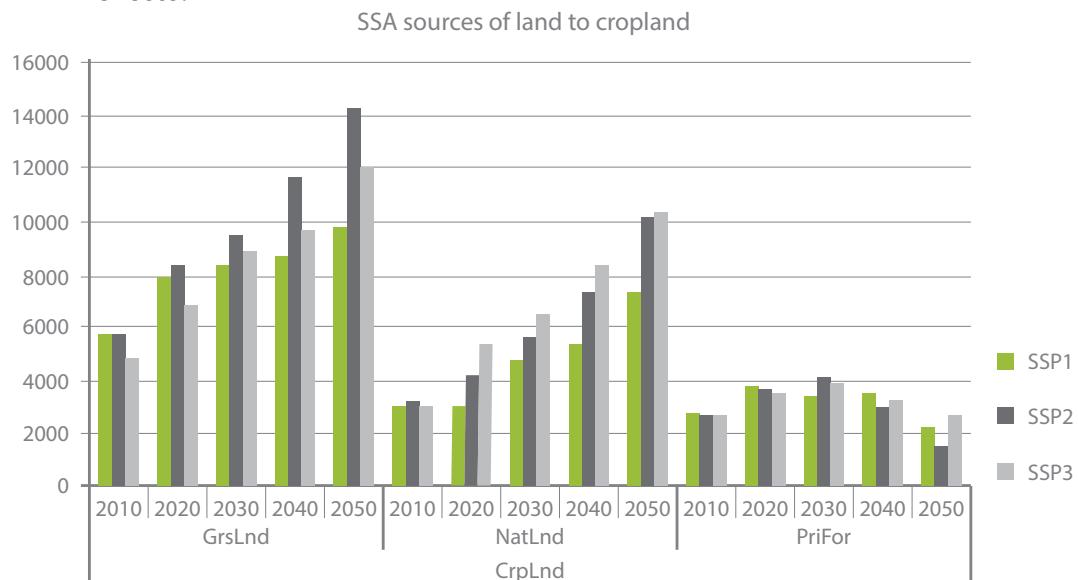
Of all land-use change in SSA, close to 60 per cent of LUC is the conversion of land to support the expansion of grasslands. Figure 46 shows the sources of land for grasslands expansion. Natural, sparse wooded savannahs are the main source of land, followed by primary forests. While LUC in natural grasslands is likely to continue increasing to 2050 in all scenarios, the deforestation of primary forests is likely to stabilize. As with cropland, the highest rates of LUC occur in SSP2 and the lowest in SSP1 due to the same factors.

Figure 46 -- Sources of land for grassland expansion to 2050 by SSP scenario (000 ha). GrsLnd = grasslands, NatLnd = natural land, PriFor = unmanaged forests.

SSA source of land to grassland
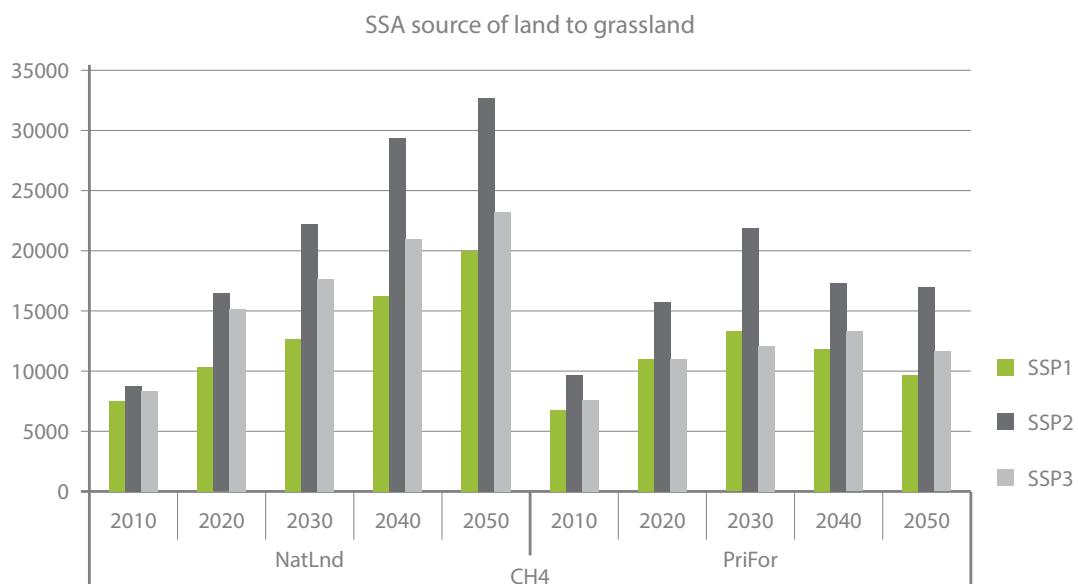
Greenhouse gas emissions

