HLPE REPORT 10

Sustainable agricultural development for food security and nutrition: what roles for livestock?

A report by

The High Level Panel of Experts on Food Security and Nutrition

July 2016

CFS COMMITTEE ON WORLD FOOD SECURITY

HLPE High Level Panel of Experts

HLPE Reports series

#1 Price volatility and food security (2011)

#2 Land tenure and international investments in agriculture (2011)

#3 Food security and climate change (2012)

#4 Social protection for food security (2012)

#5 Biofuels and food security (2013)

#6 Investing in smallholder agriculture for food security (2013)

#7 Sustainable fisheries and aquaculture for food security and nutrition (2014)

#8 Food losses and waste in the context of sustainable food systems (2014)

#9 Water for food security and nutrition (2015)

#10 Sustainable agricultural development for food security and nutrition: what roles for livestock? (2016)

All HLPE reports are available at www.fao.org/cfs/cfs-hlpe

HLPE Steering Committee members (July 2016)

Patrick Caron (Chair)
Carol Kalafatic (Vice-Chair)
Amadou Allahoury
Louise Fresco
Eileen Kennedy
Muhammad Azeem Khan
Bernardo Kliksberg
Fangquan Mei
Sophia Murphy
Mohammad Saeid Noori Naeini
Michel Pimbert
Juan Ángel Rivera Dommarco
Magdalena Sepúlveda
Martin Yemefack
Rami Zurayk

HLPE Project Team members

Wilfrid Legg (Team Leader)
Khaled Abbas
Daniela Alfaro
Botir Dosov
Neil Fraser
Delia Grace
Robert Habib
Claudia Job Schmitt
Langelihle Simela
Funing Zhong

Coordinator of the HLPE

Nathanaël Pingault

This report by the High Level Panel of Experts on Food Security and Nutrition (HLPE) has been approved by the HLPE Steering Committee.

The views expressed do not necessarily reflect the official views of the Committee on World Food Security, of its members, participants, or of the Secretariat.

Referencing this report:

HLPE. 2016. Sustainable agricultural development for food security and nutrition: what roles for livestock? A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome.

Contents

List of Figures

List of Tables

List of Definitions

List of Boxes

FOREWORD

The High Level Panel of Experts for Food Security and Nutrition (HLPE) is the science-policy interface of the Committee on World Food Security (CFS), which is, at the global level, the foremost inclusive and evidence-based international and intergovernmental platform for food security and nutrition.

HLPE reports serve as a common, comprehensive, evidence-based starting point for intergovernmental and international multistakeholder policy debates in CFS. The HLPE draws its studies based on existing research and knowledge. The HLPE thrives to clarify contradictory information and knowledge, elicit the backgrounds and rationales of controversies, and identify emerging issues. The HLPE organizes a scientific dialogue, built upon the diversity of disciplines, backgrounds, knowledge systems, diversity of its Steering Committee and Project Teams, and upon open electronic consultations.

HLPE reports are widely used as reference documents within and beyond CFS and the UN system, by the scientific community as well as by political decision-makers and stakeholders, at international, regional and national levels.

***

In October 2014, the Committee on World Food Security (CFS), requested the High Level Panel of Experts (HLPE) to prepare a report on sustainable agricultural development (SAD) for food security and nutrition (FSN), including the role of livestock. This topic is highly relevant to the 2030 Agenda agreed by the international community in 2015. The objective of Sustainable Development Goal (SDG) 2 is specifically to “end hunger, achieve food security and improved nutrition, and promote sustainable agriculture”. Yet all of the SDGs have strong implications for the achievement of SAD for FSN. In return, we should expect SAD to contribute to the fulfilment of all these goals. SAD is also relevant to the role of agriculture and agricultural development in the implementation of the 2014 Rome Declaration on Nutrition, and is central to the fulfilment of the UN commitment to the Right to Food.

SAD has been touched on in other HLPE reports, either with a sectoral focus or from a cross-cutting perspective. The HLPE Note on Critical and emerging issues for food security and nutrition (2014) stressed the importance of a food systems’ approach for the realization of FSN, and provided analysis of livestock issues. The present report draws on these previous HLPE publications as contributions to its narrative, and the reports are cross-referenced as appropriate. This process aims to ensure consistency, as well as adding value by providing SAD with a central role in the overall HLPE analysis.

In this report, agriculture is interpreted in the narrower sense of crops and livestock. Fisheries and aquaculture were treated in a dedicated HLPE report in 2014, while forestry will be covered in a report to be released in 2017. Livestock is used to designate domesticated terrestrial animals raised for food production. Bees, insects and wild foods are not covered.

Agricultural development plays a major role in improving FSN: by increasing the quantity and diversity of food; as a driver of economic transformation; and, because agriculture is the main source of income for a majority of the people who live in the most extreme poverty. Earning sufficient income from agriculture is key for the 1.3 billion people who work in the sector, and directly determines their food security. Extensive experience across many countries over many years shows that both agricultural development and economy-wide growth are needed to improve FSN, and that the former can reinforce the latter.

Given the breadth of the topic, and as reflected in its title, this report focuses on the livestock sector because it is a powerful engine for the development of the agriculture and food sector, a driver of major economic, social and environmental changes in food systems worldwide, and a uniquely powerful entry point for understanding the issues around sustainable agricultural development as a whole.

Livestock production is central to food systems' development and is a particularly dynamic and complex agricultural subsector, with implications for animal-feed demand, for market concentration in agricultural supply chains, for the intensification of production at the farm level, for farm income, land use, and for nutrition and health. Livestock has often set the speed of change in agriculture in recent decades.

Livestock is strongly linked to the feed crop sector, generates co-products including manure and draught power, and in many countries acts as a store of wealth and a safety net. It is integral to the traditional practices, values and landscapes of many communities across the world. Livestock has significant effects on the environment, both positive and negative, particularly when indirect land-use changes and feed crop production effects are taken into account.

As highlighted by numerous contributions to the electronic consultation on the V0 Draft of the report, the focus on livestock, while legitimate as a way to illustrate the complexity of SAD, should not hide the critical importance of the crop sectors. The common approach proposed in this report, to define pathways to SAD in different livestock systems, and the attention paid to crop–livestock interactions can also be used for the wider agriculture sector.

Changes in consumption and dietary patterns will be critical in shaping SAD for FSN. Those subjects will be looked at in a specific HLPE report on Nutrition and food systems to be published in 2017. Taken together, these two reports will provide a significant contribution to informing debates on sustainable food systems along the food chain from production to consumption.

The report offers policy-makers and other stakeholders a framework to design and implement feasible options of sustainability pathways for agricultural development. It will hopefully contribute to sustainable food systems and to FSN for all, and more broadly to the 2030 Agenda, now and in the future.

***

On behalf of the Steering Committee, I would like to acknowledge the engagement and commitment of all the experts who worked for the elaboration of this report, and especially the Project Team Leader, Wilfrid Legg (from United Kingdom) and Project Team Members: Khaled Abbas (from Algeria), Daniela Alfaro (from Uruguay), Botir Dosov (from Uzbekistan), Neil Fraser (from New Zealand), Delia Grace (from Ireland), Robert Habib (from France), Claudia Job Schmitt (from Brazil), Langelihle Simela (from Zimbabwe) and Funing Zhong (from China). They invested much time and effort in this report and should be commended.

This report also benefited greatly from the suggestions of the external peer reviewers and from the comments provided by a large number of experts and institutions, both on the scope and on the first draft of the report. I would also like to thank the HLPE Secretariat for its permanent support to our work.

Last but not least, I would like to thank the resource partners who support, in a totally independent way, the work of the HLPE.

Patrick Caron

Chairperson, Steering Committee of the HLPE, 15 June 2016

SUMMARY AND RECOMMENDATIONS

In October 2014, the Committee on World Food Security (CFS) requested its High Level Panel of Experts for Food Security and Nutrition (HLPE) to prepare a report on sustainable agricultural development for food security and nutrition, including the role of livestock, to be presented in its 43rd Plenary Session in October 2016. This topic is highly relevant to the Sustainable Development Goals (SDGs) as well as to the implementation of the 2014 Rome Declaration on Nutrition and to the fulfilment of the universal Human Right to Food.

Agricultural[1] development is critically important to improving food security and nutrition. Its roles include: increasing the quantity and diversity of food; driving economic transformation; and providing the primary source of income for many of the world's poorest people. Numerous empirical studies across many countries over many years show that both agricultural development and economy-wide growth are needed to improve food security and nutrition, and that the former can reinforce the latter.

The livestock[2] sector is a powerful engine for the development of agriculture and food systems. It drives major economic, social and environmental changes in food systems worldwide, and provides an entry point for understanding the issues around sustainable agricultural development as a whole. As reflected in its title, this report is focused on livestock because of the importance and complexity of its roles and contribution to sustainable agricultural development for food security and nutrition.

The report is structured as follows. Chapter 1 elaborates a *conceptual framework* and a typology of livestock farming systems, which are used to structure the report. Chapter 2 describes the main *drivers and trends of agricultural development.* Chapter 3 identifies the main *sustainability challenges for agricultural development, with a focus on livestock.* Chapter 4 proposes *pathways and responses* to address those challenges, both globally and in specific farming systems. The report concludes by providing a set of action-oriented *recommendations* addressed to states and other stakeholders.

Summary

Sustainable agricultural development for food security and nutrition: approach and conceptual framework

1. The report defines sustainable agricultural development (SAD) for food security and nutrition (FSN) as follows: "Sustainable agricultural development is agricultural development that contributes to improving resource efficiency, strengthening resilience and securing social equity/responsibility of agriculture and food systems in order to ensure food security and nutrition for all, now and in the future."

2. Importantly, FSN and the progressive realization of the right to adequate food do not depend only on global *availability* of food but also on *access*, *utilization* and *stability*. Indeed, *access* to food, but also to productive assets, markets and services are all critical for FSN. *Utilization* of food, and particularly of animal-sourced foods (ASF), from evolving and increasingly complex food supply chains, is having profound effects on human health and well-being, in some cases supplying much needed nutrients but in others giving rise to dietary concerns, for example over excessive meat intake. Finally, conflicts and extreme climate events increasingly threaten the *stability* of FSN for all now and in the future.

3. The report acknowledges the wide diversity of farming and food systems, each of which can and should improve its contribution to SAD for FSN. To sustainably supply nutritious food to a world population that is expected to reach 9.7 billion people by 2050, the report proposes the adoption of context-specific pathways to enable the transition towards more sustainable agricultural and food systems for FSN. Despite wide acceptance of the imperative of achieving food security and better nutrition for all, the multiplicity of possible entry points, perspectives and objectives has led to a coexistence of many narratives and conflicting evaluations about the state of agricultural

[1] Agriculture is interpreted in this report in the narrower sense of crops and livestock. Fisheries and aquaculture were treated in a dedicated HLPE report in 2014, while forestry will be covered in a report to be released in 2017.

[2] In this report, livestock is used to designate domesticated terrestrial animals raised for food production. Bees, insects and wild foods are not covered.

development and, most importantly, on the directions and policy instruments required to improve sustainability.

4. The livestock sector is central to food systems' development. It is a particularly dynamic and complex agriculture sector, accounting for around one-third of global agricultural GDP, with implications for animal-feed demand, for market concentration in agricultural supply chains, for the intensification of production at the farm level, for farm income, for land use and for human and animal nutrition and health. Livestock has often set the speed of change in agriculture in recent decades. Livestock is the largest user of land resources; permanent meadows and pastures represent 26 percent of global land area and feed crops account for one-third of global arable land. Livestock is strongly linked to the feed crop sector, generates co-products including manure and draught power, and in many economies acts as a store of wealth and a safety net. It is integral to the cultural identity, traditional practices, values and landscapes of many communities across the world. Livestock has profound effects on the environment, particularly when indirect land-use changes and feed crop production effects are taken into account.

5. Livestock production takes place in a wide range of farming systems: extensive (e.g. grazing in the case of ruminant livestock or foraging in the case of poultry and pigs); intensive (in which thousands of animals are fed with concentrated feed rations in confined facilities); and in the many intermediate systems that exist between the two.

6. Critical issues to be addressed by SAD for FSN are global in nature but the ways by which they manifest themselves or can be dealt with are very diverse in different livestock systems and across countries. In order to value and address this diversity of farming systems and their distinct challenges, the report considers four broad classes of livestock rearing: smallholder mixed farming; pastoral; commercial grazing; and intensive livestock systems.

Trends and drivers of agricultural development

7. According to FAO (2012a) projections, growth trends in global population and incomes will require global agricultural production in 2050 to be 60 percent higher in volume than in 2005–2007. This increase would come mainly from an increase in crop yield (80 percent of the world production increase), in cropping intensity (10 percent) and the rest from a limited expansion of land use. Consumption of ASF is expected to rise till 2050, faster in developing countries.

8. Yet, such a need for increase will be subject to variation. Over the next several decades, population increase and income growth (both of which trends are more pronounced in emerging and developing countries) are expected to drive increased demand for ASF. Population growth has been the main demand driver in agriculture and food systems in the past but its weight is declining relative to other drivers such as increasing per capita incomes, urbanization and changing dietary preferences and patterns. Much of the increased crop demand in the period to 2050 will be for feedstuffs for livestock.

9. The increasing consumption of ASF in emerging and developing countries has the potential to significantly improve FSN in many cases. However, the consensus of expert medical advice is that, in developed and some emerging countries, people should reduce their consumption of a number of ASF, in particular of red and processed meats. If there were to be a significant reduction in overall consumption of ASF in richer areas, it would have important implications on production levels and practices, on land use, and on the geographical distribution of livestock production. In general, consumption levels of some ASF needs to contract in some places and/or among some populations, while increasing in others. Such a shift would allow greater convergence of consumption at the global level.

10. International trade volumes of most agricultural commodities are projected to expand over the next several decades. While a very high proportion of ASF is produced and consumed locally, the importance of international trade in the distribution of ASF is increasing. Staple dairy products (in particular milk powder) are the most traded livestock products; more than 50 percent of total production is exported. According to OECD–FAO projections, beef will continue to be the most traded meat in the next decade. At the same time, dairy and beef products are among the commodities most affected by government policies across the world – the volume and direction of trade flows, as well as the products traded. Sanitary standards, environmental regulations, animal welfare rules and certification measures, as well as geographical indications, are all increasingly important in influencing international trade of agricultural products.

11. The food supply chain has experienced fundamental changes during the last two decades. It has become more globalized, and the scale of production and economic concentration have both increased. A shrinking number of firms dominate both the distribution and the input side of the agri-food chain. For example, four agri-business firms are estimated to control 75–90 percent of the global grain trade, raising concerns about barriers to entry, information flows and the potential for oligopolistic companies to abuse their dominant market position. Concentration among multinational companies is increasingly evident in a number of agriculture sectors, including inputs (e.g. seeds, plant and animal protection products), marketing, food processing and food retail.

12. According to OECD–FAO Outlook, real world prices of agricultural commodities and food have followed a long-term declining trend, albeit coupled with significant levels of short-term price volatility. The latter has been especially marked since the 2007–2008 food price spikes when compared with the previous two decades. Nonetheless, the underlying downward price trend is widely projected to continue for the short and medium terms.

Sustainability challenges for livestock in agricultural development

13. Some of the challenges impeding the realization of SAD for FSN for all now and in the future concern all livestock systems. Others are specific to one or more of the four broad categories of livestock systems described in the report.

14. The overarching goal for sustainable agricultural development is to ensure FSN for all now and in the future, in the context of climate change and increasing scarcity of natural resources, given the rapidly evolving and changing food demand, the growing and more urbanized human population and the need to "leave no one behind".

Food security and nutrition

15. While food security concerns historically focused on total calorie intake, today they encompass the so-called "triple burden" of malnutrition: hunger (deficiencies in dietary energy intake), estimated by FAO to affect some 792 million people worldwide; micronutrient deficiencies (such as iron, vitamin A, iodine and zinc), which, according WHO, affect some two billion people; and increasing overnutrition that now affects more people than hunger does. In 2014, WHO estimated more than 1.9 billion (39 percent) adults, aged 18 years and over, were overweight, of which over 600 million (13 percent) were obese. The relationships between food systems and nutrition will be explored in depth in a forthcoming HLPE report (2017).

Environment

16. In a context of increasing resource scarcity, and with the urgent need to reduce greenhouse gas (GHG) emissions and adapt to climate change, numerous studies have identified livestock as a key area for action.

17. Resource efficiency in livestock production will have to be improved in order to: maintain production systems within critical planetary limits; preserve the ecosystem services on which agricultural production relies; and reduce land degradation, biodiversity loss and pressure on water use and quality. As a driver of deforestation, demand for feed, and transportation and processing infrastructure, the livestock sector is directly and indirectly responsible for 14.5 percent of GHG emissions. At the same time, some livestock systems are among the most vulnerable to climate change (particularly those in dry areas) and to new environment-related emerging diseases. These challenges are huge but the livestock sector also has huge potential for improvement, if the best existing practices in a given system and region can be shared and learned from more widely.

Economic

18. Livestock plays a crucial economic role in many food systems: providing income, wealth and employment; buffering price shocks; adding value to feedstuffs; providing a source of fertilizer and draught power. Agricultural markets face three challenges: (i) imperfect competition, due to lack of information, barriers to market entry, infrastructure constraints; (ii) externalities that create significant costs not borne by producers; and (iii) market distortions arising from poor public policies, including subsidies and taxes that reward unsustainable practices. More specifically, agricultural markets are subject to unpredictable forces, such as the weather, and to time lags

between investments in production and readiness to sell that encourage producers to be risk averse unless they are supported by safety nets. International trade has introduced opportunities but also new challenges, including an increased potential for diseases to spread. International trade has also been accompanied by a growing role for multinational private actors in making investment decisions in agricultural systems. Concentrated corporate control of agriculture has also increased in the face of uneven access to market information and technologies, undermining competition.

19. Different livestock systems face different economic risks and opportunities in this more general context. Determining factors include: the degree of integration into international markets and urban distribution systems; the level of dependence on external inputs (such as feed); and the degree of concentration in the markets upstream and downstream from livestock producers.

Social

20. According to the *World Development Report (*IBRD/World Bank, 2007), agriculture provides employment to 1.3 billion people worldwide, 97 percent of them in developing countries. Agriculture and food systems are among the sectors where informal jobs are the most common, without adequate work safety, in unhealthy working conditions and for low wages. Children are also disproportionately employed in agriculture, including in ways that violate their rights. Many agricultural systems face a serious demographic challenge in failing to attract and maintain the interest of young people. Conflicts and protracted crises, such as droughts and epidemic outbreaks, strongly impinge on agriculture and livestock production, affecting feed crop production, the productivity of rangelands and access to pastures, rangelands, feed and forage.

Gender

21. Women play a vital role in the management of many livestock systems, especially poultry and pigs. Women's roles within livestock production systems differ from region to region, and the distribution of ownership of livestock between men and women is strongly related to social, cultural and economic norms. Too often, however, women face multiple forms of discrimination, from lack of access to education and productive resources to discriminatory political and legal systems that together limit their ability to benefit from the livestock sector. Not enough gender-disaggregated data are available to fully understand the specific challenges faced by women in this sector.

Animal health and welfare

22. Animal diseases are a major cause of productivity and economic losses in developing countries. The rapid expansion of the sector as well as increased movements of animals and products within countries and across borders make it all the more urgent to address infectious diseases. Even more since the majority of emerging and re-emerging human diseases are zoonotic – they come from animals and are transmitted to humans. The critical linkages between human health, animal health and ecosystems are encompassed in the concept of *One Health*, which highlights the need for collaboration across sectors.

23. Animal welfare is an increasing public concern, raised by consumers and often by retailers who are responding to consumer demand. In many countries, legislation provides for a minimum standard of animal welfare. Where this legislation does not yet exist, the World Organisation for Animal Health (OIE) provides guidelines.

System specific challenges

24. These global challenges concern the different livestock systems to various degrees. Each system is also confronted with specific challenges.

    a. *Smallholder mixed farming systems* face limited access to resources, markets and services, variable resource efficiency and big yield gaps, and have little capacity to adapt to deep and rapid structural transformation in the agriculture sector and in the wider economy.
    b. *Pastoral systems:* in addition to the challenges they share with smallholders, pastoral systems must cope with conflicts for land and water, economic and political exclusion, social (including gender) inequity, poor animal health and high risks of zoonotic diseases.
    c. *Commercial grazing systems* face the degradation of the natural grasslands they depend upon, conflicts with other sectors over land and resource use, poor conditions for workers and, in some cases, technical inefficiencies.

d. *Intensive livestock systems* face environmental challenges resulting from intensification (land and water use; water, soil and air pollution); the harm to human and animal health created by antimicrobial resistance, the emergence of new diseases; the social consequences of intensification (rural abandonment, poor working conditions, low wages, vulnerability of migrant labour, occupational hazards); and economic risks in the form of dependence on external inputs, including feed and energy, market concentration, price volatility, inequitable distribution of value added, as well as the difficulty of internalizing externalities in price signals.

Pathways towards sustainable livestock development

25. The report proposes a common approach to elaborate pathways for SAD comprised of eight steps. These steps *de facto* outline a process around which to design national SAD strategies:

    i. Describe the current situation in a specific context.

    ii. Agree on the long-term FSN goals and targets at the national level, in line with the SDGs.

    iii. Identify the challenges to be addressed to move towards SAD for FSN.

    iv. Define a set of operational priorities among these challenges.

    v. Identify available solutions that can be mobilized by stakeholders at different levels.

    vi. Define the context specific responses and technical solutions.

    vii. Set in place an appropriate political and institutional environment at the national level to enable the choice of priority actions at the farm level and along the food chain.

    viii. Set in place methods to monitor and evaluate progress, to continue to identify constraints, and to allow for a dynamic and iterative process of learning by doing.