The methane emissions from ruminant livestock are presented in Figure 47. The largest emissions come from the regions with the largest numbers of animals, and where growth in animal numbers to increase projected production is highest, in this case in East Africa. SSP1 and SSP2, the two scenarios with the highest production, have the highest emissions, with the difference that SSP1 has higher efficiency of production and therefore requires slightly fewer animals to meet the projected level of production in comparison with SSP2.

Figure 47 - Methane emissions from enteric fermentation and manure management by region and scenario to 2050 (million tons of CO2Eq)

Total CH4 emissions from livestock by region
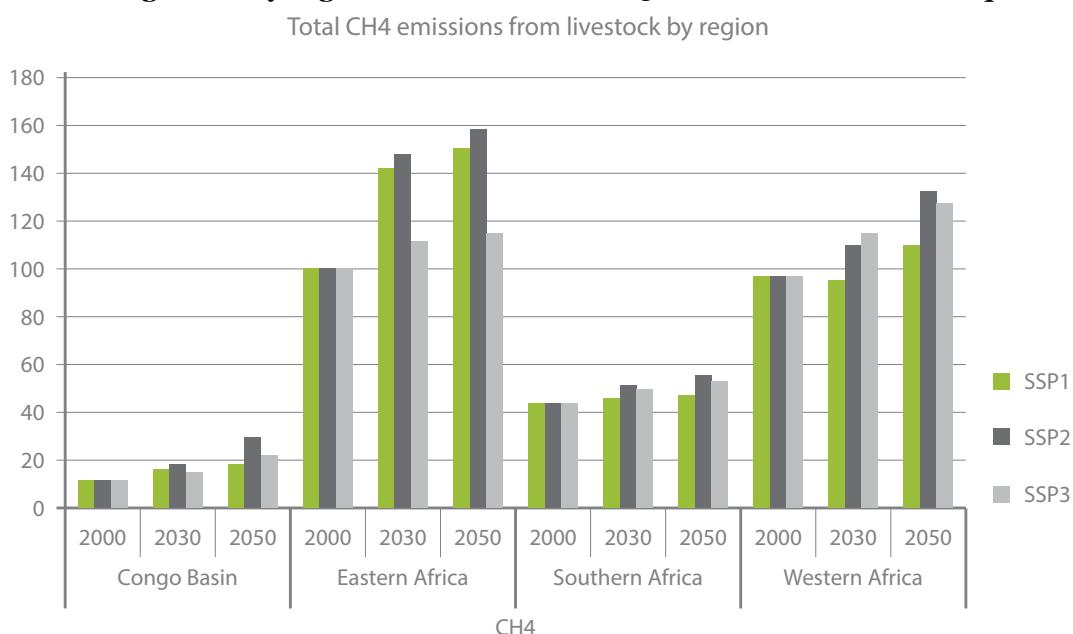
The highest emissions come from the production systems with the highest numbers of animals, in this case the pastoral and smallholder mixed systems in the arid regions. These systems, as explained before, will contribute significantly to the production of milk and meat under the SSP1 and SSP2 scenarios. This is consistent with the results of Herrero and others, 2008, 2013 and FAO, 2010, 2013.

The largest emissions from livestock come from CO2 from land-use change for cropland expansion or conversion to grassland.

Figure 48 - Distribution of methane emissions by livestock production systems (LPS) and scenarios

GHG emissions for livestock production by LPS: CH4
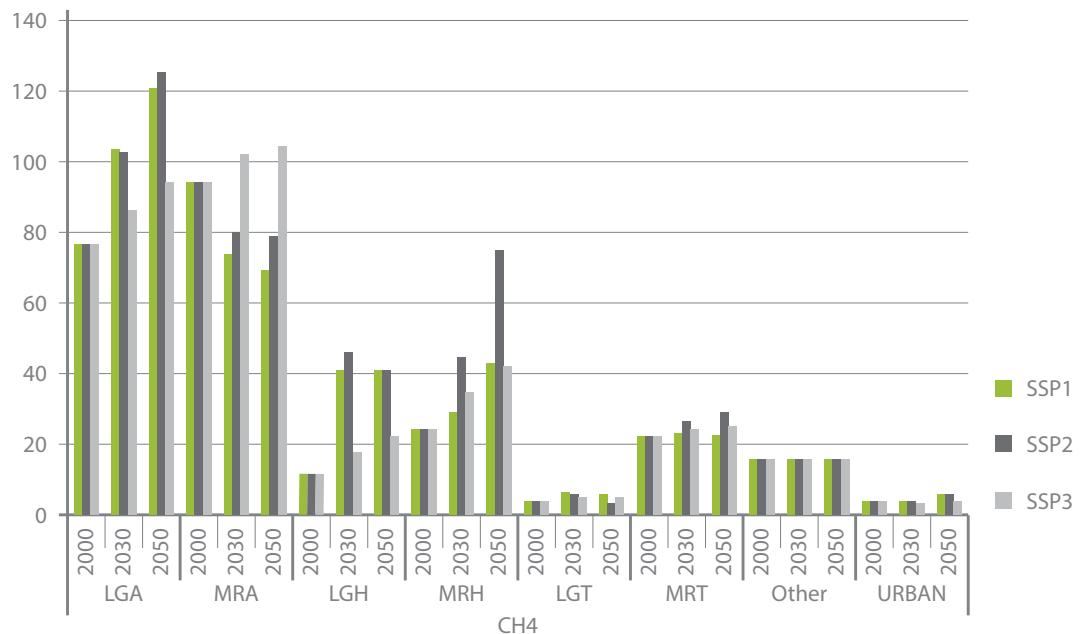
While Figure 47 and Figure 48 show emissions increasing to 2050, the GHG efficiencies of livestock production diminish significantly to 2050 (Figure 49). The combination of the differential composition of the supply of livestock products, the effects of increasing livestock yields and their associated resource-use efficiencies, together with the changes in consumption of different livestock products, create the overall effect of reducing the amount of GHG (methane and N2O) per kg of animal protein in all scenarios. The results clearly show that we could double, and in some parts triple, the GHG efficiencies of livestock production in Africa if sustainability criteria and technological change were driven by economic growth (SSP1). The largest impacts are observed in regions with the lowest initial efficiencies (Congo Basin and West Africa). Gains would also be obtained in other scenarios, but not while maintaining the level of protein intake from animal source foods.

These results are encouraging, as they show that, with a combination of demand management, sustainable intensification of land-based systems and structural change promoting more industrial monogastric systems, it is possible to make inroads in the environmental efficiency of livestock systems without sacrificing pastoral and smallholder production.

Figure 49 -- Greenhouse gas efficiencies per unit of protein produced for all livestock products and regions to 2050 by SSP scenario (kg CO2/kg protein produced)
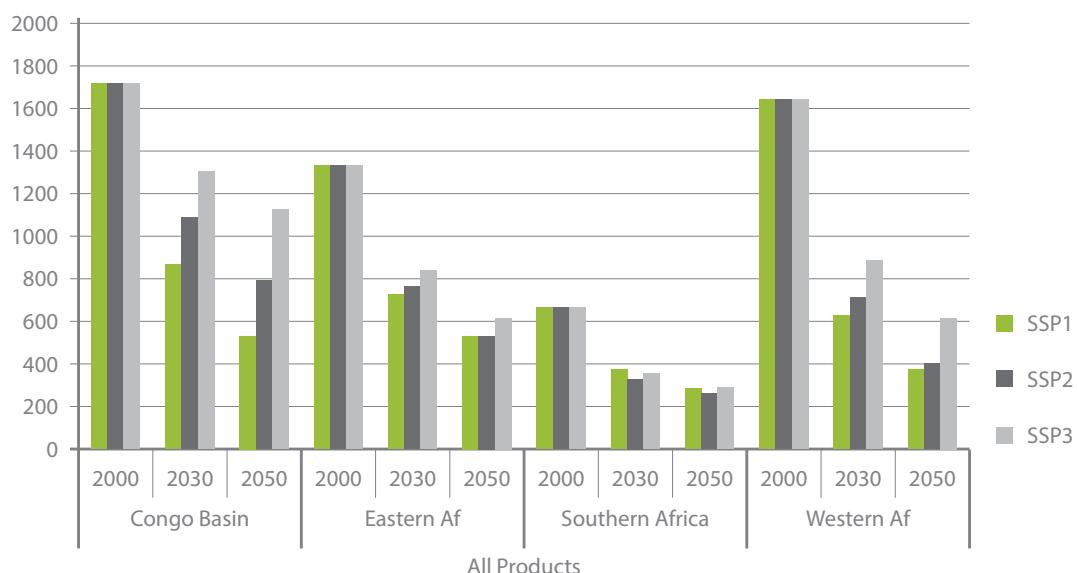
Potential health effects of the SSPs