26. Pathways combine technical interventions, investments, and enabling policies and instruments. They involve a variety of actors, operating at different scales, all working towards SAD for FSN. The pathways need to be specific to national and local contexts, and to particular scales and time periods. They can be grounded on very different narratives, each of which drives a selection of options. Amid this specificity, three interlinked principles help shape those pathways towards SAD for FSN:

    - *Improve resource efficiency.* Considerable potential exists to improve resource efficiency through the transfer and adoption of best available practices and technologies in a given context and through the adoption of diverse approaches (including "sustainable intensification", "save and grow", "ecological intensification", and "agro-ecology"), all with a growing emphasis on ecosystem services. This would make it possible to simultaneously increase productivity, to preserve and make better use of limited resources, and to reduce GHG emissions. Resource efficiency can be improved through different technical means including: improving livestock management, careful breeding, health and feed efficiency; closing the nutrient cycle; and reducing food losses and waste.
    - *Strengthen resilience.* To address changing risks and shocks, whether environmental, economic, financial, or related to human and animal health, requires building resilience in livestock systems. The diversification of production and integration of crops and livestock at all levels – from farm to landscape, community, territory and region – will contribute to strengthen resilience and improve resource efficiency.
    - *Improve social equity/responsibility outcomes.* The failure to protect social equity and cultural integrity raises some of the most wide-ranging and politically sensitive challenges for sustainability. The norms, practices and priorities of social equity/responsibility, the property rights and land tenure laws and customs, all differ across countries and communities and change over time. Working conditions need to be improved at all levels of food value chains. In line with the SDGs, national SAD strategies will have to prioritize the needs and interests of the most vulnerable populations (which typically include women, children, migrants, and indigenous peoples).

27. The report notes the need for appropriate, and where relevant gender disaggregated, data to enable stakeholders to identify priorities and monitor progress.

28. The report highlights the need for coherence and integration among agriculture, economic, nutrition, education and health policies at the national level, and to improve the international coordination across these sectors as well, so as to address sustainability and FSN challenges.

29. The twin problems of under- and overnutrition require local and national governments to coordinate policies pertaining to nutrition, health and SAD goals, taking into account the level of socio-economic development and their cultural and religious contexts. The regulation of agrifood industries and their cooperation are also necessary.

30. While recognizing that farm level is at the heart of decision-making processes, enabling environments, including good governance and effective institutions, will be critical for an effective implementation of pathways and for the success of SAD strategies. The framework for developing strategies needs to ensure that actions taken at a particular level of organization (local government, territory, value chain, country, region, international) are consistent with actions taken at other levels and with other non-agriculture sectors, in order to allocate needed resources for facilitating pathways, to strengthen synergies and to address trade-offs to best achieve SAD for FSN. In addition, pathways are needed for all farming systems and one of the critical challenges is to consistently manage the co-existence of systems and their pathways at supra levels.

31. Agriculture merits increased public and private investment and R&D for SAD: this should be a political and economic priority. This had also been shown by the World Development Report, which emphasized the specific role of agriculture as a powerful driver of growth and poverty reduction. SAD strategies must take into consideration: the role and limits of markets; the universal human right to food; and the challenge presented by the principle of "food sovereignty", which emphasizes the importance of subsidiarity and democratic voice in making decisions that affect food systems.

32. Appropriate technologies for sustainable agriculture need to be made available for all farming systems and be tailored to particular circumstances and contexts. In all cases, technological choices must be informed by solid risk assessment and impact evaluations. The application of information and communications technology (ICT) in agriculture is increasingly important, especially in the development of new innovations that can empower farmers – including smallholders – and the value chains that support them. The rapidly declining costs of ICT can make it an attractive tool for poorer farmers, extending its reach.

33. Genetic resources are a key asset for SAD. They need to be sustainably managed and appropriately conserved, in situ and ex situ, together with the knowledge associated with them, including traditional and indigenous knowledge. The means and mechanisms to facilitate access of smallholders to genetic resources as well as benefit sharing are particularly important. Such mechanisms are much more developed for plants than for animals.

Operational priorities for action

In addition to these more general principles, orientations and actions, each category of livestock system has some priority areas of intervention that better take into account its specificities.

34. *For smallholder mixed farming systems, the priorities include:* ensure better access to markets and more choice of markets; secure tenure rights and equitable access to land; design feasible growth pathways taking into consideration available resources; recognize, empower and enable the role of women; improve animal health management; encourage the use of local, more resistant, breeds; implement appropriate, tailored and participatory programmes that respond to farmers' needs; facilitate smallholders' participation in political processes; provide good quality training programmes and information; and redirect development policies and tax incentives towards the design of diversified and resilient farming and food systems.

35. *For pastoral systems, the priorities include:* improve governance and security by involving pastoral societies in participatory governance mechanisms; improve connections to markets and market choices; provide and protect access to public services, including for animal and human health, and access to pastoral resources (water and land); implement a fairer taxation system to enhance value-added activities through the processing and marketing of pastoral products; better target emergency assistance; and devise development strategies that take into account the specific needs of pastoral systems, including mobility.

36. *For commercial grazing systems, the priorities include:* the maintenance and improvement of grassland management practices to improve resource efficiency and contribute to climate change mitigation and adaptation; the development of integrated crop–livestock–forestry systems that enable several kinds of production on the same land and allow synergies between those productions; and the protection of native forests from deforestation.

37. *For intensive livestock systems, the priorities include:* investment in R&D along the complete food chain to strike a balance between increasing production and reducing environmental harm, including food losses and waste; the expansion of precision livestock farming; action to reduce the prophylactic use of antibiotics in animal care and to improve animal welfare; policies to reduce the environmental impact of intensive systems including systems that promote more recycling of animal waste to promote efficiency and reduce the harm caused by unbalanced nutrient cycles (too much depletion where the feed crops are grown and too much addition where livestock are raised and fed); and increase the sustainable production of feed while improving the ratio of feed to animal conversion.

These means can be mobilized, as appropriate, to answer the priorities determined according to each specific situation, in the pursuit of a common objective of SAD.

Recommendations

The following recommendations have been elaborated building upon the main findings of the report on *Sustainable agricultural development for food security and nutrition: what roles for livestock?* They aim to strengthen the contributions of the livestock sector to sustainable agricultural development (SAD) for food security and nutrition (FSN). They are directed at different categories of stakeholders as appropriate: states, intergovernmental organizations (IGOs), the private sector and civil society organizations, and other stakeholders. They should:

1. ELABORATE CONTEXT-SPECIFIC PATHWAYS TO SAD FOR FSN

States and other stakeholders should:

a) use the common approach presented in this report to elaborate, at all appropriate levels, context-specific pathways towards SAD. Such pathways should aim to strengthen synergies and limit trade-offs between the different dimensions of sustainability through improving resource efficiency, strengthening resilience and securing social equity/responsibility. They could draw on initiatives such as the Global Agenda for Sustainable Livestock and the Global Research Alliance on agricultural greenhouse gases. In that respect, in line with SDGs, all stakeholders should support initiatives that involve multi-stakeholders dialogue, consultation and collaboration.

2. STRENGTHEN INTEGRATION OF LIVESTOCK IN NATIONAL SAD STRATEGIES

States should:

a) ensure that their SAD strategies and plans incorporate the integrated approach to FSN advocated by the CFS and are in line with the SDGs. States should better integrate into their SAD strategies the contributions that livestock systems make to the achievement of FSN. Policies, strategies and programmes need to take into account the interlinkages between different farming systems and their dynamic nature. They should in particular promote crop–livestock integration at a scale and through means that are adapted to the diversity of systems.

3. FOSTER COHERENCE BETWEEN SECTORAL POLICIES AND PROGRAMMES

States and IGOs should:

a) foster greater coherence between sustainable agricultural development, food systems, health, social protection, education and nutrition policies and programmes, as well as between their respective institutions, agencies and ministries.

4. DEVELOP GENDER-SENSITIVE LIVESTOCK POLICIES AND INTERVENTIONS

States, IGOs and other stakeholders should:

a) collect gender-disaggregated data on women's roles in livestock production to understand where gender asymmetries persist in the livestock sector;
b) adopt and ensure implementation of legislation to provide women equal access to and control of land and resources at the community and household levels;
c) ensure that women, in particular smallholders, have access to credit and develop specific financial products for women, in order to facilitate the diversification of their economic activities;
d) improve women's labour conditions in the livestock sector, including at the processing stage;
e) take measures at the local level to ensure the inclusion of women at every stage of the livestock value chain, taking account of their productive and reproductive roles;
f) take measures to enhance women's skill and knowledge by providing inclusive training and capacity building activities including when introducing new technologies.

5. BETTER INTEGRATE SAD ISSUES FOR FSN IN TRADE POLICIES

States and IGOs in relation to stakeholders should:

a) better integrate agriculture, including livestock, feed and related technical issues, into national, regional and multilateral trade rules and policies in order to improve SAD for FSN;
b) establish appropriate national and international food safety and quality standards and ensure their implementation through capacity building and appropriate resources for compliance.

Governments, producer organizations, the private sector and civil society should:

c) consider all dimensions of SAD in the development and implementation of standards for animal-sourced foods and livestock feed.

6. LIMIT AND MANAGE EXCESSIVE PRICE VOLATILITY

States, producer organizations and other stakeholders should:

a) develop tools to limit and manage excessive price volatility, including through the use of grain storage facilities, insurance programmes and other public policy instruments and private initiatives. In particular, these tools should address the risks posed by import surges and volatility in feed markets, and the specific vulnerabilities of smallholders.

7. PROTECT, PRESERVE AND FACILITATE THE SHARING OF LIVESTOCK GENETIC RESOURCES

States, IGOs, food producers, the private sector and research organizations should:

a) in order to support SAD, increase cooperation and ensure dissemination, distribution and creation of knowledge and transfer of appropriate technologies to characterize, conserve and manage livestock genetic resources both *in situ* and in germplasm stores and related facilities;
b) act to minimize genetic erosion of the remaining biodiversity both *in situ* and in gene banks, as well as to recognize and protect traditional and indigenous knowledge linked to livestock genetic resources;
c) create conditions to facilitate access to livestock genetic resources for food and agriculture and the fair and equitable sharing of the benefits arising from their use;
d) consider the establishment of dedicated international mechanisms to realize these objectives;

e) promote the recognition and protection of smallholders and indigenous peoples' livestock genetic resources as well as the associated knowledge of those resources;

f) recognize and protect the rights of smallholders and indigenous peoples to determine access to their livestock genetic resources including their right to determine who should have access to them and to a fair and equitable share of the benefits that arise from their use.

8. IMPROVE SURVEILLANCE AND CONTROL OF LIVESTOCK DISEASES

States and IGOs should:

a) implement *One Health* approaches to improve the surveillance and response for diseases emerging from livestock systems;

b) cooperate to provide transparent reporting for early warnings on transboundary diseases and emerging zoonosis;

c) provide adequate means to ensure compliance to international and national laws and rules;

d) provide financial and technical support for improved animal health and welfare in agricultural development, including for capacity building programmes.

9. PROMOTE RESEARCH AND DEVELOPMENT

States and IGOs should:

a) integrate a participatory approach when designing an agenda and allocating resources for R&D, and focus on technologies, practices, metrics and institutions needed to improve resource efficiency, strengthen resilience and secure social equity/responsibility in diverse livestock farming systems;

b) enable participatory research in order to promote the integration of diverse knowledge systems about livestock keeping, including animal breeding;

c) promote the collaboration of researchers in livestock keepers' and other stakeholders' innovation processes and platforms to ensure dissemination of research findings and sharing of good practices.

States, IGOs and the private sector should:

d) leverage the potential of information and communication technologies (ICT) in order to gather, share and use information in different livestock systems, ensuring broad access, in particular by women, vulnerable and marginalized communities.

10. REVIEW AND IMPROVE INDICATORS AND METHODOLOGY AND IDENTIFY DATA GAPS

FAO, in coordination with relevant international and national agencies and other relevant stakeholders, should:

a) review the data sets, indicators and methodologies that are needed to monitor and evaluate SAD for FSN, using such tools as the World Agricultural Census and the preparation of indicators for the SDGs, and identify data gaps;

b) consider ways to improve the monitoring of changes in grasslands and their biodiversity, and to report on their global state;

c) make available online an inventory of evidence-based policy measures as well as producer organizations, the private sector and other stakeholders actions that contribute to SAD for FSN.

RECOMMENDATIONS RELATED TO SPECIFIC LIVESTOCK SYSTEMS

States, IGOs and other stakeholders should consider the roles of different livestock systems in all agricultural, food security and nutrition policies and promote SAD-oriented efficiency and sustainability pathways that are adapted to the specificity of each of the systems. In particular, they should:

11. RECOGNIZE THE IMPORTANCE OF SMALLHOLDER MIXED FARMING SYSTEMS FOR FSN AND SUPPORT THEM BY:

a) enhancing economic viability and access to markets; prioritizing fairer markets and measures to overcome obstacles faced especially by women, marginalized and vulnerable groups engaged in managing small-scale livestock operations;

b) creating an enabling environment for collective organizations and actions of smallholders; investing in market information and infrastructure (including informal markets);

c) strengthening security, tenure and title of customary lands, property rights and governance of common natural resources building on the CFS Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests, and other relevant instruments in the international legal framework;

d) leveraging the potential of livestock as a means for sustainable livelihoods in smallholder mixed farming systems.

12. RECOGNIZE AND SUPPORT THE UNIQUE ROLE OF PASTORAL SYSTEMS BY:

a) strengthening the role of local pastoralist organizations in adaptive land management and governance in order to increase the resilience of pastoral systems and households, in particular with respect to climate change, conflicts and protracted crises, as well as price volatility;

b) considering the use of innovative financing mechanisms to invest in the provision of basic services adapted to the needs and ways of life of pastoralists, including culturally appropriate education, health, communications, drinking water and sanitation services, and renewable energy systems;

c) exploring ways to improve the connection of pastoralists to local, national and international markets;

d) strengthening security, tenure and title of customary lands, property rights and governance of grazing resources building on CFS Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests, and other relevant instruments in the international legal framework;

e) enabling the mobility of pastoralists, including transboundary passage, through appropriate infrastructures, institutions, agreements and rules.

13. PROMOTE THE SUSTAINABILITY OF COMMERCIAL GRAZING SYSTEMS BY:

a) supporting sustainable management of livestock, pastures and feed in order to minimize harmful environmental externalities, including by promoting models of production that preserve biodiversity and ecosystem services and reduce GHG emissions;

b) exploring context specific technical possibilities and policy initiatives for integration of plants and animals at diverse scales, such as, for instance, agro-sylvopastoral systems;

c) promoting practices that enhance resource efficiency and resilience of commercial grazing systems.

14. ADDRESS THE SPECIFIC CHALLENGES OF INTENSIVE LIVESTOCK SYSTEMS BY:

a) ensuring that the working and living conditions of workers, especially women and other vulnerable workers, including temporary and migrant workers, at all stages of production, transformation and distribution, meet international standards and are protected by domestic laws;

b) undertaking lifecycle assessment along the complete food chain to identify options for increasing production while minimizing negative environmental impacts and excessive use of energy, water, nitrogen and other natural resources;

c) improving technical efficiency by monitoring the individual performance of herds and animals;

d) supporting and improving animal health and welfare by promoting good practices and by establishing and enforcing robust standards for different species in intensive systems, building upon the World Organisation for Animal Health (OIE) guidelines and private sector initiatives;

e) exploring and implementing approaches for the reduction of antimicrobial use in livestock production;

f) developing innovative approaches, with farmers' organizations, at diverse scales, in order to facilitate the use of manure as organic fertilizer – and to promote the use of crop co-products or residues and waste as feed including through technical innovations.

INTRODUCTION

Agricultural development plays a major role in improving food security and nutrition (FSN):[3] by increasing the quantity and diversity of food; as a driver of economic transformation; and because agriculture is the main source of income for a majority of the people who live in the most extreme poverty. Earning sufficient income from agriculture is key for the 1.3 billion people who work in the sector, and directly determines their food security. Extensive experience across many countries over many years shows that both agricultural development *and* economy-wide growth are needed to improve FSN, and that the former can reinforce the latter.

Agricultural development, since the Second World War, has enabled impressive progress in food production. This was mostly due to a combination of economic growth, advances in technology and knowledge, and improved management along supply chains. This increased production has mostly occurred through intensification, specialization, and economies of scale that depend increasingly on inputs including animal feed and non-renewable sources of energy. Nevertheless, extensive grass-based livestock systems, pastoral and smallholder crop–livestock mixed systems that do not rely on external inputs have also contributed significantly to increased supplies of food.

This indisputable progress has not come about without giving rise to a persistent range of concerns. Critics question whether the present and future directions of agricultural development are sustainable. To list just some of the concerns: there is currently a renewed debate about the world's agriculture and food systems' capacity to sustainably supply nutritious food to a growing population given the so-called "triple burden" of malnutrition – the persistence of substantial food insecurity, undernutrition and overnutrition; there are concerns about the social performance of food systems; about the degradation of land, freshwater and ecosystems at both local and global levels; about the impact of agriculture on greenhouse gas (GHG) emissions; and, in turn, the effects of climate change on agriculture.

Over the long run, world food prices in real terms have tended to fall – although masking much price volatility in the short run – as a consequence of food supplies increasing faster than demand. This has given rise to the concern that these past trends may dampen incentives for investing in future agricultural development, and in particular in hindering its long-term sustainability.

There are contrasting perspectives on whether supporting labour-intensive agriculture or fostering productivity (and profitability) improvements in agriculture, even at the expense of labour-intensive practices, is the best pathway for sustainable agricultural development to achieve FSN overall. Agriculture can trigger economic growth, which in turns facilitates off-farm rural and urban employment opportunities. However, in many countries, the rural population is increasing, generating concerns about their livelihoods and FSN, especially for those that are landless and vulnerable. While urbanization has continued apace (with urban citizens being generally better nourished than rural people),[4] rural people who have moved to cities – especially in the transitional phase of urbanization – are still food-insecure.

In this context, in October 2014, the Committee on World Food Security (CFS), in its 41st Plenary Session, requested the High Level Panel of Experts (HLPE) to prepare a report on sustainable agricultural development for FSN, including the role of livestock, for its 43rd Plenary Session in 2016. This topic is highly relevant to the Sustainable Development Goals (SDGs) as well as to the implementation of the 2014 Rome Declaration on Nutrition and to the fulfilment of the universal Human Right to Food.

This wide-ranging and comprehensive request implies addressing a number of key questions, including: What is the role and what directions for agricultural development are needed to fully

[3] "Food security exists when all people, at all times, have physical, social and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (World Food Summit, 1996). In 2009, the World Summit on Food Security stated that the "four pillars of food security are availability, access, utilization and stability". *Availability* is the supply of food through production, distribution and exchange; *access* is the affordability and allocation of food, as well as the preferences of individuals and households requirements of each member of the household; *utilization* is the metabolism of food by individuals, resulting from the diversity and quality of food, good care and feeding practices, food preparation, determining the nutritional status of the individual; and *stability* refers to the stability of the three other dimensions over time.

[4] Cross-country evidence consistently shows that children in urban areas are better nourished than those in rural areas. For example, in 82 out of 95 developing countries for which evidence is available the proportion of underweight children is less in urban areas (UNICEF, 2013).

contribute to sustainably supply nutritious food? What can be done to improve the way our food and agricultural systems perform economically, socially and environmentally? Can agricultural development restore the already stressed natural systems that underpin food production now and in the future? What role can sustainable agricultural development pathways play in underpinning decent livelihoods to achieve the overarching objective of food security and nutrition?

In this report, *agriculture* is interpreted in the narrower sense of crops and livestock. Fisheries and aquaculture were treated in a dedicated HLPE report in 2014, while forestry will be covered in a report to be released in 2017. *Livestock* is used to designate domesticated terrestrial animals raised for food production. Bees, insects and wild foods are not covered.

The questions of *sustainability* and *agricultural development* are particularly complex ones because, as most of the topics addressed until now by the HLPE, they require a long-term integrated perspective. This means looking at the dynamics of the agriculture sector. It also means that a very broad vision of the sector itself is needed, including its links to economic development as a whole, to natural resources, demographic, social and cultural issues, and to the trends affecting these aspects in the long term. Finally, it means to take account of interactions between the three dimensions of sustainability (environmental, economic and social) that need to be secured and enhanced for future generations, and to do so at very different scales and in a wide range of specific contexts.

Within the broad issue of agricultural development, as reflected in its title, this report focuses on the *livestock* components of agricultural systems, given their role as an engine for the development of the agriculture and food sector, as a driver of major economic, social and environmental changes in food systems worldwide, and as an entry point for understanding the issues around sustainable agricultural development as a whole.

The livestock sector is central to food systems' development. It is a particularly dynamic and complex agriculture sector, accounting for around one-third of global agricultural GDP, with implications for animal-feed demand, for market concentration in agricultural supply chains, for the intensification of production at the farm level, for farm income, for land use, and for human and animal nutrition and health. Livestock has often set the speed of change in agriculture in recent decades. Livestock is the largest user of land resources; permanent meadows and pastures represent 26 percent of global land area and feed crops account for one-third of global arable land. Livestock is strongly linked to the feed-crop sector, generates co-products including manure and draught power, and in many economies acts as a store of wealth and a safety net. It is integral to the cultural identity, traditional practices, values and landscapes of many communities across the world. Livestock has also profound effects on the environment, particularly when indirect land-use changes and feed-crop production effects are taken into account.

There is increasing evidence that some of the major challenges to which agriculture is confronted depend upon the evolution of the livestock sector. This is the case for human health through both the burdens of under- and overnutrition. This is also the case for the environment. The pressure on the agriculture sector, and the consequences for changes in land-use patterns, will strongly depend on the evolution of animal-sourced food (ASF) demand.

Livestock production takes place in a wide range of farming systems: extensive (e.g. grazing in the case of ruminant livestock or foraging in the case of poultry and pigs); intensive (in which thousands of animals are fed with concentrated feed rations in confined facilities); and in the many intermediate systems that exist between the two.