There could be increasing threats of disease affecting animals and people under all SSPs. The risks of disease-causing pathogens moving from wildlife (or even people) into domestic animal populations are significant because of the reservoirs of pathogens in African wildlife. There is a lot of contact between wild and domestic animal populations, as well as significant contact between wildlife and humans. Since pastoralism could also benefit from some sustainable intensification practices, these linkages will become more important in the future.

Another set of diseases would be associated with monogastric expansion. Infectious diseases, especially if veterinary surveillance and appropriate regulation of industrial systems does not follow the accelerated growth trajectory in this kind of system, could be catastrophic for the future of poultry and pork in sub-Saharan Africa. Governments must ensure appropriate surveillance, vaccination and guidelines for safeguarding against diseases in these types of systems.

Additionally, the increased demand for livestock products will need to be met under some circumstances (SSP2 and SSP3) by increases in the trade of livestock products. This opens up another set of potential groups of food-borne diseases if markets operated under loose standards, with a lack of cold chains and others. It is essential that, as trade increases, so do improvements in food safety in African markets.

As with most increases in animal production under current trends, non-zoonotic diseases are likely to increase if efforts for better control and implementation of improved disease management practices at the farm level are not followed. In this regard, added investment and support in veterinary services will be essential to ensure adequate future animal health in sub-Saharan Africa. Supporting the work of the tripartite agencies, the WHO, the FAO, and the OIE, to advance OneHealth approaches and also promoting the use of OIE and WHO tools and standards to strengthen veterinary and public health systems will be of paramount importance.

Sub-Saharan Africa

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Policy and Research Implications

All scenarios show major changes in African livestock production systems – ownership and management, production, consumption, trade, prices, environmental and health effects. Expanding the benefits of livestock production, while reducing the environmental and health costs, depends on increasing the competitiveness of African livestock in international, regional, and domestic markets. Improving competitiveness requires governments to invest in agricultural productivity while removing barriers that prevent producers from benefiting from market opportunities, while managing the inevitable environmental costs of more intensive production.

Governments therefore face livestock policy problems in terms of the: (i) changing role of the state; (ii) accelerating technical change; (iii) managing industrial production; (iv) protecting the interests of smallholders (and pastoralists), with special attention paid to the economic roles of women stockholders; (v) protecting the interests of pastoralists; (vi) managing environmental costs; (vii) improving animal health; and (viii) promoting intensification across all rural sectors.

Changing the role of the state

The productive roles of African states in animal agriculture will be quite different over the term of the SSPs.

Public commercial companies – in farming, ranching, processing, and trading – will have largely disappeared. The state, in its productive roles, will concentrate on building and maintaining public infrastructure – which will remain important in roads, water and energy distribution – and leave production to the private sector.

The delegation of productive roles to private agents will pose new challenges to states in their supervisory roles.

States must first regulate private infrastructure (which will dominate in telecommunications, energy generation, water production and ports) to avoid monopolies that are costly to exporters and to smallholders who trade with such monopolies. Second, states must mediate land, labour and other resource conflicts among private agents of different political stature in order to avoid resource grabs that are politically destabilizing. *The main regulatory role of the state in livestock and other agricultural sectors will be to limit costly externalities arising from intensive farming. Such externalities can occur in food safety, prevention and treatment of zoonoses, and in management of the environmental impacts of intensive farming – preserving water quality, preventing adverse human and animal health effects of farm chemicals, managing the widespread use of GMOs throughout food chains, and preserving biological reserves against encroachment by farms and cities.*

African states will face new challenges in their internal income distribution roles,

particularly in managing the absolute income gaps that will grow between smallholders and large holders in animal agriculture. Such income inequalities can be partially offset through funding for social safety nets, public service pricing, and tax and trade policies. *The fiscal and targeting capacities of governments will increase with sustained economic growth, especially in nations that grow more quickly, but governments must strengthen their capacities to create social safety nets and to target tax expenditures.*

Promoting regional cooperation.