Defining pathways for minimizing the harmful and enhancing beneficial environmental, economic and social impacts of livestock is therefore essential. Based upon this assumption, the livestock sector can also serve as an illustration for the wider agriculture sector to explore possible pathways of sustainable agricultural development for FSN, with a view to recommending appropriate actions by policy-makers and stakeholders in different contexts.

Consumption is critical in shaping the feasibility of sustainable agricultural development pathways, locally and globally. Consumption is considered, in this report on sustainable agricultural development, as a key driver of agricultural production and agricultural development. Assumptions about future food consumption patterns are crucial and nutrition and consumption issues will be more specifically considered in an HLPE report on *Nutrition and food systems* to be published in 2017. Taken together, these two reports aim to provide a significant contribution to informing debates on sustainable food systems, along the food chain from production to consumption.

The debate around sustainability, and on future directions for agricultural development, is not exempt from areas of controversy and different views on possible trajectories. One important objective of this report is to try to clarify the debates for policy-makers and all stakeholders by presenting the current controversies in a comprehensive and balanced way.

The report is structured as follows. The first chapter outlines an approach to sustainable agricultural development in the perspective of FSN, including proposing a *conceptual framework* for agricultural development for FSN, and a typology of livestock farming systems, which will be used to structure and analyse the issues addressed throughout the report.

This is followed in Chapter 2 by a discussion of the main *trends and drivers* affecting the agriculture, including livestock sector, according to various projection scenarios through to 2050.

Chapter 3 identifies the main *sustainability challenges* for the development of livestock systems (including the associated feed crops) and their contribution to FSN goals, pointing to hotspots, stresses, risks and tipping points that need to be addressed.

Chapter 4 outlines a framework and possible *pathways and responses* to address those challenges, both globally and in different farming systems, including constraints to their implementation. It includes consideration of different perspectives, visions and narratives on the pathways that have the potential to achieve sustainable agricultural development for FSN. Short case studies illustrate the wide variety of practical experiences in different contexts.

1 SUSTAINABLE AGRICULTURAL DEVELOPMENT FOR FOOD SECURITY AND NUTRITION: APPROACH AND CONCEPTUAL FRAMEWORK

This chapter aims to build a common understanding of the notion of sustainable agricultural development (SAD) for FSN. It outlines the approach and concepts used in this report.

Section 1.1 briefly explains the role of agricultural development as a driver of economic and social development to improve FSN. In doing so it examines the notion of sustainability, in line with conceptual frameworks established by the HLPE that link food security and nutrition to sustainable food systems (HLPE, 2014). The section provides a conceptual framework articulating the different elements of SAD and at the same time establishes the logic of this report.

Section 1.2 explains the key role of the livestock sector in SAD for FSN, giving the reasons for focusing on livestock in this report. Section 1.3 proposes a typology of farming systems used in this report.

1.1 What is "sustainable agricultural development for food security and nutrition"?

Understanding "sustainable agricultural development for food security and nutrition" requires considering the dynamics of agricultural development: what it does, the outcomes, and how it performs vis-à-vis the two key objectives of sustainability and FSN.

Agricultural development has a key role to play in relation to poverty reduction, in the context of economic development and growth as a whole. Also, given the economic and social importance of agriculture, which provides a livelihood to 38.3 percent of the world total labour force (FAO, 2015a), and the importance of food as a basic human need, agricultural development is a key domain for the universally agreed human rights framework, including the progressive realization of the Right to Food. Considering the crucial importance of agricultural development to ensure FSN, to reduce poverty, and to ensure sustainable management of natural resources, SAD is central for the implementation of the 17 Sustainable Development Goals (SDG) agreed in 2015.

What are the relationships between food security, sustainable food systems and sustainable agricultural development? In line with HLPE (2014), "Sustainable food systems are food systems that ensure food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition of future generations are not compromised".

In this report, sustainable agricultural development is envisaged in its contribution to achieving food security and nutrition, and is defined as follows:

Definition 1 Sustainable agricultural development

Sustainable agricultural development is agricultural development that contributes to improving resource efficiency, strengthening resilience and securing social equity/responsibility of agriculture and food systems in order to ensure food security and nutrition for all, now and in the future.

1.1.1 Agricultural development in relation to food security and nutrition

Agricultural development is key to food security in several ways, contributing to food availability, access and stability and – through the diversity of foods produced – food utilization. It has accompanied population growth providing a threefold increase in global agricultural production in 50 years, with an increase in the area of land farmed of only 12 percent (FAO, 2014a), thanks notably to the "Green Revolution", although with significant variations across countries and regions. The Green Revolution built on the work of crop scientists and, targeting specific crops, involved the use of high-yielding varieties, expanded irrigation and application of synthetic fertilizers and pesticides, as well as improved management techniques. But the specialization of agricultural systems has resulted in significant levels of biodiversity loss, with potential effects on the environmental sustainability of farming systems and on the possibility for a diversity of food supplies in the future.[5]

Today, people are hungry not because there is not enough food overall in the world, but because they cannot afford food or do not have the means to produce it. It is access to food, the effective demand for food (meaning demand by people who can pay for it) and how food is distributed across and within countries, as well as within households and across genders, that ultimately matter (Grafton *et al.*, 2015). A significant part of the world population produces food for self-consumption.

Population growth, income growth, urbanization and changing diets are seen as the main drivers of increased demand for agricultural production over the coming decades. Chapter 2 provides an elaboration of these drivers. Suffice it to note here that, based on 2008 UN projections of a global population of 9.15 billion in 2050 and continuing trends in consumption, FAO estimates that global agricultural production in 2050 will need to be 60 percent higher in volume than in 2005/07 (FAO, 2012a). Some livestock products – in particular poultry – could show much greater growth than this aggregate average figure. Which production systems and market access arrangements will provide for rising food demand in different regions of the world is a central issue for the future of agriculture and the global food system. Absolute increases in production of the magnitude projected by FAO will not be achieved without difficulty as land, water and other resources come under greater pressure. A shift in diets, as a contribution to healthier diets, and a reduction of food loss and waste could also dampen the projected rate of demand increase. According FAO, the evidence cautiously suggests that, globally, there are sufficient resources to satisfy the additional demand projected to 2050, but that resource availability, income and population growth are unequally distributed and local resource scarcities are likely to remain a significant constraint in pursuing food security for all (FAO, 2012a).

The relationship between agricultural development and access to food is a central issue, due to the paradox that most of the 792 million hungry people worldwide[6] are found among farmers and rural people. As recognized by the 2008 World Development Report (WDR), *Agriculture for development*, (IBRD/World Bank, 2007) three out of four poor people in developing countries live in rural areas and most depend on agriculture directly or indirectly for their livelihoods.

The WDR report showed how, in the “agriculture-based” countries particularly, agriculture and associated industries are essential to reduce mass poverty and food insecurity and will require a productivity revolution in smallholder farming, a sector that in these countries tends to be dominated by women. In “transforming” countries, the WDR suggests extreme rural poverty must be addressed by providing multiple pathways out of poverty, including through a shift to higher-value agriculture, more rural-based non-farm economic activity and assistance to people transitioning out of agriculture. In “urbanized” countries too, agriculture can help reduce the remaining rural poverty if smallholders can be connected to modern food market chains and if jobs can be created in agriculture and agro-industry along with the creation and application of markets for environmental services. The WDR proposes a revitalization of the agriculture sector by tackling underinvestment and mis-investment in agriculture, reducing poverty, ensuring economic growth, improving livelihoods and strengthening food security across the developing world (Box 1).

Concerns about the capacity of agriculture and food systems to enable improved nutritional outcomes have grown with the progressive recognition of “hidden hunger” or micronutrient deficiency, which affects those undernourished as well as those who can meet their *energy* but not their *nutritional* needs essential for human health and development. Poor nutritional outcomes are the result of unbalanced diets, a lack of access to potable water and sanitation (HLPE, 2015), as well as health conditions. Much of sub-Saharan Africa and the South Asian subcontinent are subject to a high prevalence of hidden hunger.

---

5 According to the FAO report *The State of the World’s Animal Genetic Resources for Food and Agriculture* (FAO, 2007), a total of 1 491 (20 percent) of the breeds were classified as being at risk. But the actual figure could be even higher as data were unavailable for 36 percent of the breeds.

6 See FAOSTAT: http://faostat3.fao.org/download/D/FS/E (accessed June 2016)

Box 1 Rural worlds – importance of agriculture in the economy

Agriculture provides employment to 1.3 billion people worldwide, 97 percent of them in developing countries. Between 60 and 99 percent of rural households derive income from agriculture in 14 countries with comparable data.

Agriculture-based countries – Agriculture is a major source of growth, accounting for 32 percent of GDP growth on average – mainly because of its large share in GDP – and most of the poor are in rural areas (70 percent). This group of countries has 417 million inhabitants, mainly in sub-Saharan African countries; 82 percent of the rural sub-Saharan population lives in agriculture-based countries

Transforming countries – Agriculture is no longer a major source of economic growth, contributing on average only 7 percent to GDP growth, but poverty remains overwhelmingly rural (82 percent of all poor). This group, typified by China, India, Indonesia, Morocco and Romania, has more than 2.2 billion rural inhabitants. (Ninety-eight percent of the rural population in South Asia, 96 percent in East Asia and the Pacific, and 92 percent in the Middle East and North Africa are in transforming countries.)

Urbanized countries – Agriculture contributes directly even less to economic growth – 5 percent on average – and poverty is mostly urban. Even so, rural areas still have 45 percent of the poor, and agri-business and the food industry and services account for as much as one-third of GDP. Included in this group of 255 million rural inhabitants are most countries in Latin America and the Caribbean and many in Europe and Central Asia. Eighty-eight percent of the rural populations in both regions live in urbanized countries.

Source: IBRD/World Bank (2007).

The undernutrition concern has been enlarged to a so-called "triple burden" of malnutrition (undernourishment, micro deficiencies and obesity). The unprecedentedly large and rapid transition across countries during the last decades towards the so-called "Western diet" (Popkin *et al*., 2012) has meant higher average intakes of refined sugars and carbohydrates, refined fats, oils, and red and processed meats. The human health concerns associated with the diet include overweight and obesity, cardiovascular diseases, diabetes and autoimmune diseases, and some cancers (Murray *et al*., 2013). The transition to more Western diets is linked to rising incomes and urbanization in the developing world as well as to social, technological and economic changes in food systems. Overconsumption (particularly of some food groups) and associated obesity has mainly been a problem of the rich in low-income countries and the poor in high-income countries; the situation is evolving, however, and in middle-income and increasingly even in low-income countries there is a mixed picture, with a tendency for overconsumption and obesity to shift from the rich to the poor, especially in women (Dinsa *et al*., 2012). The forthcoming HLPE report on *Nutrition and Food Systems* (2017) will deal in depth with these issues.

1.1.2 "Sustainable" agricultural development for FSN

Today's debates on agricultural development differ in nature and complexity from those of the 1970s when global efforts to tackle hunger ushered in the Green Revolution. A subsequent wave of sustainability concerns focused on the *environmental* dimension, as evidence mounted on the consequences of inadequate attention being paid to ecosystems and natural resource use linked to food production, processing and distribution systems. Critical concerns focused on the impact of agricultural development on water availability and quality, soil degradation, air quality, greenhouse gas (GHG) emissions and climate change, and on ecosystems and biodiversity. *Social inequalities* generated by the Green Revolution were also subject to strong criticism, as the incorporation of the new practices and technologies was closely associated with processes of social differentiation and rising land prices, strongly affecting the socio-economic situation of the rural poor.

The persistence of hunger and malnutrition, the fact that malnutrition is taking on new forms and the food price rises of 2007–2008 have led to a resurgence of anxiety about the "grand challenge" (Hertel, 2015) of sustainably feeding the planet, with an increased attention to the role of all the dimensions – economic, environmental and social – of the development pathways that should lead to reaching those overarching FSN goals.

In this report, SAD encompasses the economic, social and environmental dimensions of development, including ecosystem conditions and human well-being, in so far as they all ultimately affect FSN. The importance of a multidimensional approach giving full recognition to social, cultural and human implications (including human health issues) of agricultural development is reinforced by the following considerations:

First, there is an increased concern that food insecurity and the constraints to the realization of the right to food are quite often the result of social inequalities, at different levels, such as unequal access to production assets, imbalances of power across social groups and discrimination related to ethnicity, gender, generation, religious beliefs or place of living. For a significant part of the world population, including smallholders, pastoralists, agricultural workers, artisanal fisherfolk and indigenous peoples, access to land and security of tenure stand as crucial elements in the achievement of the right to food. In urban settings, social and economic inequalities affect FSN for low-income households and minority populations, also with gender and generation gaps, leading to differential access to livestock products, fresh fruits and vegetables.

Second, there is an increased recognition of the risks and benefits to human health and well-being associated with the industrialization, intensification and concentration of agricultural production and expanded international trade with longer, more complex food supply chains. Food-borne diseases resulting either from biological contamination (pathogens, microbes) or chemicals are still a significant cause of human health problems related mainly to fresh food products such as animal-sourced foods (ASF) as well as fruits and vegetables. Surveillance and reporting systems have been improved in developed countries but remain problematic in many developing countries where capacity is limited and safety protocols are less well established, especially in informal markets. New and resurgent zoonotic diseases (those transferred from animals to humans, often in systems where there is close proximity of humans to animals, including in urban livestock farms) are also a big concern as reflected in outbreaks of avian and swine influenza, and severe acute respiratory syndrome (SARS), resulting in deaths, serious illness and very significant costs for containment and eradication. A related risk to human health of growing concern is anti-microbial resistance linked to the use of antibiotics for farmed animals, mainly in intensive systems.

Third, there is an increased preoccupation that the way in which food is now produced and consumed comes with far-reaching human development and social implications. Food is increasingly produced in larger, more formal and more intensive systems. Food is frequently sold in global markets for distribution after elaborate transformation and packaging, through supermarkets. The intensification and industrialization of agriculture and food chains have resulted in a wider range of food at lower prices becoming reliably available throughout the year to more people, with supply chain management controls having reduced the risk of food-borne diseases. But there are also concerns: about the care and welfare of farmed animals and the human and animal disease risk associated with intensive production; about the consequences of distancing consumers from agricultural production, making them unaware of the processes that produce their food; and, about the loss of "protective factors" in the shift from more traditional diets to a modern "Western diet", with associated risks of losing nutrient and dietary diversity, including microbial diversity (Miller, 2014).

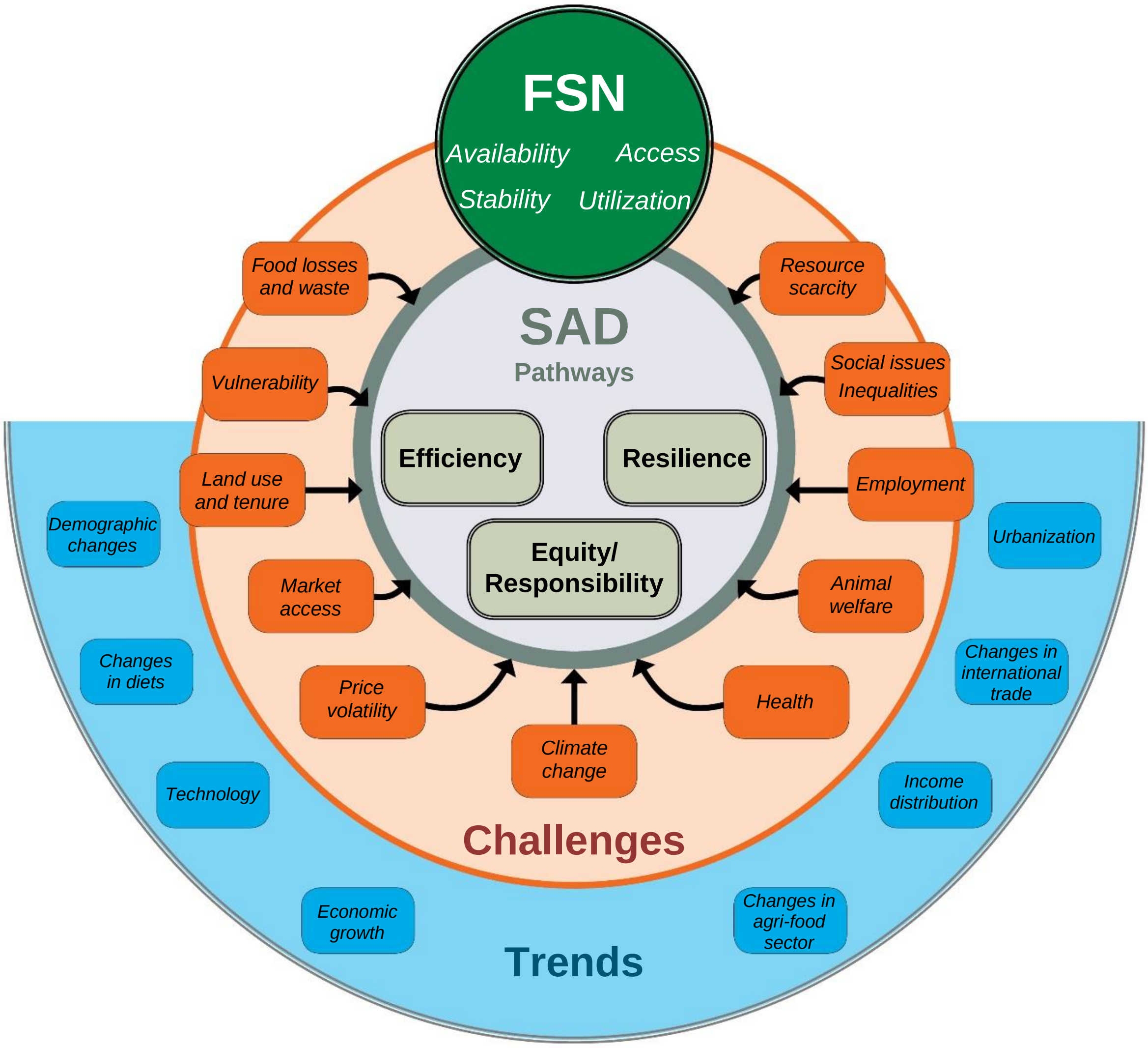
Fourth, a range of economic and social concerns relate to the growth in market concentration over recent decades among the companies that sell both food products and agricultural inputs. Many of these firms are transnational, selling in international markets, with significantly more market power than the agricultural producers from whom they buy farm products and to whom they sell seeds, fertilizers and other inputs (Lang, 2004; James *et al.,* 2012). This can further marginalize the most vulnerable populations. There are also issues for consumers through the extension of what is sometimes called the "supermarket revolution", including in developing countries. The largest companies influence product development and processing technologies, while the relatively few dominant but competitive retail gateways exert an influence over consumer tastes and choices. While larger-scale production and distribution put downward pressure on food prices, these trends are also thought by some to undermine healthy nutrition through the ready availability of cheap processed food products, often exacerbated by advertising targeted at particular groups of consumers, including children (Lang, 2004; Nestlé, 2012).

1.1.3 Conceptual framework

The central objective of this report is to identify the challenges that agriculture has to address and to propose possible pathways towards SAD for FSN to policy-makers and other stakeholders. The conceptual framework used in this report (Figure 1) illustrates the elements and relationships that guide SAD pathways for FSN. It is based on an understanding of the potential contributions of SAD to FSN in different contexts, on the identification of the challenges from global level to farm level that agricultural development must address to improve its sustainability, and of ways forward in terms of "SAD pathways" to contribute to FSN.

This framework is compatible with the definition of FSN, the definition of sustainable food systems provided by the HLPE (HLPE, 2014), and the definition of SAD elaborated earlier in this report.

Figure 1 Conceptual framework: relationship between sustainable agricultural development and food security and nutrition



The framework acknowledges that food systems encompass multiple components, levels, scales and sectors, affecting and being affected by other systems. It can be applied in several contexts, from local and national to international levels, and within and across farming systems.

The lower level captures the *trends* that shape the context of agricultural development, including on the demand-side, population and income growth, technology, urbanization and changing diets, within a context of economic and social development, and diverse cultural norms and practices. *Trends* and their interactions shape the *challenges* that SAD has to address.

The second level identifies the *challenges* faced by farming systems*.* These challenges can be either cross-cutting or more relevant to certain systems and situations. The challenges impinge on food production, and are shaped by natural resource endowments, technology and farm structures, scale and management practices, land use and tenure arrangements and the organization of labour in agriculture.

On the third level, Figure 1 identifies three interlinked principles for SAD: resource efficiency, resilience, and social equity/responsibility***. Resource efficiency*** denotes the efficiency of resource use: it includes both the conventional relationship between factor inputs and output, as well as the relationship between the use of natural resources and environmental impacts, which are not factored into conventional productivity calculations. *Resilience* includes the ability of farming systems to respond and adapt to shocks due to external factors such as climate change and weather events, diseases and economic events such as price volatility. S*ocial equity/responsibility* includes distributional, gender, tenure and property rights issues, as well as social or corporate responsibility with respect to ethical business practices and animal welfare. These principles are further elaborated in Chapter 4.

These principles enable the identification of possible areas for policy intervention. Solutions and actions can be considered as falling into three overarching categories: linkages within and across farming and food systems through diversification and integration; economic organization through markets, trade and food chains; and an enabling framework of governance through collective and institutional actions. Actions to implement sustainable development pathways can be implemented at all levels, from the farming system to the national and international levels.

At the top of the diagram appears the overarching objective, *FSN* in its four dimensions, to which all SAD pathways will hopefully lead.

Figure 1 does not aim to capture all the complex interrelationships. The conceptual framework is intended rather as a tool for exploring key decision areas within the food systems relevant for thinking at the global level as well as for particular regional or local food and agricultural settings across production systems.