Transformation of livestock production to 2050 will require greater international cooperation. Such cooperation includes water use for hydropower, flood control and irrigation, which can have important collateral benefits for animal production; collaboration on transboundary biodiversity, which is needed to protect wildlife; joint work on the international effects of climate change, especially for animal disease control.

Ensuring market access.

African livestock cannot thrive without lower trade costs within Africa and with the rest of the world. Lower trade costs will derive from investment in infrastructure, including rehabilitation and construction of rail networks, and in private services. Associated with this new investment must be faster logistics, meaning a higher turnover from each infrastructure site, which will generally occur under pressure from domestic producers who benefit from cheaper trade. *Beyond investments in infrastructure and better incentive policies, African states must do more to improve their access to markets through trade agreements starting with intra-continental trade. Because of the human and animal health issues that are prominent in livestock trade, it is urgent that African nations collaborate on transboundary health problems, especially zoonoses.*

Accelerating technical change

The continuing development of agricultural technology on a global scale is inevitable and will benefit Africa if global research can be adapted to regional conditions. The situation differs for livestock because of the greater complexity of animal agriculture and the many environment-by-technology interactions, but the promise of new technology for growth, food safety and environmental management is still high. There are several policies to realize that promise.

Correct the traditional underinvestment in agricultural research, especially in high-end science.

African countries have traditionally underinvested in agricultural research and technology transfer. As a result, their rates of innovation and productivity growth are lower and their capacities to use external innovations are weaker. Increasing the impact of agricultural research in Africa requires action on the following problems:

• Spending for agricultural research and for the development of African scientific capacities must grow at all levels – national, regional within Africa, and international (with world research centres focusing on African problems), or African farmers have no hope of becoming more competitive in global markets;

• The misguided focus on adaptive research must be dropped in favour of more basic research on African problems;

- New investment in agricultural research and technology transfer must have an explicit focus on small farmers and must be related to the cost conditions – transport, communications, water supply – in which they operate;

- New investment in agricultural research and technology for large farmers should be minimized except to study environmental costs – solid waste, the water footprint, zoonoses, and drug resistance – because large farmers can commission their own research or borrow from middle-income countries; and

- Barriers to imported technology, especially in irrigation, fertilizers, machines, and planting materials, must be dismantled.

Making better use of modern biology.

The trend of global farm technology will be to use more biotechnology products to raise crop yields, to develop new products, and to adapt to biotic and abiotic stresses, notably those caused by global warming. African farmers have benefitted from biotechnology products, as summarized in a recent book on agricultural innovation (Juma, 2011, pp. 35-43), while simultaneously suffering from national policies and from measures in OECD nations that impede the use of GMOs. Valuable research is deferred or ignored altogether because it uses GMOs. This policy bias - against modern biology in Africa - is damaging because it makes African farmers less competitive compared to foreign growers who can use the products of modern biology. This may be especially true of livestock, where the problems are more complex than in crops and the potential for innovation is correspondingly greater.

To close the biotechnology gap in African agriculture, it is important for the African Union to lead a continuous continent-wide review[8] of biosafety and public-information issues related to the use of biotechnology in general. This would: (1) identify specific biosafety risks and propose measures to manage those risks; (2) review capacity needs in biotechnology in terms of labs and African scientists; (3) advise member governments on regulations, tools, and capacities so that they may make better-informed national biosafety policies; and (4) support African scientists in using biotechnology.

Health research.

One production research priority involves the interactions between animal and human health. As animal production intensifies and becomes more concentrated in places, risks of animal diseases – swine fever, poultry diseases, mastitis in dairying – will rise. Hence, animal research must add resources to deal with these problems in addition to its traditional focus on ruminants in extensive systems.

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[8] As done by Cooke and Downie (2010) for Zambia, Kenya, and South Africa and more generally in Juma (2011).

Managing industrial production

What are the implications of a shift to industrial livestock? One is greater physical concentration of monogastric production in large firms and in cities. The second is that smallholder production will lose market share, and their incomes relative to those of large holders will decline, most quickly in monogastrics but also in ruminants as the shifts from ruminant to monogastric proteins occur.