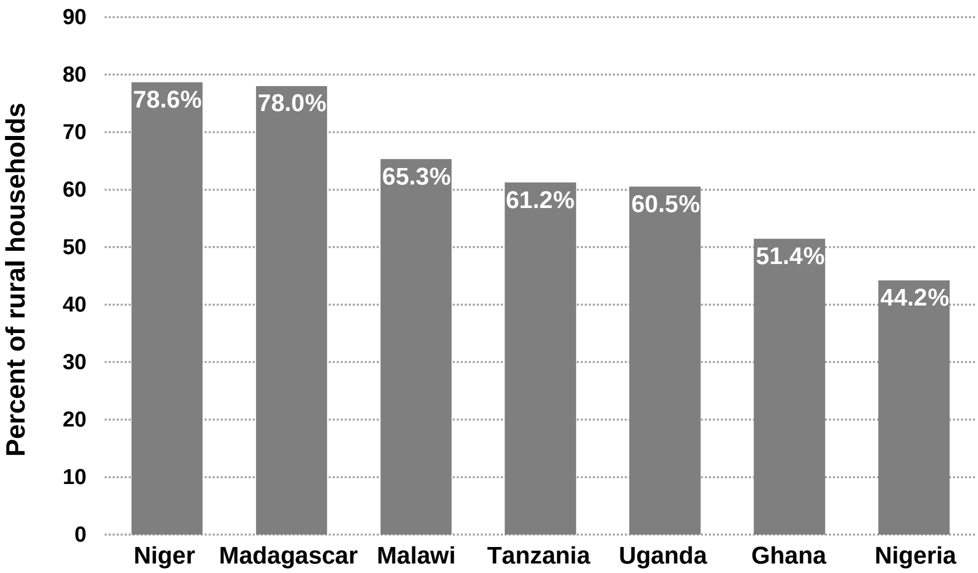
A central aspect of the report is the acknowledgement that food systems are dynamic and evolve over time. Thus the report recognizes that the transition to more sustainable food systems is made possible by adopting SAD *pathways,* which impact on the three interlinked principles for SAD, and, as a consequence, on FSN. This framework, and the report more broadly, acknowledge the complexities of the food, environment and social interface as well as the contextual specificities across and within countries and the differentiated effects of change on different food system stakeholders along the supply chain, as well as on different social actors. The challenges and priorities for SAD vary across time and countries and depend on whether the focus is on the farm, or at the national or global levels. Different perspectives and disciplines, including economics, agronomy, social sciences and anthropology, all offer insights. There are also many stakeholders operating in and affecting the system, some of them critically dependent on specific farming systems for their cultural integrity, livelihoods and food security. Agricultural development is affected both by changes at the farm level and by those outside agriculture, as well as by a whole range of policies and regulations either targeted to agriculture or applicable to other sectors of the economy and society.

Despite wide acceptance of the imperative of achieving food security and better nutrition for all, the multiplicity of possible entry points, perspectives and objectives has led to a coexistence of many narratives and conflicting evaluations about the state of agricultural development and, most importantly, disagreement on the directions and policy instruments that could best improve sustainability. Particularly important among these are the market orientation and food sovereignty narratives, which are considered in Chapter 4.

1.2 The key role of the livestock sector

This report focuses on the livestock sector, acknowledging the diversity of livestock systems, because of its critical roles, negative and positive for the FSN status of billions of people; as an engine for the development of the agriculture sector as a whole; because of its dynamic nature in the face of rapidly growing ASF demand; and, because of its significance with respect to the sustainability challenges that agriculture is facing overall.

Figure 2 Share of rural households keeping livestock



Source: Adapted from Pica-Ciamarra (2013)

In 2013, the livestock sector accounted for one-third of global agricultural gross production value (FAOSTAT). It makes a huge positive contribution to livelihoods and nutrition including for poor and vulnerable people in the developing world. It is often said that 1.3 billion people depend on livestock for their livelihoods, among which 600 million poor farmers.[7] A study conducted by FAO in seven African countries, based on the latest National Panel Surveys, shows that between 44 and 79 percent of rural households keep livestock (see Figure 2).

For these rural households, livestock is integral to their cultural identity, traditional practices, values and landscapes. Livestock also generates co-products including manure and draught power, and in many economies acts as a store of wealth and a safety net.

The livestock sector has been one of the fastest growing sectors in global agriculture, due to rapid demand growth in low-income and emerging economies. Delgado *et al*. (1999) stressed the importance of livestock in agricultural development, which led to coining the expression "livestock revolution". Livestock keeping is also strongly influenced by values and ethics and plays a key role in shaping many landscapes and communities.

In 2013, the world's livestock headcount was estimated to be 23 billion poultry birds, 1.6 billion cattle, 2 billion sheep and goats, and 1 billion pigs (FAOSTAT).[8] Among milk-producing livestock, cows have an important significance, and sheep, goats, horses, buffaloes and camels produce milk of particularly high nutritional value. Livestock also has an important role in providing manure, power, hides, fibres and medicines, as well as being important capital assets for livestock owners.

In 2010, animal products such as meat, milk and eggs (excluding fish and seafood) globally provided 16 percent of total calories and 31 percent of dietary protein (FAOSTAT). They are sources of essential micronutrients such as iron, vitamin A, iodine and zinc, thus contributing to optimal nutrition. All the key micronutrients present in ASF except vitamin B12 can also be found in plant foods but their density and bioavailability is greater in ASF making them an important nutritional source, especially for groups with high needs such as young children, pregnant and lactating women and people suffering from malnutrition (Gibson, 2011). Milk consumption is especially associated with increased height (preventing stunting) and meat consumption with increased cognitive development.

However, the livestock sector is heavily implicated in negative effects on the state of the earth's natural resources, including high GHG emissions, deforestation and land conversion in particular for

---

[7] See http://www.livestockglobalalliance.org/

[8] Note that this estimated "head count" is on a "point-in-time" basis, and is used as one indication of the size of the livestock sector. Because of the short production cycle of some species (e.g. chickens, pigs), the number of animals used by the global commercial meat industry over one year will be considerably higher.

monocultures to generate feed, biodiversity loss, and reduced water quality and availability. It is also implicated in conflicts over land rights and access to natural resources.

Livestock is the world's largest user of land resources. In 2013, with almost 3.4 billion hectares, permanent meadows and pastures represented 26 percent of the global land area (i.e. the earth's ice-free terrestrial surface) (FAOSTAT). FAO estimates that between one-third and 40 percent of global arable land is used to grow feed crops (FAO, Global livestock environmental model – GLEAM[9]). Together, permanent meadows, pastures and land dedicated to the production of feed thus represent 80 percent of total agricultural land.[10]

In broad terms, at the global level, livestock accounts for an estimated 14.5 percent of GHG emissions, when accounting for all direct and indirect emissions along the production chain, including land-use change, feed production and transport (FAO, 2013a). Livestock is a major user of water resources, including irrigation water for animal feed production, but this varies considerably across countries and production systems and estimates of the level of water use and its impact are still subject to some dispute, often related to whether the livestock system depends on rainfed or irrigated water systems.

Various authors (Altieri, 1999; Gliessman, 1997; Thrupp, 2000; Perfecto *et al*., 2009) have noted that biodiversity in agro-ecosystems, including the animal component, performs important ecological services beyond food production. These services include recycling of nutrients, pollination, pest control, regulation of microclimate and local hydrological processes, detoxification of noxious chemicals, control of GHG emissions, risk reduction under unpredictable environmental conditions and the conservation of surrounding natural ecosystems. Agricultural production itself depends on healthy eco-systems. As suggested by FAO/PAR (2011), agricultural systems cannot be reduced to simplified input–output systems: they function best when the interconnectedness of the different ecosystems' components and functions is preserved and optimized through the promotion of positive synergies between crops, breeds and natural ecosystem diversity. Animals are often an essential part of these cycles. However, the wide diversity of livestock systems worldwide means that livestock has varying impacts on the socio-economic viability of communities, and on natural resources and the environment, including climate change.

Livestock production and products may also carry important health risks, especially in terms of food-borne diseases, emerging diseases and occupational hazards. There are in addition significant social and ethical concerns such as human health, animal care and corporate social responsibility associated with many livestock systems, with attendant social and economic costs, as well as issues related to lack of tenure and access to credit (especially for women), and the marginalization of vulnerable, indigenous, migrant and landless peoples.

Some of these concerns are relevant to particular countries and systems, while the diversity of social, cultural, and political norms and preferences require taking a disaggregated and context specific approach to SAD for FSN.

Drawing together disparate trends, drivers and opportunities for harnessing SAD for FSN, a recent paper by the Global Agenda for Sustainable Livestock notes there is a "much needed unifying, evidence-based 'all-in-one' narrative on the role of livestock in sustainable development" (GASL, 2014). The present report aims to addressthat need.

1.3 Typology of farming systems

Diversity in agriculture is the result of the co-evolution, in time and space, of human societies and ecosystems, through the practice of farming, unfolding in different patterns of resource use and development trajectories (Ploeg and Ventura, 2014). The heterogeneity of farming systems reflects, in many senses, the diversity of social, economic and ecological responses to changing adaptive conditions in different settings (Ploeg, 2010).

The analysis and recommendations presented in this report are built upon the recognition of the diversity of farming systems worldwide, using a simplified classification of farming systems. The aim of this classification is not to encompass all the empirical variability of farming systems around the world, but to help policy-makers and other stakeholders address the various challenges and elaborate

[9] See http://www.fao.org/gleam/en/

[10] In FAOSTAT, agricultural land includes: arable land, permanent meadows and pastures, and permanent crops.

context-specific pathways and strategies at different scales. The pathways towards SAD and responses to deal with the challenges facing agriculture vary considerably across countries, among different farming systems and through time.

The diversity of livestock production systems, at the global level, has been captured through different classification schemes (FAO, 1996; Herrero *et al*., 2009; Robinson *et al*., 2011). In most cases, livestock systems are treated as a subset of farming systems. The livestock classification system proposed by FAO (1996) encompasses all the cases in which livestock contributes "*more than 10 percent to total farm output in value terms or where intermediate contributions such as animal traction or manure represent more than 10 percent of the total value of purchased inputs*". It divides livestock production systems in two broad categories: "solely livestock production systems" (either "landless" or "grassland-based") and "mixed farming systems" (either "rainfed" or "irrigated"). These broad categories are further divided to take into account the agro-ecological zones, and to distinguish monogastric from ruminants.

Subsequent studies, such as Robinson *et al.* (2011), called attention to the fact that this general classification includes features that cannot be measured using available spatial datasets, particularly at a global scale. It is important to highlight, as well, that applying the concept of the farm unit – a spatial reference – to some livestock systems may be challenging, considering the mobile character of many livestock systems, as pastoralism, and the fact that, for many of these systems, collective land use is a central feature.

In general terms, as suggested by Robinson *et al.* (2011) and Notenbaert *et al.* (2009), the classification proposed by FAO (1996) can be used as a starting point as it "*provides a relevant stratification through which to describe, visualize and explore livestock and livestock-related issues, and constitutes a useful baseline that can be refined, improved upon, and adapted through time*" (Robinson *et al.,* 2011).

For the purpose of this report, a simplified classification in four broad livestock production systems is used: smallholder mixed, pastoralist, commercial grazing and intensive. Plant-based systems are gathered in a fifth category to consider their potential links with livestock systems.

Table 1 Share of livestock systems in animals population and in main livestock products

Population heads (percent)						
	Grazing	**Mixed**	**Feedlots**	**Backyard**	**Intermediate**	**Industrial**
Cattle & Buffaloes	32.7%	64.0%	3.3%	n.a.	n.a.	n.a.
Small Rum.	44.2%	55.8%	n.a	n.a.	n.a.	n.a.
Pigs	n.a.	n.a.	n.a.	45.2%	16.6%	38.2%
Chickens	n.a.	n.a.	n.a.	18.5%		81.5%
Production (percent)						
	Grazing	**Mixed**	**Feedlots**	**Backyard**	**Intermediate**	**Industrial**
Cattle & Buffaloes Milk	32.5%	67.5%	n.a.	n.a.	n.a.	n.a.
Cattle & Buffaloes Meat	30.7%	57.0%	12.2%	n.a.	n.a.	n.a.
Small Rum. Milk	37.6%	62.4%		n.a.	n.a.	n.a.
Small Rum. Meat	44.3%	55.7%	n.a.	n.a.	n.a.	n.a.
Pork	n.a.	n.a.	n.a.	26.2%	17.6%	56.2%
Chicken meat	n.a.	n.a.	n.a.	1.8%	n.a.	98.2%
Eggs	n.a.	n.a.	n.a.	7.9%	n.a.	92.1%

Source: FAO, GLEAM, base year 2010. In this table, small ruminants (Small Rum.) stands mainly for sheeps and goats.

In distinguishing these categories, five guiding principles were considered:

(i) The characteristics of the livestock system;
(ii) The interaction between livestock systems and whole farming systems,
(iii) Consistency with the body of scientific evidence, acknowledging that the precise definition of boundaries can vary considerably according to different countries' contexts and conditions;
(iv) As suggested by Robinson *et al*. (2011), room for investigation of future developments in response to global drivers; and
(v) Relevance to exploring FSN issues such as access to food, markets and means of production.

The Global Livestock Environmental Assessment Model (GLEAM), developed by FAO, provides estimates of the relative weight of those different livestock systems (see Table 1).

1.3.1 Smallholder mixed farming systems

This category covers the following GLEAM systems: "Mixed", "Backyard" and "Intermediate". Smallholder mixed farming systems combine livestock and crops on farm. They are found in all countries throughout the world, but are most heavily concentrated in Asia and Africa. In developing countries, most farms are mixed crop–livestock, often managed by smallholders. These small farms, often keeping only a few animals, produce up to 80 percent of the food consumed in Asia and sub-Saharan Africa. [11]. The diversity inside these systems enables positive synergies between crops and livestock (such as recycling of animal waste and crop residues) and a multifunctional use of livestock. Rainfed mixed farming systems occur in the temperate zones of Europe and America and in the sub-humid regions of Africa and Latin America (de Haan *et al.,* 2001).

Smallholder mixed farms are the most internally diverse of all farm types, usually employ family labour and include urban and peri-urban holdings, especially in pigs and poultry and some dairy production.[12] Pigs and poultry are often produced under mixed farming systems, where crops provide feed and the livestock provide manure for crop fertilizers, often in a largely closed system.

They are important in providing food at the local level in short market chains. These livestock systems provide multiple non-marketed benefits such as food for household consumption, manure, draught power and fuel. They generate local employment and highly valued social cohesion in many rural areas.

Access to land can limit the growth of these farm enterprises and thus the ability to reap economies of scale and improve productive efficiency, which often results in an exodus of young family labour, particularly men, leaving a population that is often disproportionately female and ageing with less capacity to adopt new skills.

They often depend on external inputs and are thus sensitive to the variability of the prices of inputs and outputs. The farms that are less well integrated into financial and commodity markets in long market chains have some resilience to price volatility but they can be vulnerable to weather shocks and climate change. Their small scale is often associated with weak financial viability, and smallholders cannot always meet the sanitary measures and regulations demanded in long chain markets.

They often rely on ecological processes such as nutrient recycling (in a circular economy), and the impact of smallholder poultry and pig production, for example, on environmental degradation may be less important than it is for large-scale livestock systems (FAO, 2008).

Smallholder mixed farming systems are associated with a great variety of livelihood strategies with different levels of integration into markets (HLPE, 2013a). The diversified agricultural systems developed by these smallholders are often characterized by the presence of different species of animals and multipurpose breeds. Under certain circumstances, in response to pressures and opportunities, mixed farming systems in both developed and developing countries have converted into specialized farming systems that are highly dependent on the use of external inputs.

[11] See: http://www.fao.org/fileadmin/templates/nr/sustainability_pathways/docs/Factsheet_SMALLHOLDERS.pdf (accessed June 2016)

[12] For an in-depth study of smallholder agriculture, see HLPE (2013a).

1.3.2 Pastoral systems

This category is included in the GLEAM “Grazing” system. Pastoral systems are the result of a co-evolutionary process between populations and the environment. They have developed a variety of modes of land tenure and management that are strongly associated with mobility, the use of common pool resources and the ability of animals to convert local vegetation into food and energy. Pastoralism is globally important for the human populations it supports, the food and ecological services it provides, the economic contributions it makes to some of the world’s poorest regions, and the long-standing civilizations it helps to maintain (Nori and Davies, 2007; WISP, 2008).

Pastoralism occurs mostly in the developing world, in areas where intensive crop cultivation is limited or physically not possible (FAO, 2001). IFAD estimates the number of pastoralists to reach nearly 200 million (IFAD, 2009a). In different contexts, extensive livestock rearing can be combined with crop production, mainly for household consumption.

Pastoral systems are found from the drylands of Africa and the Arabian Peninsula to the highlands of Asia and Latin America, in the Sahel, Sahara, the Horn of Africa, the Middle East, Central Asia and China, in some parts of Latin America, and in mountainous areas worldwide. They are widespread in the arid zones with low and irregular rainfall, water and natural forage resources. In these areas, they are one of the main economic activities on which the poorest populations are dependent as a source of food and cash income. Pastoral livestock is also the main insurance for millions of poor people whose livelihoods depend on rainfed agriculture.Pastoral systems have low levels of productivity in physical terms due to dependence on often poor quality and scarce local resources and limited access to purchased inputs, resulting in both low levels of overall inputs used and output produced.

They have relatively high levels of biodiversity in the form of livestock species and locally adapted animal breeds.

They are often traditional, using common land that is enshrined in legal and customary property rights. This implies that the collateral and assets available to pastoralists are embedded in the ownership of animals and not in private land rights. Pastoralists’ access to land is under threat from the often considerable pressure on the environment, competition for land from other economic activities and the frequency of droughts.

Pastoralists have developed different strategies over time to keep a balance between pastures, livestock and people, such as: raising a variety of species and breeds in order to make an optimum use of different ecological conditions; controlling access to water in order to manage the use of pastures; and investing in animals, particularly in fertile females, as an insurance against drought, diseases and other extreme events (Hesse and MacGregor, 2006; ODI, 2009). The distribution of assets according to social arrangements based on systems of reciprocity is also an important strategy in the social and economic continuation of pastoralist forms of livelihood.

1.3.3 Commercial grazing systems

This category is also included in the GLEAM “Grazing” system. Commercial grazing systems can be found both in developed and developing countries in areas covered by grasslands, but also in forest frontiers where pastures expand into forests and woodlands such as in the Amazon Forest in Brazil. Latin American countries can be characterized as having a small number of commercial farmers, which produce the bulk of agricultural production and co-exist with a much larger number of small farms. Commercial grazing (and ranching) systems in Canada, Australia, New Zealand and the western United States of America are much larger enterprises than in Europe, or in Asia, Africa and the Middle East. Commercial grazing is important in beef, dairy and sheep production in the agro-ecological zones concerned.

These systems are predominant where there is abundant pasture and a pool of rural labour for hire. As grazing and ranching systems intensify, producers can increase production by sowing improved pasture species. The use of high-yielding animal breeds can also be an important feature of these systems with different levels of dependency upon external inputs. An important distinction between pastoral and commercial grazing systems is that the latter has more secure access to land and stronger land property rights, as well as more fully developed links to global value chains.

In different agro-ecological zones commercial grazing is important for beef and sheep production. In Europe, it is often the principal way by which grasslands are valued. Commercial grazing can also result from the conversion of forests and woodlands, as has happened in Brazil. The intensification and the environmental impact of these systems can vary significantly across different biomes.

1.3.4 Intensive livestock systems

This category covers the following GLEAM systems: "Industrial" and "Feedlots". Intensive livestock farming systems are most typical in pig and poultry production and are to be found in all regions of the world, especially in high-income countries and emerging economies. Intensive landless systems can be found around urban conglomerates of East and Southeast Asia, Latin America or near the main feed-producing or feed-importing areas of Europe and North America (de Haan *et al.,* 2001).

Intensive livestock systems have a high level of productivity (number of animal units per worker, animal productivity per worker), which manifests itself in an intensive substitution of labour and land by capital, high dependence on external inputs, including feed and fossil fuels, and the application of forms of organization based on a division of labour. Intensive systems seek opportunities to expand the farm and increase size, exploiting economies of scale to enhance competitiveness. They are relatively significant employers of hired labour.

Their main objective is to maximize profitability based on: (i) technical and managerial efficiency in the use of resources (in particular feed resources) by animals with a high yield potential; (ii) finding cheaper feed resources wherever they are sourced; and (iii) intensifying animal density per unit of area (per ha, per square metre of buildings), as these operations have high investment and operating costs.

They are very well integrated into commodity supply chains (input and output, including through international trade), which favour the lowest possible production costs, standardization of products and high levels of sanitary rigour. The technologies and practices used tend to be relatively uniform across the world. As a result, upstream and downstream players exert decisive influence on the standardization of the technical processes at the farm level and along their supply chains (foodstuffs, equipment, animal genetics and veterinary products). This also has implications for the regional concentration of farms and food processing.

1.3.5 Links with plant-based systems

Although mainly focused on livestock systems, this report also acknowledges the complementarity between crop and livestock systems.

In plant-based systems, where animals represent less than 10 percent of the total farm output in value terms, livestock is still very important as an outlet for feed crop production and as a potential source of diversification and value added, in particular where access to land is limited. Chapter 2 describes more precisely those crop–livestock linkages and Chapter 4 highlights the potential contribution of integration and diversification to SAD pathways.

Crop and feed-producing systems

This category comprises large areas of land cultivated with a small number of crops using, quite often, methods that require the intensive use of external inputs. In the case of grain monocultures, particularly maize and soybeans, the connection with intensive livestock systems is mostly established through global (traded) commodity chains.

Plant-based smallholder systems

The specialization of smallholder systems in plant production can be a result of agro-ecological conditions more suitable to farm strategies based on a combination of different crops or the result of market specialization. The intensive production of fresh vegetables for the market by specialized smallholders depends on the use of animal manure – which is common in peri-urban settings – and is a good example of a farming system where the contribution of animal production is negligible but nevertheless useful and where there is room to increase livestock products (especially poultry).

1.4 Concluding comments

Sustainable agricultural development is agricultural development that contributes to improving resource efficiency, strengthening resilience and securing social equity/responsibility of agriculture and food systems in order to ensure food security and nutrition for all, now and in the future.

Livestock is arguably the most dynamic agriculture sector, with socio-economic implications for animal-feed demand, for concentration and intensification, and for increased income creation and nutritional status and health. Livestock systems are also strongly linked to crop sectors, both large-scale and small-scale. Livestock raising directly contributes to livelihood and nutrition through the production and sale of ASF and generates by-products including manure and power, acting as a store of wealth, and is integral to the traditional practices, cultures, values and landscapes of many communities across the world. Livestock also has significant implications for the environment, both positive and negative, particularly when impacts on land-use change and water quality are taken into account.

Critical issues in SAD for FSN include both cross-cutting issues and issues that vary across different livestock systems and situations within and between countries. The biological and cultural diversity embedded in farming systems and the knowledge associated with the practice of agriculture in different agro-ecosystems must be kept in mind when designing adapted sustainable pathways. This diversity is an important asset for SAD pathways that support FSN at different levels, as well as for the capacity to adapt agricultural production to climate change and to diversify diets. Pathways towards SAD must take into account the important linkages between livestock and crop sectors. This diversity is captured in this report by four broad types: smallholder mixed farming, pastoral, commercial grazing and intensive livestock systems.

Chapter 2 looks at the trends and drivers affecting livestock systems.

2 TRENDS AND DRIVERS OF AGRICULTURAL DEVELOPMENT

As mentioned in Chapter 1, the last 50 years have been marked by dramatic demographic and economic changes (including population growth, urbanization, economic and income growth, changing diets), which have driven a considerable increase in agricultural production and will continue to shape agricultural development. Agricultural development also interacts with the evolution of agricultural markets.

In this context, over the same period, farming and food systems have experienced a radical transformation characterized by: specialization at the farm and territorial levels, which entailed an important modification of the linkages between crop and livestock production; by the complexification of food supply chains; and, by growing market concentration in the agro-food industry.

This chapter describes these changes and concludes with an outline of various projections of demand and supply of agricultural products, which prepares the way for an analysis of the challenges facing SAD for FSN in Chapter 3.

2.1 External trends affecting agricultural development

2.1.1 Demographic changes, economic growth and their impacts on FSN

The world population has increased dramatically from 3 billion in 1960 to 7.3 billion in 2015 (UNDESA, 2015). Most of this increase occurred in developing countries.

Between 1961 and 2010, global GDP multiplied more than five times, from 9 300 to 52 700 billion in constant 2005 USD (World development indicators). During the same time, the value of global agriculture gross production increased faster than population, from 700 to 2 100 billion in constant 2004–2006 USD (FAOSTAT).

While food security concerns have long focused on total calorie intake, today they have expanded to the so-called “triple burden” of malnutrition: hunger (deficiencies in dietary energy intake), estimated by FAO to affect some 792 million people worldwide (FAOSTAT); micro-nutrient deficiencies (such as iron, vitamin A, iodine and zinc), which affect some two billion people, the majority living in developing countries;[13] and over nutrition, which affects a growing number of people. In 2014, more than 1.9 billion (39 percent) of adults aged 18 years and over were overweight, of which over 600 million (13 percent) were obese (WHO, 2015a). These categories overlap: both calorie deficiencies and obesity can co-exist with nutrient deficiencies, while nutrient deficiencies can occur in people who consume enough calories. Under nutrition is mainly a problem in low- and middle-income countries. On the other hand, over nutrition is an increasingly entrenched problem in high-income countries and also an emerging problem in low- and middle-income countries, with a worldwide shift to “Western-style” diets (that are characterized in part by a higher intake of animal sourced foods).

The growth in income and in agricultural production at the global level allowed important progress towards food security and nutrition. In fact, FAO (2012a) estimates that between 1969/1971 and 2005/2007 the average per capita food consumption at the world level increased from 2 373 to 2 772 kcal/person/day (in developed countries, average per capita consumption exceeds 3 300 kcal/person/day). According to WHO (2015a), the proportion of underweight children under five years declined globally from 25 percent in 1990 to 15 percent in 2013. Over the same period, the number of children affected by stunting declined globally from 257 million to 161 million, representing a decrease of 37 percent (WHO, 2015a). However, meanwhile, the burden of over-nutrition and obesity has grown in importance: at the global level, obesity has more than doubled since 1980. In 2013, 42 million children under five years old were overweight or obese (WHO, 2015b), and the problem exists not only in developed countries but also in developing countries.

[13] Estimate for anaemia worldwide from WHO (available at http://www.who.int/nutrition/topics/ida/en/).

During the next decades, the world population will continue to grow, although more slowly. This growth at the global level should not hide the differences between regions. Most of the increase in population will take place in Africa, where agricultural productivity gains have been limited, where people are already more food insecure and more vulnerable to climate change. Between 2015 and 2050, the population is expected to double in Africa, to increase by 20 percent in Asia and by 12 percent in the rest of the world (UNDESA, 2015).

The share of the world population living in urban areas increased from 30 percent in 1950 to 54 percent in 2014. By 2050, 66 percent of the world's population is expected to be urban (UNDESA, 2014). In Africa and Asia, the urban population rates are projected to grow faster, from 40 and 48 percent in 2014 to respectively 56 and 64 percent by 2050. However, the rural population will continue to grow in Africa, in Oceania, and in the least developed countries.[14] In Africa, around 122 million young people will enter the workforce between 2010 and 2020, and even under optimistic off-farm wage growth scenarios, one-third to one-half will need to find jobs in agriculture (Jayne *et al.,* 2014).

Compared with the less diversified diets of rural communities, city dwellers are more likely to enjoy a varied diet rich in animal proteins and fats, characterized by higher consumption of meat, eggs, milk and dairy products. But, according to Ruel *et al.* (1999), there is a steady shift in the locus of poverty in developing countries, where food insecurity and malnutrition are moving from rural to urban areas. Urbanization in developing countries is posing new questions regarding economic and social policies in general, particularly in the case of food security, as it is proceeding quickly while policies, and agri-food and institutional structures, are adjusting more slowly (Díaz-Bonilla, 2015).

Urbanization and income growth create new opportunities for food products. It also stimulates improvements in infrastructure, including cold chains, food safety and quality standards, which facilitate trade and transportation of perishable foods. Smallholders and family farmers can benefit from these opportunities as long as there is an enabling environment to facilitate access to markets. Urbanization also results from rural-urban migration that can entail an ageing and feminization of the agricultural workforce that stays behind.

Urban agriculture does not escape from such a deep transformation. Recent studies suggest 450 million people keep livestock in urban areas. Poultry is the most common type of livestock kept in urban areas, followed by dairy cattle. Pig keeping is common in Southeast Asia, and sheep and goat fattening in West Africa and the Middle East (Grace *et al.,* 2015). Most of the 2.5 billion people who live in developing country cities buy their food from urban live animal markets, wet markets and slaughterhouses (Grace *et al.*, 2015). Urban livestock keeping can make important contributions to FSN and livelihoods but requires careful management to mitigate pollution, diseases, accidents and social tensions (Correa and Grace, 2014).

With economic growth and urbanization, there is a long-term tendency for average farm size to increase, as young workers seek employment outside farming, and farms amalgamate and modernize. However, in some developing countries, particularly in Africa, the lack of off-farm employment opportunities, and the increase in rural population, is associated with land fragmentation and smaller farm units. This phenomenon undermines traditional farming cultures and social cohesion in rural areas. Some of the most dramatic changes, over a relatively short period of time, have been seen in China and some countries in Southeast Asia.

The case of China presented in Box 2 illustrates some of the links between economic growth, demographic change, transformation of the agriculture sector and food security and nutrition.

[14] The least developed countries gathers 34 countries in Africa, 9 in Asia, 5 in Oceania, and 1 in Latin America and the Caribbean.

Box 2 Economic growth, demographic change and adjustment in China's agriculture sector

China's economy has experienced strong GDP growth, at 9.8 percent per year, on average, from 1978 to 2013, with the demographic dividend acknowledged as one of the major contributors to the fast growth. In particular, the massive migration from rural/agriculture to urban/non-farm sectors has improved labour productivity to a great extent.

The rural–urban migration of more than 300 million people since 1978 is the largest of its kind in peacetime in human history. It has contributed greatly not only to the national economy, but also to the welfare of the immigrants themselves and their families. Income from agriculture sources accounted for about 75 percent of rural households' net income during the mid-1980s; however, it declined to about one-third in recent years, while the share of wages increased to about one-half of household net income in rural areas. Partly due to the increase of income from non-farm sources, per capita income in rural households has grown at an annual rate of 7.5 percent from 1978 to 2012.

This rural urban migration is expected to continue in the next decades and, between 2014 and 2050, the rural population in China should fall drastically from 635 to 335 million (UNDESA, 2014).

The joint effect of income growth and labour out-migration is a dramatic shift of the supply curve in the rural labour market. As a result, rural wage rates increased by more than four times in 13 years, from 20.8 yuans/day in 2000 to 109.8 yuans/day in 2013. As the recorded wage rate is an annual average, the actual wage during peak season would be much higher, due to the seasonality of labour demand in agriculture.

Farmers have two options when facing continuous increases in labour costs: they may shift to high value products, or substitute machinery for labour if they wish and are able to continue grain production. Due to strong demand resulting from income growth in the urban areas, the areas sown to vegetables have increased from 2 percent to 12 percent in total, at the cost of grain production, despite labour inputs required in vegetable production being about 5–6 times greater than for grain production, and rapidly rising labour costs. The relatively high price of vegetables covers the high labour costs involved.

Grain production has been the least profitable option due to relatively low prices, which could not go up with labour costs. Therefore, one major option for continued growing of grain crops is to substitute machinery for labour, if technical and economic conditions permit. One of the major technical constraints is topography, which determines feasibility of machinery services.

Reflecting these factors, in the four southeastern coastal provinces, over the last 20 years grain production has reduced by 45 percent in Zhejiang, between 25–30 percent in Fujian and Guangdong, and has kept at the same level in Jiangsu. The four provinces have experienced the same dynamics: relatively faster economic growth and demographic change, and higher income and labour costs, compared with other provinces. However, while crop sown area accounts for about half of the total land surface in Jiangsu, the share of sown area in the other three provinces is less than 20 percent, implying a large portion of the arable land is likely to be located in hilly regions, not easily accessible for machinery.

Source: NBSC (National Bureau of Statistics of China), various years and State Bureau of Statistics, 2015

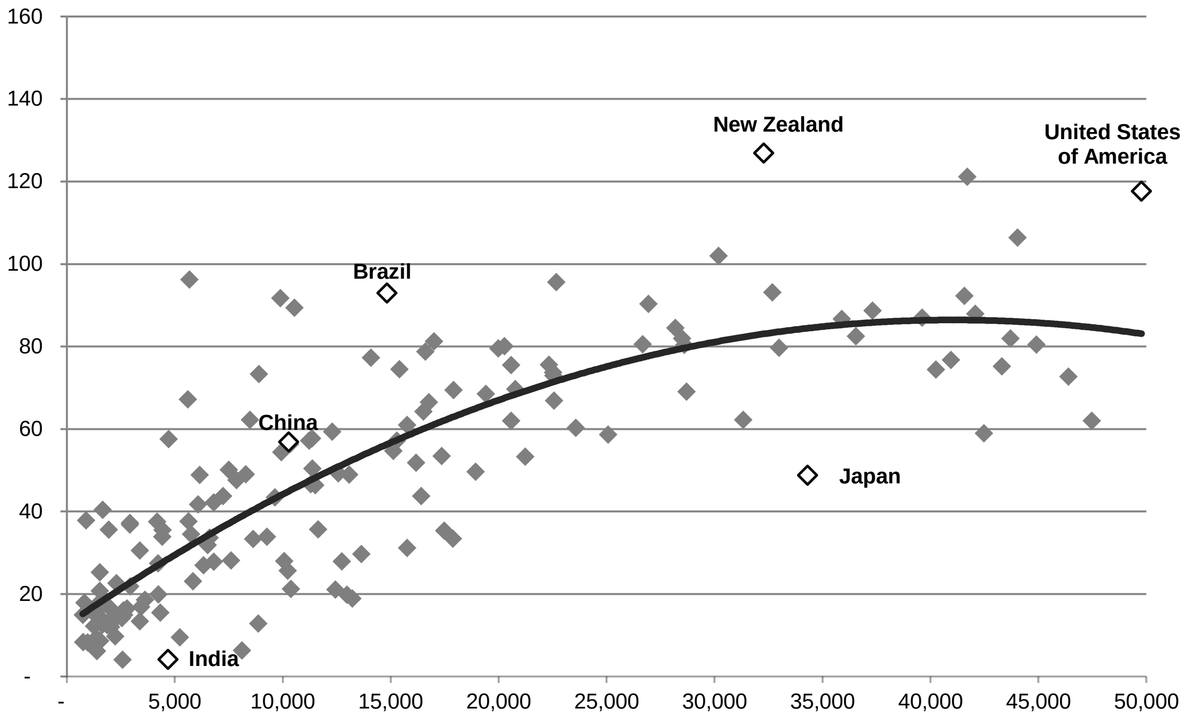
2.1.2 Changing diets: evolution of ASF consumption

Between 1961 and 2010, to meet the growing demand, global meat production has quadrupled from 71 million tonnes to 292 million tonnes; milk production (excluding butter) more than doubled from 342 to 720 million tonnes; and eggs production rose from 15 to 69 million tonnes (FAOSTAT).

FAO (2012a) draws attention to the rapid increase in consumption of ASF and vegetable oils. ASF and vegetable oils together provide 22 percent of total calories in developing countries, up from 13 percent in the early 1970s. This share is projected to rise to 26 percent in 2030 and 28 percent in 2050 (in the developed countries the share has been flat at around 35 percent for several decades now).

According to FAO (2012a), global average meat consumption in 2005/2007 amounted to 39 kilograms/capita/year (28 kg/capita/year in developing countries and 80 kg/capita/year in developed countries). Figure 3 shows the relationship between meat consumption and GDP in different countries. While milk and dairy consumption (excluding butter) was 83 kg/capita/year globally, with a greater difference between developing and developed countries than in meat (52 and 202 kg/capita/year respectively).

Figure 3 Relationship between per capita meat consumption and income in 2011



Source: Adapted from FAO (2009a). Based on data from FAOSTAT (FAO, 2015a) for per capita meat consumption and the World Bank for per capita GDP. *Note:* GDP per capita (horizontal axis) is measured at purchasing power parity (PPP) in constant 2011 US dollar. Per capita meat consumption (vertical axis) is measured in kg/capita/year.

In recent years, the growth in the demand for ASF has come mainly from the rapidly expanding economies among developing countries. Much of this growth has been concentrated in East Asia, and in poultry and pigs. In developed countries, production and consumption of livestock products are now growing either slowly or are stagnating, although they have reached high levels. Red meats (in particular beef and sheep meat) have experienced a lower rate of demand growth. In developed countries, and to some extent in developing countries and transition economies, changes in diet have exerted a growing influence on food demand – in particular livestock.

Dietary advice from governments and nutritional scientific communities – advice that is remarkably similar across countries – have played a more significant role in food demand choices, but to some extent the advice has evolved and changed over time while often in conflict with the marketing and promotion efforts of the post-farm sectors of the agri-food supply chain. The trend towards a larger role for nutrition advice in consumer food choices is most noticeable in developed countries but is also starting to have an impact in developing countries and transition economies. Yet the evolving advice (together with sometimes misleading media reporting) has led to some confusion among consumers.

There is also considerable controversy over the role of the agri-food industries. Some commentary emphasizes their role in feeding more people at lower cost over time, while others draw parallels between the food and tobacco industries and conceptualize overconsumption as a “profit driven” disease (Buse and Kent, 2015). Despite isolated areas of improvement, there has been little overall progress in shifting “Western-style” diets to healthier alternatives or decisively reversing overweight trends (Roberto *et al.,* 2015). Poor diet and non-communicable disease are increasingly associated with poverty in both developed and developing countries, but it is not clear to what extent this is driven by food availability and price, by retail marketing, or by consumer preferences for heavily flavoured, convenient and cheap food.

Consumption of ASF is expected to rise till 2050, faster in developing countries, with meat consumption reaching 49 kg/capita/year globally (respectively 42 kg/capita/year in developing countries and 91 kg/capita/year in developed countries) while milk and dairy consumption will reach 99 kg/capita/year globally (respectively 76 kg/capita/year in developing countries and 222 kg/capita/year in developed countries).

The evolution of the consumption of ASF is projected to vary considerably by region. It is estimated that demand for livestock products will nearly double in sub-Saharan Africa and South Asia, from some 200 kcal/capita/day in 2000 to around 400 kcal/capita/day in 2050. In member countries of the Organisation for Economic Co-operation and Development (OECD) (currently at 1000 kcal/capita/day or more), consumption levels will barely change, while in South America and countries of the former Soviet Union it is expected to increase to OECD levels (Van Vuuren *et al*., 2009).

2.2 Evolution of agricultural markets

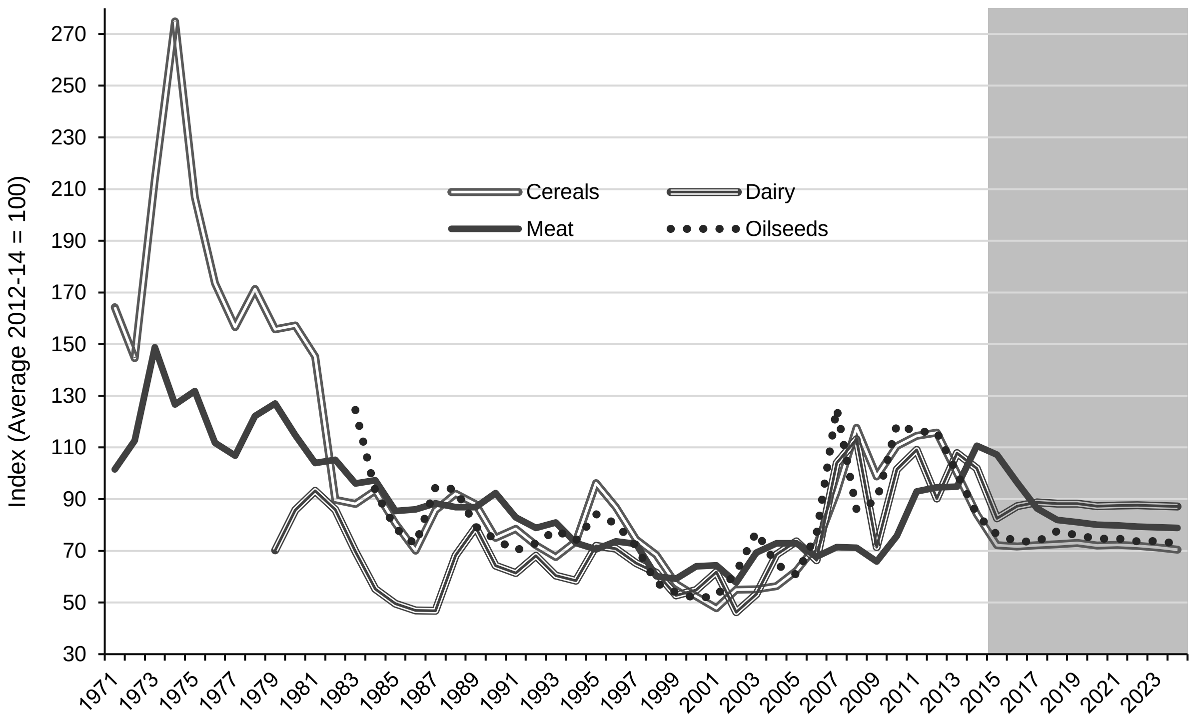
2.2.1 Real prices follow the long-term declining trend

Price levels affect both the production and consumption of food. There is often tension between producers' preference for higher prices and that of consumers for lower prices; much of the debate regarding different policy approaches to agricultural production and food security has revolved around the policy dilemma of whether governments should support profitable prices for producers with important associated benefits for the wages of farm workers (Wiggins and Keats, 2014) or affordable prices for consumers (Díaz-Bonilla, 2015).

Despite the sharp price spikes in recent years, in the light of the evolution of real prices over the last century, prices are projected to continue on a trend of long-term decline. Prices during the early 2000s were below the trend, while current and projected prices are closer to trend.

The annual OECD–FAO Outlook provides an assessment of prospects in agricultural commodity markets – including nominal and real prices – for the coming decade. The latest edition (OECD/FAO, 2015) covers the years 2015 to 2024. It identifies the drivers and trends influencing agriculture prices in the medium term at a global level. The following paragraphs summarize some of the Outlook findings with regard to SAD, including the livestock sector.

Figure 4 Medium-term evolution of commodity prices in real terms



Source: OECD.Stat (http://stats.oecd.org/). Note: Index calculated by a constant weighting of commodities within each aggregate. The weight is calculated by the average 2012–14 real terms production value. 2015 figures are provisional.

In real terms, world prices for all agricultural products are expected to decrease over the next decade, consistent with the long-term secular decline trend. They are projected to decline from their 2014 levels but remain above their pre-2007 levels. When considering only the last 15 years, projected prices appear to be on a higher trend (Figure 4). The period of low prices in the early 2000s was followed by a period of high and volatile prices starting in 2007. Prices started to moderate in 2013, but are not expected to drop to the levels witnessed in the early 2000s.