These moves to concentration and to the advantage of large holders of monogastrics – pigs and poultry – will increase in numbers as demand grows, all the more so if their production becomes cheaper.

Such a structural change has many negative effects, such as the risk of pollution from the excreta of animals concentrated together and (in the absence of high biosecurity) the risk of diseases (including those that can be transmitted to humans or other species), and the development of antibiotic resistance in microbes. These adverse effects can be managed through regulation and incentives, but African capacity for such management is currently low. Policy must therefore focus on developing such capacity, including the use of benefit-cost tools for regulation economics.

Regulation.

The SSPs all show more animal production and more concentrated animal production in SSA. The growth of output, and the particular problems of the concentration of animals in industrial production systems require stronger regulation. The development and regulatory capacities of African states in all agricultural domains, especially those involving animals because of their roles as disease reservoirs, must be strengthened so that livestock products derived can be used safely. Regulatory capacity building is all the more urgent in smaller countries, which will require assistance in bioregulation from their larger neighbours and from regional organizations.

Protecting smallholders (and pastoralists)

The policy goal for smallholder agriculture should be to protect its competitiveness and its asset bases.

What can policy do to promote smallholder competitiveness?

The first thing to do is NOT to subsidize large producers, whether of animals or of crops and whether of foreign or domestic origin. Such subsidies often stem from the belief that small farms cannot grow or cannot grow in the more competitive export sectors.

The question of large versus small farms in the tropics has been exhaustively discussed, mainly with respect to arable farming and less so with respect to livestock. The evidence about livestock production costs as functions of enterprise scale in monogastrics seems clear – large enterprises can produce more cheaply because of economies of scale in housing, veterinary care, marketing and feed supply. The cost evidence for ruminants is not so clear because African ruminant grazing systems tend to operate at large scales anyway and can thereby exploit economies of scale in management and veterinary care.[9]

Production of livestock and products based on smallholder units can be competitive.

This has been demonstrated both in the dairy sector (operation Flood in India, the Milk vita in Bangladesh and smallholder milk production in Kenya), in the poultry sector (Bangladesh), and in the beef sector of Latin America. The SSP projections show

The protection of women's interests in their roles as livestock owners and managers is a special policy problem. Women stockholders are often less mobile than men because of the domestic work of the former. Women are therefore relegated to owning and managing small stock, such as sheep, goats, poultry and pigs. As such, women holders of small stock suffer from policy discrimination. If sheep and goats are less well-served by animal health programmes, then women holders of those animals lose disproportionately compared to male holders of the same stock. If large-scale enterprises of pigs and poultry benefit from public subsidies, then women smallholders of those stocks lose markets and therefore income owing to the subsidies.

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[9] Deininger and Byerlee (2011, pp. 38-39) found that large investments in plantation crops can create more employment than investments in grains on a large or small scale, but at a higher cost per job created. IFPRI (Thurlow and others, 2008, Table 8, inter alia) in Zambia projected output, income and poverty status by farm size. Small farms, including those specializing in high-value crops, started from lower productivity than large farms and grew at a slower rate, so their poverty rate remained higher, and they fell further behind large farms in relative income over time. Despite the relative decline of small farms, and despite the fact that many small farmers remained poor, IFPRI showed that small farms can grow, can create employment, can compete in exports and can reduce their absolute numbers in poverty.

Protecting pastoralists

Policies affecting pastoralists confront several unusual problems. First, pastoralists are often economically and politically marginalized and hence less able to claim rights held by arable farmers. Second, pastoralists' reliance on mobility makes them vulnerable to conflict, which can block their access to water, pasture, and markets. Third, because tropical pastoralists work almost exclusively in hot dry areas, their livelihoods are vulnerable to higher temperatures and extreme events related to climate change. Fourth, the prices of their animal assets are often negatively correlated with the prices of their consumption goods (usually cereals) because of distress sales of animals during droughts when cereal prices are high.

Political and economic entitlement.

The first policy for pastoralists is one of political and economic entitlement – creating rights to hold and manage pastoral lands, water, and grazing corridors.

Creating services.

Pastoralism requires public and private services to expand and to compete with large producers. Those services include veterinary services, research, mechanical services, financial services, transport, local infrastructure, and education. These all need to be adapted to the needs of smallholders, who also need to be able to access up-to-date and reliable market information. Within the local community, this includes investment in infrastructure and market development, including the upgrading of roads and bridges and the construction of marketplaces. It also includes the establishment of both cold-storage and processing facilities, such as mills and abattoirs, and increased local-level provision of agricultural services. This process should be enhanced through the legal and political recognition of herders' organizations.

Building feed markets.

Currently, less than one-third of grain in SSA reaches commercial markets. That share will rise across the SSPs. The policy question is, again, for governments to improve incentives for grain production so as to lower the costs of feeding grain to livestock, especially for smaller stockholders who may lack access to markets.

Broader insurance for pastoralists.

Pastoralists can self-insure against animal disease, pasture scarcity, and the threat of violence by diversifying species and breed, by mobility, and by making alliances among and between tribal groups. It is very unlikely that policy can do anything to improve such self-insurance.

Policy can, however, facilitate new forms of insurance. First, it can finance investments in public infrastructure, which allow greater mobility of people and

animals in response to shocks and which lower trading costs at all times. Second, it can allow financial markets to emerge for commercial index-based insurance products. Third, it can link such products to participatory disease surveillance and to market information via cellular phone networks.

Managing environmental costs

The environmental costs of livestock growth are GHGs, the water footprint of livestock production and consumption, the disposal of manure, and damage to range productivity from overgrazing.

Adapting to climate change.

Climate change will affect livestock production along several paths:

- It will reduce crop yields, making feeds scarcer and animal production less profitable;

- It might also reduce pasture productivity, with the same negative effect on livestock productivity;

- It might increase heat stress on animals, especially in dairying and poultry, again reducing productivity;

- It might increase vector density, notably for ticks at medium altitudes, causing increased incidence of vector-borne diseases and of "tick burden";

- The risks of higher human and animal disease related to greater vector spread are also likely to increase.

All of these factors – potentially lower yields, larger and more frequent storms, graver health risks, higher price variability – call for policy adaptations for which many African countries are unprepared (Thornton, 2011).

The main adaptation to such projected impacts will be to invest in insurance. A particular problem of climate adaptation in Africa is the prevalence of small farms whose poverty and market isolation prevent them from self-insuring, either through physical investments or through financial instruments. Short-term support to small stockholders through research will be unimportant because of the small feasible rates of genetic gain in the main animals and feeds.

Appropriate forms of public insurance for small stockholders are:

- Strengthening legal and management agreements for regional water bodies, which are at particular risk (from high and low water levels, electricity production sharing, irrigation management, and biodiversity are all notable risks);

- Holding greater financial reserves, or contracting forward, against costs of food if domestic prices become more variable with higher temperatures and more severe storms;

- Defining programmes to create jobs for those who have lost income or work, notably in pastoral areas affected by extreme climate events;

- Investing in regional research on plant materials, and farming practices that will resist higher temperatures and deeper flooding, which might allow diversification of livelihoods by pastoralists who are now specialized in livestock.

Promoting payments for environment services.

Possible integration of non-market environmental goods (GHGs and others) into markets, such as carbon trading and manure markets.

Protecting animal health

There will be two broad animal health research and development paths. The first is the traditional one of the major diseases of ruminant livestock, chiefly beef and dairy cattle, in which the public sector provides most services. Those diseases – CBPP, trypanosomosis, PPR, ECF – plus the burdens of ectoparasites and endoparasites will continue to be the chief health causes of low productivity and of lagging competitiveness. Research on such problems will continue to be largely public and international, with some input from private drug companies. Veterinary service will gradually have more private providers, who will work with commercial herders, especially in converging middle-income nations.

The second animal health development path will be that imposed by intensification of ruminant production and by the rising demand for poultry and pork. Intensification of ruminant production will raise the demand for veterinary research and veterinary services because the value of livestock will rise. A more commercial livestock sector will also create new health problems related to breed specialization, intensive feeding, confinement of animals, and food safety regulations, all the more so if livestock products are exported. Rapid growth in poultry production, and in commercial fattening of sheep and goats, will also pose new animal health problems, given the risks of zoonoses and major animal disease outbreaks in small areas.

Keeping livestock influences human health services.