Rising demand for animal feed remains the core driver of cereal consumption growth. Poultry, widely considered to be affordable meat, with low fat content and few religious and cultural barriers, dominates meat consumption with an average annual growth rate of 2 percent. It is expected to account for half of the additional meat consumed in 2024. Although the emergence of biofuel and other industrial uses was an important driver of rising demand for cereals throughout the past decade (coarse grains use for biofuels almost tripled from 2004 to 2014), current stagnation in biofuel demand implies feed-use will become the more significant driver of cereal demand (see Box 4 on Biofuels).

Favourable meat-to-feed price ratios over the coming period will favour production growth, particularly in poultry and pork, which rely on intensive use of feed grains. A short production cycle allows the poultry sector in particular to respond quickly to improved profitability and, underpinned by robust demand, production is projected to expand by 24 percent over the outlook period to 2024. In 2024, developing countries (but excluding the least developed among them) will account for 58 percent and 77 percent of the additional global poultry and pigmeat production, respectively. However, in many developed countries, production growth is projected to be slower.

Consumption of dairy products has expanded rapidly over the past decade and constitutes an important source of dietary protein. At a global level, the demand for dairy products is expected to expand by 23 percent over the ten-year projection period. Growth remains strongest in the developing world and, in light of the preference for fresh dairy products within these regions, almost 70 percent of additional dairy production will be consumed fresh.

Rising milk production throughout the past decade was a result of dairy herd expansion, as average yields declined by an annual average of 0.2 percent, due to fast increasing dairy herds in low-yield regions. Over the outlook period, milk production is projected to increase by an annual average of 1.8 percent, with the bulk of the additional milk produced in developing countries, notably India, which is expected to overtake the EU to become the largest milk producer in the world. Within developing countries, growth in milk production will result from both herd expansion and productivity gains. In contrast, dairy cow numbers are projected to decline in most developed countries, reflecting productivity gains as well as constraints in water and land availability.

2.2.2 Price volatility

There is a consensus that price volatility has been higher in recent years than in the previous two decades but is much lower than it was in the 1970s (see Figure 4 and HLPE, 2011a). Higher price volatility is associated with price spikes. This has been the case in the four commodity booms associated with food crisis since the First World War: 1915–17, 1950–57, 1973–74, and, most recently, in 2007–08 (World Bank, 2009). Price volatility thus interacts with the price level to affect FSN and increases risks to producers with implications for resource allocation and for investment decisions. Price volatility is argued by some economists to be readily absorbed by poor consumers because their time horizons are very short (Barrett and Bellemare, 2011) but poor consumers have to make difficult choices when food prices rise sharply, which are likely to compromise longer-term investments in such things as children’s education and productive resources (Heltberg *et al.,* 2012).

Huchet-Bourdon (2011) found more price volatility in staple products such as wheat and rice compared with beef, dairy and sugar during a study period of 50 years. To some extent, livestock is “opportunistic”, absorbing surplus calories when food is plentiful and yielding value (e.g. through slaughter) when crops fail. This is an important dimension of livestock for FSN, in particular for pastoral and smallholder mixed livestock systems.

Price volatility in developing countries can be imported from world markets or result from domestic changes in supply and demand. In countries whose staple foods are not traded internationally, domestic sources of price volatility are clearly dominant. The main local factors that exacerbate price volatility in developing countries include weather (especially in regions that are dependent on rain-fed agriculture), high internal transport costs, failures in the functioning of domestic agriculture markets and policies, including macro-economic instability (HLPE, 2011a). Over time, however, as markets have been opened, imported volatility has become increasingly important in many countries (Konandreas, 2012).

Even though real prices are projected to decline over the long-term (see above), this does not preclude the likelihood that prices will experience bouts of volatility, including upward price spikes, in the coming period. Such price spikes have a demonstrable effect on production and investment decisions.

2.2.3 Trade, SAD and FSN

The liberalization of agricultural markets and increasing role of international trade has had significant effects on food security and nutrition. Some of the trends have been positive for FSN, while others have undermined desired outcomes (FAO, 2015b).

The pattern of food trade has changed in the last twenty years. The large cereal exporters are largely the same but the US share of the growing global total has declined, as South American countries (in particular Brazil) have expanded their production significantly. Despite the growth in exports, especially from Latin America and from some parts of Asia, developing countries as a whole went from net food exporters to net food importers in 1990. Since then, the level of food imports to the global South has increased steadily, driven by two quite distinct sources of demand. The first is rising incomes, primarily in Asia, that have changed diets and increased demand for processed foods, and for ASF in particular. The second, predominantly in Africa and the Near East, is driven by a rising gap between the demands of a growing population and too slow growth in agricultural production.

According to the OECD–FAO Outlook 2015–2024, international trade volumes of most agricultural commodities are projected to expand over the next ten years. While a very high proportion of ASF is produced and consumed locally, the importance of international trade is increasing.

Skim milk powder is the most traded ASF, with more than 50 percent of total production currently exported. According to the OECD–FAO projections, beef will continue to be the most traded meat in the next decade (with less than 20 percent of total production currently exported).

The growth in livestock production impacts on the demand for feed grains and oilseeds, with trade of coarse grains for feed having risen faster than the trade in some ASF products. For some producers, such as in the European Union (EU) and China, availability of imported feed is vital for their livestock sectors.

Exports of livestock products are concentrated in fewer than ten countries and regions, in particular Australia and New Zealand (dairy and sheep), the EU (dairy and pork), United States of America (beef, poultry, pork and dairy products) and Brazil (beef and poultry). India is currently the country that exports the largest volumes of beef.

National trade-related policies such as some subsidies and domestic support measures, that are provided mainly by developed countries, but increasingly also in some developing countries including India and China, and tariffs have a major impact not only on national agriculture and food systems, but also on the agricultural performance of other countries. It is worth noting that dairy and beef products are among the most protected commodities across the world. Moreover, sanitary, environmental and animal welfare certification measures are of increasing importance for international trade.

The relationship between trade reform and food security has been a topic of long-standing debate among governments, stakeholders and in the academic literature, which has resulted in different prescriptions and policies, ranging from those prioritizing national self-sufficiency to those that rely heavily on open markets and freer international trade. Many analysts argue that environmental and social concerns resulting from freer trade need to be addressed with well-targeted complementary domestic policies. Others do not think such complementary measures enough, in particular for low-income countries that lack the revenue to invest significantly in social protection. The controversy over trade has deepened in the wake of the commodity price spikes of 2007/2008, which pushed a number of net food importing developing countries to change their food security strategies to increase either domestic production or production overseas on leased plantations. The recent FAO State of Agricultural Commodities Markets (FAO, 2015b) is focused on international trade and reviews the debates in some detail. The implications for SAD and FSN of price volatility and the impacts of trade reform policies are examined in the discussion of pathways in Chapter 4.

2.3 Radical transformation of farming and food systems

Over the last two decades, the global food and agriculture system has undergone rapid restructuring and transformation, with important differences among regions, nations and in local contexts (McMichael, 1993; Goss *et al.,* 2000; Busch and Bain, 2004; Konefal *et al.,* 2005; Thompson and Scoones, 2009, Sumberg and Thompson, 2012).

2.3.1 Structural transformation in agriculture and the livestock revolution

Structural transformation in agriculture describes a broad development trend in which agricultural productivity grows while agriculture's share in GDP and employment declines. Structural transformation has historically been accompanied by rural-to-urban migration, the development of an industrial and service economy, and a demographic transition from higher to lower birth and death rates (Timmer, 2007).

However, other paths of structural transformation have also been observed (Dorin *et al.,* 2013). In a number of lower-income countries (especially in Africa), the demographic transition is delayed, off-farm opportunities are limited and substantial agricultural productivity gains remain elusive (HLPE, 2013a). Unlike other regions of the world, sub-Saharan Africa has seen urbanization without industrialization (Losch, 2014) and a recent review found evidence of "premature de-industrialization", with de-industrialization starting at low levels of GDP (Rodrik, 2015).

The HLPE (2013a) has shown that the agricultural sectors in some countries are facing economic divergence; in other words, per capita agricultural incomes are declining relative to other sectors while the population working in agriculture is increasing. This divergence creates social and economic tensions, as the value added from agriculture has to be shared among more, relatively poorer, people.

Within such a context, the "livestock revolution" (Delgado *et al.,* 1999) accounts for the accelerated growth in demand for livestock products, particularly in the developing world, tied to human population growth, rising incomes, continuing urbanization and changing food preferences. The notion of the livestock revolution – with its promise of dietary diversity, improved nutrition and health; economic opportunities for small-scale producers; and growing, often negative, effects on natural resources – is considered to be one of the most powerful ideas to emerge in the areas of food, nutrition and agricultural development in recent decades (Sumberg and Thompson, 2012).

Analysis by Delgado *et al*. (1999) identified seven characteristics of the livestock revolution:

- *"rapid worldwide increases in consumption and production of livestock products;*
- *a major increase in the share of developing countries in total livestock production and consumption;*
- *ongoing change in the status of livestock production from a multipurpose activity with mostly non-tradable output to food and feed production in the context of globally integrated markets;*
- *increased substitution of meat and milk for grain in the human diet;*
- *rapid rise in the use of cereal-based feeds;*
- *greater stress put on grazing resources along with more land-intensive production closer to cities; and*
- *the emergence of rapid technological change in livestock production and processing in industrial systems".*

Such substantial increases in global demand and supply for food, and ASF in particular, if it continued at the same pace, would have profound implications for livestock production systems and for land-use changes over the coming decades. FAO (2012a) estimates that between 2005/2007 and 2050 the global cattle and buffaloes population would increase from 1.5 billion to 2 billion, and the global goat and sheep population from 1.9 billion to 2.9 billion. Crop production growth in the future would come mostly from yield increases rather than from area expansion (see Section 2.4 on projections). The increase in livestock production would be mainly the result of expansion in the number of animals, although increased animal productivity is also essential if natural resources are to be used wisely. And the expansion of herds will occur largely in developing countries (Thornton, 2010). These livestock changes would impact on land-use patterns, both locally where the livestock is raised and at a distance, through the production and trade of animal feedstuffs.

As noted by Erb *et al.* (2012), production of meat, milk and eggs requires large amounts of animal feed. The shift towards more intensive livestock production systems has had a profound effect on the composition of agricultural land-use (Taheripour *et al*., 2013).

At the global level, grass, which is mostly grown on land unsuitable for crops, represents 48 percent of the biomass eaten by livestock, followed by grains (28 percent of biomass consumed), and by occasional feeds and stovers (fibrous crop residues). However, in most developing countries, stovers are a key feed resource, comprising sometimes up to 50 percent of the diet of ruminants (Herrero *et al.,* 2013). Many smallholder mixed-systems in developing countries rely on local crop residues to provide the basic diet for livestock, resulting in a very low-cost feed although these feeds, especially cereal straws, have low nutrient values. In these systems, improving the nutrient content and digestibility of feed in a cost-effective manner is a priority (Wright *et al.,* 2011). Attempts have been made to upgrade the fodder quality of crop residues by chemical, biological and physical treatments, but few of these interventions have been widely adopted.

Between 1961 and 2013, arable, permanent meadows and pastures increased by 9 percent (FAOSTAT), mainly to provide crops for livestock feed and grasslands for cattle-raising. The demand for protein sources for animal feed has led to a considerable increase of cropland planted with feed. In Latin America, for example, soybean area has risen from 0.3 to 53 million ha between 1961 and 2013 (FAOSTAT). Between 1990 and 2013, South America’s agricultural land increased by 66 million hectares (12 percent) while forest area decreased by 85 million hectares, an area that included 29 million hectares of primary forest (FAOSTAT).

Globally, the area devoted to maize and soybean – the dominant feed used in concentrated livestock diets − has risen by 56 million hectares over the first decade of the twenty-first century (FAOSTAT). Meanwhile, the area devoted to permanent meadows and pastures – typical of extensive livestock production − fell by 57 million hectares (FAOSTAT), with the use of animal feed crops such as hay and fodder falling as well (Taheripour *et al*., 2013). In turn, ruminant grazing intensity on rangelands is projected to increase, resulting in more intensification of livestock production in the humid and sub humid grazing systems of the world, particularly in Latin America and the Caribbean.

2.3.2 Intensification and specialization of farming systems

Over the last 20 years, increasing demand for livestock products has been met primarily through a shift from extensive, small-scale, subsistence, mixed crop and livestock production systems towards more intensive, large-scale, geographically-concentrated, commercially oriented and specialized production units (Robinson *et al.,* 2011).

The intensification of animal production, however, is not necessarily associated with the industrialization process. For example, small-scale livestock keepers may intensify their production by increasing labour productivity; using improved management practices such as feeding with crop residues or using manure as fertilizer; by procuring services off-farm; or, by adopting improved breeds. Diversification generates opportunities to increase land productivity and to improve the resilience of the system. The dairy sector in India is a good example, where large numbers of smallholders contribute to the provision of milk for the surrounding urban markets. Milk production in India increased from 78 million tonnes in 1999 to 116 million tonnes in 2009, an increase of 49 percent (FAOSTAT), with an average herd size (cows and buffaloes) of only 3.3 head (Wright *et al*., 2011).

Intensification may lead to a degree of mechanization of operations on the farm, at which point production may become industrial. This enables farmers to invest in more targeted technologies and enables greater market integration, offering the possibility of improved economies of scale. Monogastric species (pigs and poultry), in particular, due to their high feed conversion ratios and short reproductive intervals, are well suited to the rapid intensification of production.

Developed countries – and increasingly developing countries - have experienced considerable specialization, intensification, and economies in agricultural production, driven by economic growth, policies directed at increasing production, careful use of new and existing technologies and a substitution of capital for labour. This has led to a decrease in mixed farming systems: most cereals are produced on specialist arable farms, and large-scale industrial units dominate the monogastric livestock sector. The dairy sector, especially in North America and to some extent in Europe, is also rapidly moving towards industrial-style production systems. This trend has been accompanied in some countries, such as The Netherlands, with the release of land for green spaces to enhance biodiversity.

In developing countries, on the other hand, mixed crop–livestock systems produce 65 percent of beef, 75 percent of milk and 55 percent of lamb, the vast majority from smallholder systems. Mixed crop–livestock farming systems are crucial to contributing to the livelihood of almost 2 billion people in developing countries, half of whom are poor, and to global food security (Wright *et al.,* 2011).

With limited land and water resources and environmental concerns relating to the impact of agricultural practices, more production in developing countries will come from increasing the productivity of existing resources (intensification). A key question is whether this intensification in developing countries will result in more specialization and industrialization, as is the case in developed countries, or in the intensification of smallholder mixed systems. The answer will depend very much on country situations and trajectories, economic drivers, and public policies (see HLPE, 2013a).

As production systems become more efficient, less feed is needed to produce a given unit of livestock product, with positive effects on the environment. Consequential changes in stover production are expected to occur, but vary widely from region to region. It is foreseen that large increases will occur in Africa mostly as a result of productivity increases in maize, sorghum and millet. Yet it is expected that stover production will stagnate in areas such as the ruminant-dense mixed systems of South Asia (Herrero *et al.,* 2009).

2.3.3 Evolution of crop–livestock linkages

Livestock can feed on a wide range of crop products, by-products, residues and roughage. Trends towards industrial specialized livestock systems have increased the demand for crop product feed and changed the interlinkages between crop and livestock production at farm and territorial levels.

Ruminants can graze on land that is generally unsuitable for growing arable crops but have a larger overall area requirement, whereas monogastrics have a smaller overall area requirement but indirectly require more cropland. This can potentially lead to land-use competition (food versus feed production). The corollary to the expansion of cropland for providing increased quantities of affordable food and feed are the associated harmful ecological, social and cultural consequences, such as deforestation, reduced biodiversity, forced displacement of indigenous people and pastoralists from their customary lands, loss of livelihoods, cultural decimation and related trans-generational trauma. Other elements that form part of the localized crop–livestock nexus, particularly in developing countries, include the contribution of livestock as draught animals, and as providers of manure, which is an important source of plant nutrients in developing countries and in organic farming worldwide.

Animal draught power

According to FAO, the term “agricultural mechanization” generally refers to the application of tools, implements and powered machinery as inputs to achieve agricultural production. In general, three sources of power are used in agriculture: manual, animal and motorized (FAO*,* 2013b). If engine power (electric or fossil fuel) tends to be more appropriate for large-scale farming and long-distance transport, animal power is a renewable and affordable source of energy particularly suited for smallholders, family farming and local transport.[15] Animal power is accessible and sustainable in rural areas with little dependence on external inputs. Many different species are employed, particularly cattle, buffaloes, horses, mules, donkeys and camels (FAO, 2010).

The use of animal power in mixed farming systems can improve crop–livestock integration and encourage sustainable farming practices. Draught animals can assist directly with crop production (ploughing, planting and weeding), but also for transport of water, fuelwood, agricultural inputs or products. Draught animals contribute directly to food production through milk, meat, manure and offspring. They contribute to improved livelihood and strengthened resilience of smallholders mixed farming systems through time saving,[16] increased productivity, income growth and diversification.[17] Women in many countries can particularly benefit from transport animals (FAO, 2010).

[15] On the benefits of transport animal, please refer to FAO (2009b)

[16] The rates of work achieved by work animals range can be 5 to 20 times greater than manual labour (FAO, 2013b).

[17] See: http://teca.fao.org/read/7306 (accessed June 2016).

Farm power systels are a major determinant of smallholders livelihoods (FAO, 2005). Although there is unfortunately no updated global database on the relative importance of human, animal and engine power, it is often said that a huge majority of farmers, particularly smallholders, still use only human power. In the first years of this century, the number of tractors worldwide was estimated to be 28 million, and 450 million of agricultural workers had no access to engine or animal power (Mazoyer, 2002). In sub-Saharan Africa, human power is estimated to account for 65 percent of the power for land preparation (FAO, 2006a) and between 50 and 80 percent of cropland is still cultivated manually (FAO*,* 2013b).

In 1997/99, according to FAO, 25 percent of cropland was cultivated using animal power in sub-Saharan Africa, 35 percent in South Asia and 40 percent in East Asia (without China). By 2030, the shares of human and animal power are expected to decrease in all regions, except in sub-Saharan Africa, as they will be replaced by tractors. However, the sustainability of such tractor-based systems will be highly dependent on farm size, profitability of agriculture and infrastructure allowing access to fuel and maintenance. Where those conditions are not fulfilled, farmers could revert to human and animal power (FAO*,* 2014b).

Manure

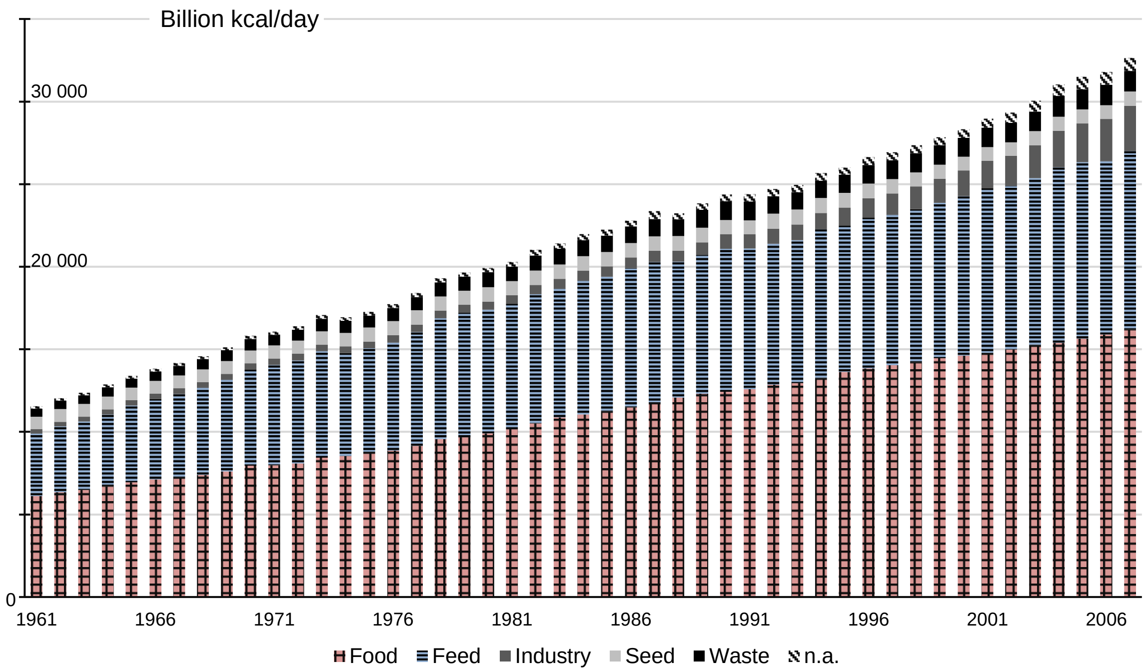
Prior to the 1950s, organic manures were almost the only sources of soil and plant nutrients in most countries. Manure is not captured in FAO statistics but remains undoubtedly a major source of soil fertility in many countries (FAO*,* 2014b). Potter *et al.* (2010) estimated that, in 2000, manure accounted for about 60 percent of global nutrients. The proportion of manure used as fertilizer depends on the dung collection efficiency and is difficult to estimate, but is probably less than 50 percent in most regions (FAO, 2003; Harsdorff, 2012). In some countries, manure can also be used as a source of energy, through methanization.

Feed and food production

In 2010, about 34 percent of world production of cereals (2.2 billion tonnes) went to feed (FAOSTAT). According to FAO (2012a), this proportion could reach nearly 50 percent by 2050. At the global level, maize is the principal feed cereal, while wheat and especially rice are used only to a small degree as animal feed. Oilseed cakes, a co-product in the production of vegetable oils, form a crucial protein feed input for livestock. A large share of this market feed is traded internationally (Erb *et al*., 2012).

Most crop production is used to feed humans and animals (Figure 5), but in highly variable proportions, depending on the region.

Figure 5 Use of plant food calories – world (1961–2007)



Source: Paillard *et al.* (2011); updated figures in 2016 by B. Dorin.

In sub-Saharan Africa and Asia, over 70 percent of available plant food in 2003 was used to directly feed humans, whereas this rate was only 35 percent in OECD countries, which for a long time have devoted over 55 percent of available plant food to feeding animals. This share of plant calories used for feed has been increasing since the early 1960s in Latin America (LAM), the Middle East and North Africa (MENA), and Asia, where it now ranges between 20 percent and 40 percent. The share of plant calories used neither for food nor feed (a category that includes biofuels), has increased in most regions, especially since the 1990s. The growth is primarily in LAM and OECD countries, where non-food or feed use of crops now accounts for over 5 percent of production (Paillard *et al.,* 2011).

Herrero *et al.* (2015) place the livestock sector at the heart of agricultural development, showing the importance and the multiplicity of crop-livestock linkages (Figure 6). Their analysis suggests, *inter alia,* that livestock consume about 45 percent of global cropland products (on a dry matter basis), and occupy about 80 percent of agricultural land.

Among the drivers and trends leading to the projected feed/food requirements in 2050, a number of alternative scenarios, as to changes in human diets have been examined. Le Cotty and Dorin (2012) have developed an empirical analysis on feed crop needs for livestock in 2050, based on three very distinct diet scenarios (from no animal sourced foods in the human diet to a uniform extension of the Western diet to all regions of the world). These scenarios are not meant to be plausible but to generate values that can be used for foresight purposes. In one extreme scenario, if the world adopts the average consumption of developed countries, the daily total use of food plant calories to feed animals would need to increase by 50 percent at present and by 117 percent (i.e. more than double) in 2050.

Within developing regions, almost 60 percent of total cereal use was consumed as food between 2012 and 2014, in contrast with the developed world, where food use accounted for only 10 percent of total cereal use (OECD/FAO, 2015). Developing countries now account for 42 percent of the global feed use of coarse grains, up from 30 percent ten years ago. They are expected to continue to increase their share of consumption of coarse grains for feed, up to 56 percent by 2050, as their livestock sector grows. In contrast, feed consumption in developed countries is not projected to increase much (FAO, 2012a)

Over the last 50 years, the proportion of food use in soybean world domestic supply decreased from 17 percent in 1961 to 4 percent in 2010. In 2010, 6 percent of soybean global domestic supply is directly used for feed and 85 percent is processed. Worldwide, the soybean cake is predominantly (98 percent) used for livestock feed (FAOSTAT).

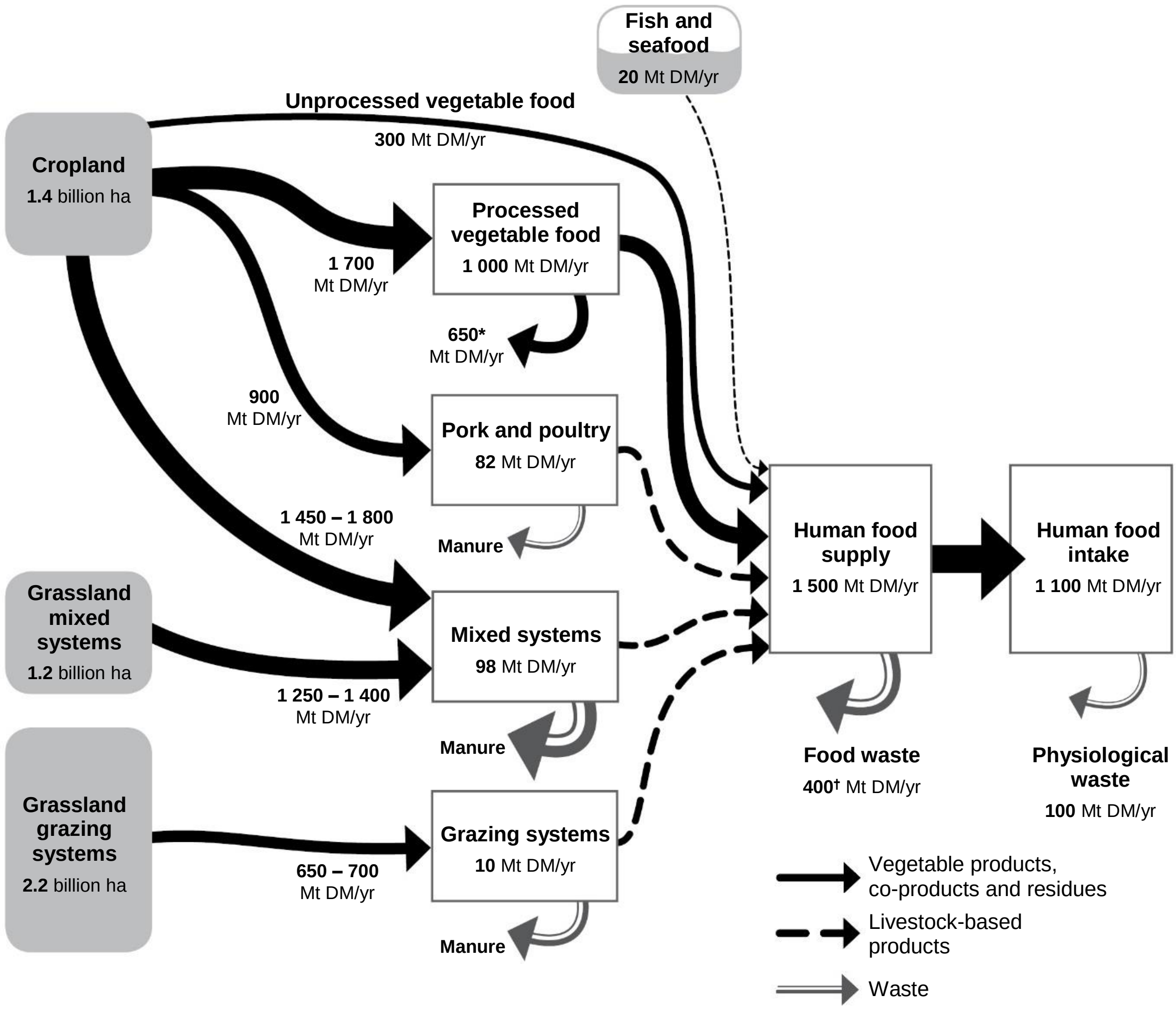
A point of interest is the increased trade flows of livestock feeds, particularly soybeans (Box 3).

Box 3 Trade flows of livestock feeds in China

Given China's focus on becoming self-sufficient in food grains, it is foreseen that feed grain imports will increase further, with China becoming the second largest importer of coarse grains with barley and sorghum imports becoming larger than maize. China is the world's largest import market for soybeans, having seen a phenomenal expansion from just over 2 million tonnes of soy imports in 1990 to 65.5 million tonnes in 2013.[18] Brazil is China's largest supplier of soybeans, having overtaken the United States of America in 2013 (OECD/FAO 2015). The majority of the soy imported by China is in the form of whole soybeans, which are then processed by domestic soy crushers to produce meal, oil and other soy products. China's soybean tariffs encourage this trend and protect the domestic value-added crushing process by applying a 3 percent tariff on whole soybean imports, 9 percent on soybean oil, 5 percent on soybean meal and 9 percent on soybean flour. As a consequence, China is now a net exporter of soy meal.

[18] See http://faostat3.fao.org/browse/T/TP/E. Accessed June 2016

Figure 6 Land-use and major flows of biomass and its derivatives in the global food and agriculture system (circa 2000)



Source: Adapted from Herrero *et al.* (2015). Mt DM/yr = million tonnes of dry matter per year. *Of which 250 million tonnes are used as feed. †Of which 50 million tonnes are used as feed.

2.3.4 Complexification and growing concentration in food systems

Agro-food industries produce, sell and promote products responding to market incentives (in particular relative prices), consumer behaviour, policy signals (such as taxes and subsidies) and regulations. Currently, incentives in general tend to favour:

- selection of varieties for high and consistent yield rather than nutrition or health properties;
- production of poultry and pig meat and milk from intensive farms relying on purchased feed;
- processing that increases shelf-life, reduces food preparation time and still tastes palatable, which often entails increased fat, sugar and salt content, although in some regions the industry has responded to criticism by marketing foods with lower fat, lower sugar, and, more recently, lower salt content as well; and
- vigorous marketing especially to children, which can contribute to overconsumption and increased consumption of less healthy foods.

The food supply chain, which encompasses all those activities that lie between on-farm production and the point of consumption, has experienced fundamental changes during the last two decades. It has become more globalized and marked by upward trends in scale of production and economic concentration. Farmers are increasingly confronted with substantial concentration, as a small number of large, often multinational, firms have come to dominate the retail, distribution and the input side of the agri-food chain. This concentration has raised concerns about the risk of abuse of dominant market positions and unfair trading practices.

Concentration in virtually all sectors of the food and agriculture industry has been documented (Hendrickson, 2014; Wise and Trist, 2010; GIPSA, 2011; James *et al.,* 2012). Four agribusiness firms undertake 75–90 percent of the global grain trade (Murphy *et al.,* 2012). For example, in the United States of America, in 1967 the four largest firms controlled one-quarter of the non-poultry animal slaughtering industry. By 2007 the top four controlled more than 50 percent of the market. In 1990, the top four firms in the pork packing industry controlled 40 percent of the market; by 2010 the four firm concentration ratio had increased to 67 percent (James *et al*., 2012; GIPSA, 2011; Wise and Trist, 2010). For steers and heifers, the corresponding figure in 2010 was 85 percent (marginally up from 81 percent in 1996, but considerably up from 36 percent in 1982). The level of concentration in the EU food processing sectors has also been an on-going concern (Fischer and Hartmann, 2010). In meat production, however, concentration levels are significantly lower than in North America (the top 15 companies account for 28 percent of EU meat production [Brown, 2012]) and the firms are not present outside the EU, unlike the major firms in North America (and increasingly in China and Brazil as well). Concentration is nonetheless growing rapidly (Brown, 2012).

Three-quarters of food sales in most industrialized countries are now channelled through supermarkets. The role of supermarkets is rapidly increasing in developing countries. FAO (2015b) notes that the proliferation of supermarkets in developing countries is driven by multiple factors, including: trade, urbanization, increases in incomes, changes in lifestyles and women's participation in the labour force, liberalization of foreign direct investment, increasing use of refrigerators and other domestic appliances, and changes in information technology that facilitate better organization of supply chains.

Despite rapid growth, supermarket expansion in most developing regions is still lower than the development in richer countries. In Latin America, grocery sales through supermarkets are still less than 50 percent of total grocery sales, in comparison with figures above 70–80 percent in Western Europe and the USA. Only in Chile, are more than half of the grocery sales made through supermarkets (65 percent), while the average of the Latin American countries is 43 percent (OECD, 2015). Modern retail, essentially supermarket chains, hold on average about a 10 percent market share of overall food in Eastern and Southern Africa (Tschirley *et al.,* 2013). In India, supermarkets shares are currently very low (around 2 percent) and supermarkets food sales would have to grow at an annual rate of 20 percent for 20 years to reach just 20 percent of market share (Tschirley, 2007; Tschirley *et al.,* 2010). This suggests traditional retail outlets are likely to dominate in some developing countries for the near future.

Consumers in developed and developing countries have benefited from the lower prices and the larger variety of products on offer at which supermarkets excel. These are benefits of the economies of scale that supermarkets with a large market share can offer consumers. Moreover, the increased competition that supermarkets bring has increased the pressure on producers to supply higher-quality goods at lower prices.

Changes in the retail sector may therefore have mixed or negative effects on farmers. Although the supermarkets offer new and possibly larger markets for their production, the investments and organizational adjustments to meet volume, cost, timeliness, quality and consistency standards may be challenging for many farmers and processing firms, particularly small ones.

From the governance perspective, according to Lang and Barling (2012), the locus of power and decision-making has moved steadily away from farmers to retailers and traders, and from the state to the private sector, whose power within the food supply chain and intergovernmental policy regime is growing.

This introduces a shift in the control of food systems. The state, or government, is no longer as dominant. Corporations now have an overarching influence in the industry. The governance of food supply chains has consequently become more complex and multiscalar, involving many public, private and civil society actors (Lang *et al*., 2009).

At the same time, advances in improved infrastructure and integration of markets in many developing countries (Rashid *et al*., 2008) have increased with urbanization. Important structural modifications in the processing and marketing of food products linked to the expansion of supermarkets, even in poor urban and rural areas (Reardon and Timmer, 2012), have contributed to the diversification of consumption and a decline in the percentage of calories and proteins associated with traditional staple crops, although these are still dominant in country's food security stocks.

2.4 Projections and scenarios for agricultural development, focusing on livestock supply and demand

Although there are few certainties when forecasting, informed analysis provides a valuable assessment of likely levels of consumption and production. A broadly accepted expectation of future requirements can provide for an informed debate and help determine the challenges and potential pathways/responses for SAD. The best known, and most widely quoted, of the various agricultural projections are those of Alexandratos and Bruinsma in *World agriculture towards 2030/2050: the 2012 revision* (FAO, 2012a), which is used as a baseline for this section. They are supplemented with analysis from other sources.

2.4.1 FAO projections

As mentioned in Chapter 1, FAO (2012a) projects that, in response to the growth in global population and incomes, a continuation of recent trends implies global agricultural production in 2050 will need to be 60 percent higher than in 2005–2007 in volume. Upon disaggregation, FAO's broad projection reveals some interesting regional, country or commodity particularities.

This 60 percent increase in world production volume would come mainly from an increase in crop yields (80 percent of the production increase at the world level), some increase in cropping intensity (the number of cropping seasons per year) (10 percent of the total increase) and limited land expansion (the remaining 10 percent). It is worth noting that within the overall 60 percent increase in agricultural production, livestock's contribution to the total will rise slightly from its current 36 percent of gross agricultural value to 39 percent in 2050. This reflects a projected increase in meat production by 76 percent, from 258 million tonnes in 2005–2007 to 455 million tonnes in 2050, most of which will occur in developing countries.

FAO projections foresee global milk production rising between 2005–2007 and 2050 at an annual growth rate of 1.1 percent. This rate will be greater in developing countries (1.8 percent per annum) than in developed countries (0.3 percent per annum). Given the still low consumption levels in developing countries, this provides scope for nutritional gains.

Alexandratos and Bruinsma's analysis (FAO, 2012a) includes population growth, income growth, urbanization and changing diets as drivers of the projected production requirement in 2050. Their analysis cautiously suggests that there are sufficient global resources available to satisfy the resulting anticipated additional demand. This result suggested at the global level is, obviously, not equivalent to saying that food insecurity will be eliminated, which also depends on the distribution of incomes. Moreover, this conclusion assumes that the necessary investments are undertaken, and appropriate incentives and policies are put in place but does not examine the environmental or social impacts of the implied production increase. Their findings might also be questioned by:

- the possibility of greater than expected population growth: the latest UN (UNDESA, 2015) estimation of the world population in 2050 (9.7 billion people) is greater than the 2008 estimation (9.15 billion people) used by FAO (2012a);
- the effects of climate change on production (particularly in developing countries), which were not explicitly modelled in the projections; and
- the possibility of greater than assumed use of crops in biofuel production and novel biomaterials.

Concerning biofuels, there are uncertainties both in energy markets and in biofuel policies (mandates and subsidies) and Alexandratos and Bruinsma opt for the OECD-FAO Outlook figures up to 2020 (see Box 4) after which they assume no change in quantities.

Box 4 Biofuels

In the period from 2001 to 2014, world biofuel production increased six times to nearly 130 billion litres (HLPE, 2013b).

A pertinent question is whether such high growth (from a small base) will continue, and under what circumstances. Particularly within the developed world, the emergence of biofuel and other industrial uses was an important driver of rising demand for cereals over the past decade. The use of coarse grains (predominantly maize) for biofuels almost tripled from 2004 to 2014, with almost 40 percent of additional coarse grains consumed over the past decade processed for biofuels. Over the OECD–FAO 2015–2024 Outlook period, however, the significantly lower crude oil prices projected result in biofuel demand staying closely tied to the policies mandating their use because the market conditions do not favour their use (OECD/FAO, 2015). The International Energy Agency (IEA) forecasts global biofuel production of 139 billion litres in 2020 (OECD/IEA, 2014). Although the first commercial advanced biofuel plants (using ligno-cellulose as feedstock) opened in 2014 in the United States of America, food-crop based feedstocks are expected to continue to dominate ethanol and biodiesel production over the coming decade, with the inherent competition for land, water and crops that have alternative uses directly as food and as feedstuffs for livestock production.

However, biofuel production creates valuable by-products, such as distillers' dried grains (DDGs) and oilseed meals that can be used as animal feed and can substitute for grain in animal rations. Dairy and beef producers traditionally use DDGs in their feed rations, as it is well digested.

2.4.2 Other projections and scenarios

FAO's definition of food and nutrition security covering its four dimensions (availability, access, utilization and stability) was agreed at the 1996 World Food Summit. However, there is no global scenario study dealing with these four dimensions of food security. Most studies deal with availability, sometimes with access and stability analysed as co-products of availability (e.g. increased availability contributing to decreased food prices and thus improved economic access to food and contributing to less volatile prices). The utilization dimension is rarely dealt with in the global scenarios except through the consideration of dietary adjustments that could contribute to reducing the prevalence of non-communicable diseases associated with overconsumption (obesity, diabetes and cardiovascular diseases, for instance).

Several recent scenario studies (e.g. Reilly and Willenbockel, 2010; van Dijk, 2012; Wise, 2013; von Lampe *et al.,* 2014; van Dijk and Meijerink, 2014; Foresight, 2011) focus, at least partially, on global food security. Reilly and Willenbockel (2010) propose a typology of scenarios, which is a useful way to classify studies.

They distinguish three types of scenarios:

1. "Projections", which are usually used either to estimate the future of a system under "business as usual" assumptions (baseline projections) or to assess the reaction of a given system to a set of "what if" assumptions (what if projections).
2. "Exploratory scenarios", which are designed to explore possible futures, allowing for changes in the structure of the system and boundary conditions.
3. "Normative scenarios", which are designed to support vision building and develop narratives for the agri-food system to meet specific targets.[19]

Of the *exploratory scenario* studies, the Millennium Ecosystem Assessment (MEA) is probably the most well known (Carpenter *et al*., 2005). The MEA was undertaken by an international network of scientists and other experts, under the auspices of the United Nations, with a procedure modelled on the Intergovernmental Panel on Climate Change (IPCC). The objective was to "assess the consequences of ecosystem changes for human well-being and the scientific basis for action needed to enhance the conservation and sustainable use of those systems and their contributions to human well-being". The MEA proposes four exploratory scenarios developed along two axes: one describing global governance for international cooperation and trade (globalized versus regionalized), the other covering attitudes towards ecosystem management (pro-active versus reactive). Among the four

[19] For further comments on the difference between normative and exploratory scenarios, see Iversen (2006).

scenarios, global orchestration (globalized, reactive ecosystem management) was the reference scenario in the *Agrimonde* study.

The *Agrimonde* foresight study is a *normative scenario* exercise that was undertaken by two French agricultural research institutes, INRA and CIRAD (Paillard *et al*., 2011). It focuses on feeding the world in 2050. It considers two scenarios: a baseline scenario ("business as usual"), which relies closely on the "global orchestration" scenario from the MEA foresight study, and a normative scenario involving less food consumption inequalities and more sustainable agricultural production across the world, implying breaks in both diets and agricultural yield trends. The assumption of uniform diet worldwide up to 2050, resulted in projections of reduced consumption of animal products in developed countries and increased consumption in developing countries, and stagnant or only slowly increasing agricultural yields in most regions in the world.

From the "what if" *projection scenarios*, the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD) study, *Agriculture at a crossroads* (IAASTD*,* 2009), is probably one of the most well known. The IAASTD study was the result of an international effort initiated by the World Bank and FAO with the objective of assessing the impacts of agricultural knowledge, science and technology (AKST) on food security and sustainable development. The IAASTD was relatively close to the MEA regarding the process and method used. But both exercises differed as regards the type of scenarios they proposed: the IAASTD did not propose global exploratory scenarios as in the MEA study, but a baseline projection and a set of "what if" projection scenarios. In the baseline projection, current trends were projected to 2050. The baseline and the variant scenarios were simulated with a wide set of quantitative models, in particular using the IMPACT model designed by IFPRI.

Another "what if" study, *Eating the planet* (Erb *et al.,* 2009) is of special interest for the present report since it explores the consequences of combinations of various assumptions on four aspects of agricultural and food systems. First, land-use change: massive change, or business as usual; second, yields: intensive, intermediate, or relying on organic production; third, on diets: "Western high meat", current trends, less meat, or far less meat (which reduces the assumed share of protein from animal sources to 20 percent instead of 30 percent); and, fourth, on different livestock systems: intensive, humane or organic. It analyses the interrelationships and possible trade-offs among the resulting 72 possible scenarios, the feasibility of which is tested through a biomass balance model.

The "Western high meat" scenario is defined in *Eating the planet* as: high calorie intake (3 171 kcal/cap/day), rich in animal protein (44 percent of protein intake) assuming economic growth beyond the current trends, and a globalization of the Western trend towards high consumption of animal products. The feasibility analysis reveals that the "Western high meat" would require a combination of massive land-use change, intensive livestock production systems and more intensive use of existing arable land (reaching intensive crop yields as defined by FAO as crop yields forecasted to grow by 54 percent on average and cropland area by 9 percent by 2050).

It is interesting to note that, more generally, the feasibility analysis in this study indicates that the additional costs of humane and organic livestock rearing systems, in terms of feeding efficiency and demand for additional area, seem to be relatively low. Differences in the livestock systems assumed in the scenarios play only a minor role in determining whether a scenario was feasible or not. However, the study also shows that the data uncertainties and the current limited scientific understanding of the feeding efficiency of humane farming systems demonstrate the need for better data to enable more robust conclusions to be drawn on that issue.