The distribution of human populations affects the availability of health services across Africa (Linard and others, 2012). Related to population effects on human health services is the fact that keeping animals may have positive or negative human health effects. Livestock may act as a buffer, for example, between trypanosomosis-carrying tsetse flies or malaria-carrying mosquitoes and people; in such cases, livestock act as alternative hosts, effectively protecting people. In other cases, livestock are an amplifying host, for example, where pigs harbour and multiply Japanese encephalitis and so increase the risk to people.

Large commercial poultry flocks, if kept near dense human populations, can harbour avian influenzas for direct transmission and even run the risk of passing them to migratory fowl.

Policy must recognize the potentially conflicting roles of livestock in human health. Buffer zones should be created in densely settled areas where there is intensive livestock production; such zones may be even more necessary where there are high human and animal population densities near irrigated areas, which can attract wild birds.

Promoting intensive agriculture

Intensive agriculture – farming that uses more purchased inputs and achieves higher yields per animal or per unit of land – will inevitably accompany livestock production because of the feed-use linkage between the crop and animal sectors. Policies to promote intensive agriculture, and to relieve its adverse environmental effects, are therefore necessary.

The first policy is to allow free trade in farm inputs – fertilizers, seed and other planting materials, pumps and other irrigation gear, and renewable energy (wind and solar, notably) equipment. Free trade in inputs and investment goods lowers production costs while promoting competition among supply and maintenance industries.

A second class of policy is to spend more on public energy transmission and distribution where infrastructure density is low. Public energy transmission and distribution, linked to a well-regulated mixed public-private energy-generation system, will promote farm industries in water lifting, grain milling, food processing, and milk chilling, to name a few.

A third class of policy is to promote irrigation. Irrigation is important for animals as a source of feed (fodder crops, crop residues and by-products) and services concentrated around project zones. At the same time, promoting irrigation creates water conflicts between crop and animal production, it can aggravate human and animal diseases, and it can absorb public spending that could be used directly for livestock development.

Most of the contribution of irrigation to livestock development will be to ruminants through crop residue and by-product production. Quantifying that contribution is difficult because of potential errors in projecting the pace of irrigation development. It is clear, nonetheless, that irrigation in Africa lags behind that of other continents and that promoting irrigation requires new policies. One measure is to reduce the costs of irrigation development by reducing taxes on irrigation equipment, which would help to lower the cost of water control in small perimeters. The second is to extend modern energy supplies, especially off-grid energy and renewables, so that the variable costs of lifting water become cheaper; this can be done at much lower cost today because of the dramatic decline in the costs of solar generation.

The third is to promote competition in irrigation investment so that builders cannot extract rents on water-control investments.

Policies to manage the adverse effects of irrigation on animal production and on human health are important as well. These policies include: (i) ensuring herders' rights to water in irrigated areas; (ii) ensuring their access to dry-season grazing in lands converted from pastures to irrigated crops; (iii) defending grazing lands against invasive species (such as prosopis julifloria), which may have been stimulated by land clearing for irrigation; and (iv) managing human (malaria, RVF, schistosomiasis) and animal health (RVF, endoparasites) risks aggravated by irrigation investments.

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The risks associated with unmanaged increases in livestock production prompt national decision-makers to ask a number of questions. What kind of livestock policies will contribute to the expansion of livestock production in Africa in ways that bring equitable benefits to societies? How best to ensure that they also contribute to people enjoying good health? What are the options for ensuring that livestock production practices are sustainable from social, environmental, economic and climatic perspectives?

Such questions prompted an investigation of plausible trajectories for African livestock up to 2050 aiming to provide policy recommendations for realizing the potential of livestock as an engine of economic growth, food security and environmental well-being in sub-Saharan Africa.

The key recommendations of the African Livestock Futures Study presented in this report are:

- *Policies that encourage healthy food consumption patterns, the sustainable intensification of all livestock production systems and selective promotion of monogastric livestock production, could result in increased environmental efficiency of livestock systems in sub-Saharan Africa. This can be done in ways that protect production in pastoral communities, and by smallholder farmers.*

- *Sustainable intensification of livestock production will yield significant benefits for food security, incomes, trade, smallholder competitiveness and ecosystems services. These benefits need to be widely appreciated: at the present time farmers face major challenges when attempting to increase their investments in livestock production especially when the sector's contribution to sustainable development and economic growth is not appreciated.*

- *The required investments include increased provision of veterinary services, inputs, institutional support, processing and markets. These are all essential if current livestock production systems are to evolve into viable commercial operations.*