2.5 Concluding comments

Population growth has been the main driver in agriculture and food systems during the twentieth century, but its relative weight is declining, relative to other drivers such as increasing per capita incomes, urbanization and changing dietary preferences. If the current trends towards westernization of diets continue, the demand for animal-source foods will increase strongly in the coming decades with significant implications for more resource use worldwide, unless moderated by advances in and adoption of resource efficiency raising technologies.

Livestock production is currently and will be central to developments in food systems. Much of the increased crop output required over the period to 2050 will be in the form of feedstuffs for livestock as consumers seek to enrich their diets based on increased purchasing power, mainly in developing countries.

This increase in ASF demand can affect FSN positively in many ways: first, by providing opportunities for increasing the incomes of smallholders; and second, by facilitating the correction of nutrient deficiencies and addressing under nutrition. However, it also raises considerable challenges.

Sustainability challenges and the possible contributions to FSN are quite different for each livestock production system. This makes it more difficult but also opens important possibilities to identify pathways to achieve sustainable livestock systems in contributing to FSN.

3 SUSTAINABILITY CHALLENGES FOR LIVESTOCK IN AGRICULTURAL DEVELOPMENT

The overarching goal for sustainable agricultural development (SAD) is to ensure food security and nutrition (FSN) for all now and in the future, in the context of climate change and increasing scarcity of natural resources. The growing and rapidly evolving demand for food, and particularly ASF, creates huge opportunities for agricultural development, including livestock. However, the expected growth in production to meet this demand will also raise challenges if agricultural development is to become more sustainable.

This chapter focuses on the challenges for SAD and looks at both the cross-cutting challenges that affect all livestock production, and the more specific challenges faced by different livestock systems, using the typology outlined in Chapter 1: smallholder mixed farming, pastoral, commercial grazing, and intensive livestock systems. The challenges are further disaggregated according to whether they are mainly environmental, economic or social. In order to facilitate the design of system specific pathways to SAD, addressing all the challenges faced by each farming system, challenges that have more importance or are more visible in a specific system are considered within this system, which does not mean that they are irrelevant in other systems.

3.1 Cross-cutting global challenges

3.1.1 Environmental challenges

Many studies have identified livestock as a key area for action in efforts to reduce stresses on natural resources (in particular land and freshwater), as well as to reduce GHG emissions and adapt to climate change (Foresight, 2011; FAO, 2006b).

Resource efficiency of livestock production systems:

There are numerous claims that in terms of calories harvested per hectare the resource efficiency of ASF is much lower than that of edible plants. In a forthcoming paper, Mottet *et al.* (in press) analyse global feed rations and feed conversion efficiencies. One of their salient findings that challenges the assumption that ASF rely on an inefficient use of plants is that 75 percent of global livestock's dry matter feed intake consists of products such as leaves, grass, fodder crops, crop residues and swill that are non-edible to humans. Grains represent just 12 percent of global animal feed, with an additional 9 percent derived from by-products that can be considered edible to some extent.

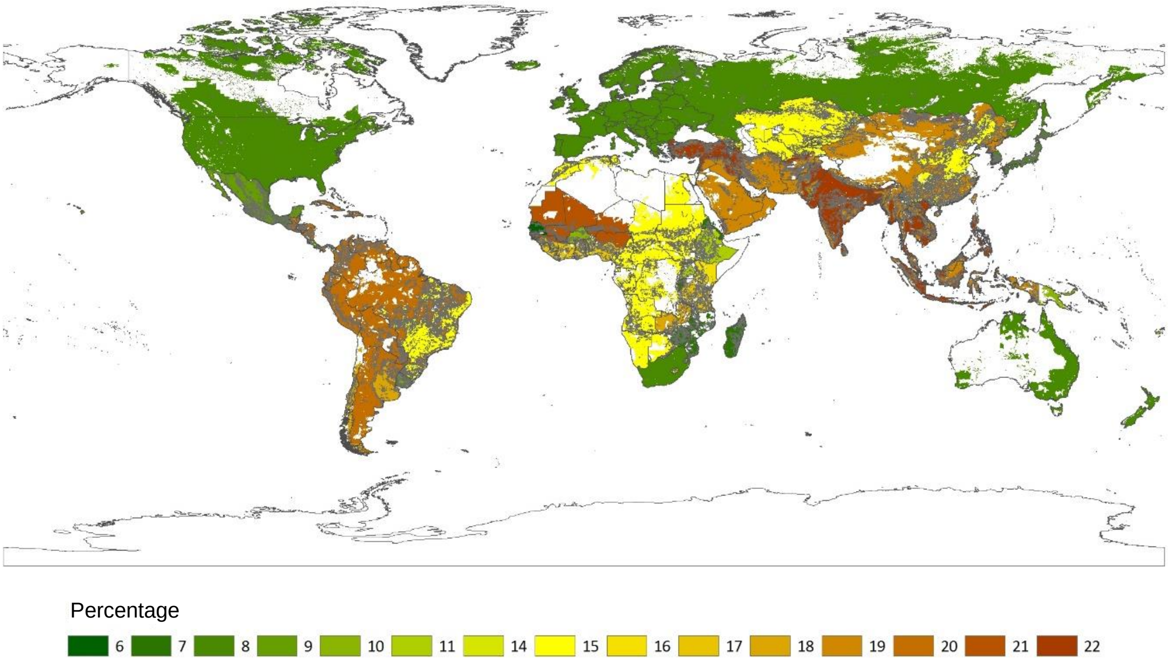
The Mottet *et al.* (in press) analysis reports that to produce 1 kg of animal-source protein requires an average of 8.8 kg of protein feed (17.3 kg for ruminants and 7.4 kg for monogastrics). However, when accounting for the source of animal feed (whether human-edible or non-human-edible feed), the requirement for human-edible protein feed in animal rations is lower for ruminants than for monogastrics, as the typical ruminant eats plants that humans cannot.

Reflected within these figures are considerable variations by production system and by level of productivity, which permit scope for overall efficiency improvements if appropriate technical and management improvements are implemented.

Likewise, the carbon footprint of ASF per gram is higher than in crop-based foods and the reduction in ASF consumption is often recommended as a measure to mitigate climate change. However, this recommendation does not take into account the higher micronutrient levels and better protein quality found in ASF (linked to ASF's higher nutrient density), or the fact that livestock, in particular ruminants, consume feed that is non-edible by humans (in particular, grass) and recycled waste. It is true that improvements in the feed conversion efficiency component of livestock production will be important to meet global environmental challenges (Revell, 2015).

Improving the efficiency of livestock production systems would, in turn, require addressing a range of associated challenges and, for instance, to reduce animal mortality rates, which are still very high in some developing countries (see Figure 7 and Section 3.1.4). The most obvious and important way to do this will be to improve farmers' access to veterinary and extension services.

Figure 7 Mortality rate of calves (%)



Source: FAO (2016a), GLEAM, http://www.fao.org/gleam/resources/en/

Sustainable management of natural resources:

Keeping production systems within critical planetary limits: Agricultural ecosystems provide humans with food, animal feed, fuel and other material and non-material goods and services essential to collective and individual well-being. Production relies on ecosystem services including pollination, biological pest control, the maintenance of soil structure and fertility, and nutrient and water cycling (Power, 2010). One major assessment identified 24 such ecosystem services, approximately 60 percent of which are being degraded at an unsustainable rate (MEA, 2005). This degradation is putting the resource base of future agricultural production at risk (Steffen *et al.,* 2015). Livestock production, particularly when concentrated in a small geographical area, can have significant negative effects on the associated ecosystems, ranging from pressure on water availability and quality, to eutrophication and acidification, to land degradation, reduced air quality, increased GHG emissions, biodiversity loss, and a reduction of genetic diversity. Agricultural production is the largest cause of human alteration of the global nitrogen, phosphorus and carbon cycles, and in some regions livestock is the major agricultural contributor to this disruption. (Leip *et al.*, 2015).

Pressure on land-use: Livestock is the world's largest user of land resources (see Chapter 2). As such, the livestock sector is a major driver of deforestation and other changes in land use. In particular, livestock expansion is the main reason that previously uncultivated land is brought into production, which some analysts believe is a process that has reached critical limits (Steffen *et al.,* 2015). According to several authors, extensive cattle raising in the Amazon region accounts for 65–80 percent of the deforestation in the region (this represents a rate of forest loss of 18–24 million ha/year) (Herrero *et al.,* 2009). Up to 600 000 ha/year are reported to be cleared for feed crop production for pigs, poultry and dairy (UNEP, 2007; Thornton and Herrero, 2010). Deforestation has also occurred in Southeast Asia and Central and West Africa, some of which has directly or indirectly been driven by livestock production (Thornton, 2010).

Pressure on water use and quality: The water footprint of livestock products (per calorie produced) is much higher than for crops. When the nutritional value of protein is considered, however, no plant protein is significantly more efficient at using water than the protein produced from eggs, and only soybean is more water-efficient than milk, or goat and chicken meat (Mekonnen and Hoekstra, 2012; Schlink *et al.*, 2010). Water quality is an issue mainly linked with intensive livestock systems: animal products from industrial, feed-based systems are generally more water-intensive and generally consume and pollute more ground- and surface water resources than animal products from grazing or mixed systems (Mekonnen and Hoekstra, 2012).

On average, almost one-third of the total water used in agriculture is used by the livestock sector: feed from cropland uses 37 percent of the water used for crop production; biomass grazed by livestock represents 32 percent of the evapotranspiration from grazed lands; while direct consumption for livestock drinking represents less than 10 percent of total water use (Herrero *et al.,* 2012). There are, however, considerable regional differences in livestock's share of water use (HLPE, 2015); for example, in the United States of America, livestock uses less than 1 percent of total freshwater use, whereas in Botswana livestock accounts for 23 percent (FAO, 2006c). In any case, water scarcity is not an issue in many temperate countries, which leaves space for the sector to develop. However, increasing livestock production in the future will add to the overall demand for water, particularly in the production of livestock feed.

Significant land degradation is a major challenge for SAD. Livestock production drives the transformation of natural ecosystems into pastureland, and from pastureland to other agricultural uses, such as feed crop production. Livestock production is also too often accompanied by significant land degradation, by soil erosion, drought, salinization, waterlogging and desertification (UNEMG, 2011). Land degradation affects more than 20 percent of all cultivated land and touches all types of farming systems. Globally, some 20 000–50 000 km^2 of potentially productive lands are lost annually through soil erosion and degradation, and 2.9 million km^2 are considered at very high risk of desertification, most of those areas being in developing countries (UNEP, 2007).[20] An estimated 20 percent of the world's pastures and rangeland have been degraded to some extent, and the proportion may be as high as 73 percent in dry areas (FAO, 2006b). Projections indicate that less water may be available and more droughts and other extreme weather events may occur in coming decades, exacerbating the loss of agricultural land. If current trends in increasing population density continue, then by 2030 urban land cover will increase by 1.2 million km^2, nearly triple the global urban land area in 2000. Most of this urban growth is concentrated in a few areas of Asia and Africa (Seto *et al.,* 2012). This expansion will increase pressure on productive agricultural land and on a number of biodiversity hotspots.

Many of the natural grassland ecosystems around the world suffer from overgrazing and degraded vegetation (Carvalho *et al.*, 2011). Dryland ecosystems, in particular, are extremely vulnerable to overexploitation and inappropriate land use. Grassland degradation, often accompanied by soil degradation and erosion, reduces the productive and ecological contribution of grasslands (Zhang, 1995). Such degradation leads to a decline in biological diversity (Wu, 2008), reduced grass and animal production from pasture, a deterioration of human living environments, soil erosion (Zhang, 1995), and the displacement of biodiversity-rich mixed farming systems. Land degradation contributes to reduced FSN over the long term.

Biodiversity loss: Biodiversity underpins the ecosystem services that supply benefits to agriculture and people. The principal causes of biodiversity loss are habitat degradation, overexploitation, alien invasive species and climate change. Agriculture is the single most important threat to vertebrate diversity (MEA, 2005). While biodiversity loss and land degradation are global phenomena, they are now most pronounced in the tropics and subtropics. Africa, followed by Latin America and the Caribbean, has experienced the highest biodiversity losses as a result of major land-use changes (especially in increases in pastureland and biofuel production) combined with increasing land degradation (UNEP, 2007).

Climate change

Climate change is a major challenge for agriculture and for food security (FAO, 2016b). Its impacts can differ widely among latitudes, regions, countries and agro-ecological zones. Most poor livestock keepers live in Africa and South Asia – regions especially vulnerable to climate change. Drylands in Africa and the Middle East may be severely affected by climate change, with significant impacts on the availability of water and forage resources (IPCC, 2014) and on the evolution of transhumance routes. Therefore, pastoralists and smallholders in these areas will be highly vulnerable to climate change and to the conflicts it is likely to trigger. Commercial grazing is also vulnerable to climate change. There is evidence that development of agriculture combined with climatic warming patterns have pushed the grassland agro-ecosystem in the Great Plains of North America and Queensland, Australia, into a more fragile status (Dong *et al.,* 2011).

[20] See: http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/use/?cid=nrcs142p2_054028 (accessed June 2016)

Box 5 Global climate change, food supply and livestock production systems: A bioeconomic analysis

In their assessment, Havlík *et al*. (2015) not only account for changes in crop yields but also for changes in grass productivity and feed rations. They also consider different systems and environments: grass-based (arid, humid, temperate/highlands), mixed crop–livestock (arid, humid, temperate/highlands), urban and other, for ruminants; and, smallholder and industrial production for monogastrics. Feed rations are defined as consisting of grass, stover, feed crops aggregates and other feedstuff. Outputs include products, as well as environmental factors (manure production, nitrogen excretion and GHG emissions).

From an initial distribution of livestock across the different systems, the projections that have been modelled show that:

- Climate change impacts on crop and grass yields are projected to have only a small effect on global milk and meat production by 2050, which remains under any climate scenario within +/-2 percent of the projected production without climate change.
- Effects can be more pronounced at regional level. In sub-Saharan Africa, effects are both the most uncertain and potentially the most severe; for example, ruminant meat production could increase by 20 percent or it could decrease by 17 percent.
- Effects on regional consumption are less pronounced because the impacts are buffered through international trade. Virtually all the negative effects are smaller than 10 percent.
- Adjustment in the structure of production systems will be key to adaptation. Grass yields benefit more (or are hurt less) from climate change than crop yields. Climate change would hence favour grazing systems, leading potentially to a change in the current trend towards more intensive systems.
- Optimal adaptation strategies (such as switching among production systems, feedstuff substitution, intensification or extensification) can be very diverse and heavily depend on the underlying climate change scenario, complexifying the search for robust strategies that are effective under many different future climate scenarios.

Climate change affects livestock systems in many ways, through: adversely affecting the quality and quantity of feed; exposing livestock to heat stress and extreme events (such as, severe winters in Mongolia, El Niño-associated flooding in east Africa, and droughts in southern Africa); reducing water available for livestock; and modifying the distribution of livestock pests and diseases (Thornton *et al.*, 2009). These include many diseases that are transmitted by insects or that have a life stage outside the animal host (Grace *et al*., 2015). Among the livestock diseases that most affect poor communities, more than half could be spread farther and faster by climate changes (Grace *et al.*, 2015).

Climate-associated changes are complex and difficult to predict. Some changes may be beneficial to livestock production (for example, growth in carbon dioxide concentration will increase pasture productivity; reduce some heat-sensitive diseases; and, produce indirect effects on livestock from changes in feed-crop productivity). However, the consensus is that the likely negative effects of climate change may outweigh the positive and create an increasingly difficult environment for livestock production in most systems (Thornton *et al*., 2015), and livestock systems will all need to adapt to climate change. A recent study by Havlík *et al.* (2015) provides a detailed global assessment of climate change impacts on the livestock sector (see Box 5).

Reduction of GHG emissions

With emissions estimated at 7.1 gigatonnes CO_2-equivalent per annum, when including all direct and indirect emissions through a life cycle analysis, representing 14.5 percent of human-induced GHG emissions (FAO, 2013a), the livestock sector plays an important role in climate change. Livestock, in particular grass-fed ruminants, account for significant emissions of methane, a particularly potent GHG. Emission intensity varies among species, by product and according to the system of production. In general, the higher the level of productivity (output per unit of input) the lower the emissions per unit of product (FAO, 2010). Numerous studies have shown that, in general, ASF from animals reared in more intensive and specialized systems have a relatively lower carbon footprint per animal than those in extensive systems, and dairy products, eggs and meat from monogastrics have a lower footprint than meat from ruminants (Garnett *et al.*, 2015). Ruminant systems operating at low productivity in Africa, South Asia, Latin America and the Caribbean are major contributors to GHG emissions (FAO, 2013a). In developing countries, industrial systems are less GHG intensive, and these are followed by mixed crop–livestock systems and by grazing systems (Herrero *et al*., 2012). However, extensive pigmeat and poultry systems have generally low GHG emissions per unit of output (FAO, 2013a).

Feed production and processing, and enteric fermentation from ruminants, are the two main sources of emissions, representing 45 and 39 percent of sector emissions, respectively. Manure storage and processing represent 10 percent, with the remaining 6 percent attributed to the processing and transportation of animal products. These emissions could be reduced by between 18 and 30 percent if producers in a given system, region and climate adopted the practices currently applied by the 10 to 25 percent of producers with the lowest emissions intensity in the system considered (FAO, 2013a).

The challenges are to develop breeding (genetics) and feeding regimes to achieve a lower level of GHGs per animal, and reduce deforestation (to increase soil carbon and biomass) while maintaining livestock production, and increasing resource efficiency and resilience, thus addressing at the same time the need for adaptation and contributing to mitigation.

3.1.2 Economic challenges

Markets: Well-functioning markets are important for SAD and FSN. Price signals are crucial though they play out in sometimes complicated ways. For example, the recent period of higher crop prices benefited many producers and triggered an increase in agricultural investment in most regions. But higher and more volatile prices were hard on livestock producers that depend on purchased feed, in particular the pig and poultry sectors. Higher food prices for consumers can be negative for FSN in the short run, in particular for low-income rural people, many of whom are net food buyers, and the urban poor. In the longer run, however, higher prices can bring important benefits to rural economies, including higher average levels of purchasing power.

Markets do not always give the price signals that lead to SAD and improved FSN status. There are three main reasons for this. First, markets are imperfect and sometimes non-competitive as a result of information gaps, poorly defined or enforced property rights and regulations, and because some livestock farmers, particularly smallholders, are not connected to supply chains or lack bargaining power in the markets they do access. Second, the social and environmental externalities (both positive and negative) of agricultural production and food consumption, as well as the natural resources used in production, are either not priced or under priced and therefore marginalized or ignored in farmers' decision-making. Third, some government policies distort price signals through poorly designed subsidies, and trade, investment and tax policies (OECD, 2005; 2012).

The time lag in agriculture – and in particular in the livestock sector – between prices, investment and production responses is a factor that makes many farmers risk-averse, sometimes leading to resource use that is suboptimal from a long-term sustainable development and FSN perspective. Together with the unpredictability of weather, the time-lag is also a cause of the price volatility commonly observed in agriculture.

While large or rich farms can often hedge against volatile prices, using financial resources to cushion a downturn in prices or entering into long-term contracts with food processors to reduce risk, small-scale farmers do not have the means to hedge their risks, unless they are part of a larger collective, whether voluntary or organized by the state. The vulnerability of poor farmers and consumers to price levels and price volatility has been extensively discussed with respect to agricultural development and FSN objectives (HLPE, 2011a; 2013b).

Trade-related risks: As shown in Chapter 2, international trade in feed and livestock products is growing, which brings new opportunities and challenges. The challenges include competition from subsidized imports, the failure of states to equitably redistribute the gains from trade in the economy (Rodrik, 2015), the risk of spreading emerging or reviving diseases (Thow, 2009; Grace *et al.,* 2012), and the difficulty of conforming to a range of sanitary and phytosanitary standards, both private and governmental.

Lack of agreement over deepening international trade integration: Rules governing international trade of agricultural products have evolved considerably over the last four decades, in particular with the conclusion of the Uruguay Round of negotiations under the auspices of the General Agreement on Tariffs and Trade in 1994. The Uruguay Round launched the World Trade Organization (WTO) and created, for the first time, dedicated international trade rules for agriculture. Trade rules and policies can affect FSN positively or negatively and there is little consensus on how trade rules should be adapted to support FSN objectives (FAO, 2015b).

Constraints due to small-scale farm size: Average farm size has fallen in most low- and middle-income countries, where the majority of smallholders live (FAO, 2014c). This can be a significant constraint on providing sustainable livelihoods for smallholders and their families. Although it does not necessarily demonstrate that small-scale farms have low productive efficiency, smallholders do face significant challenges when competing with heavily capitalized farms, which in many countries access public subsidies and many of whose costs are externalized through poor regulation of labour conditions and the environment (Quan, 2011).

Low levels of investment in agriculture research and development (R&D): Public investment in agriculture had been stagnant for some time, with subsidies claiming the larger share of public expenditures on agriculture in many countries (IBRD/World Bank, 2007). Private investment remains concentrated in a handful of developed and emerging countries. Overall investment in R&D of new technologies and their adaptation to smallholder farmers remains inadequate.

Corporate concentration in the livestock sector: Nearly all the predicted growth in livestock production is expected to occur in developing countries, where food systems tend to be heterogeneous and fragmented, with large numbers of actors, many of them small-scale and with little by way of formal organization. In China, for example, food production is said to be dominated by "elephants and mice"; in other words, there are a few large companies with incentives to evade or exercise influence over regulation while the great majority of the rest are in the informal sector and thus are difficult to monitor and are poorly regulated (Alcorn and Ouyang, 2012). As discussed in Chapter 2, there are concerns related to growing concentration all along the agri-food supply chain, from artificial insemination and the provision of young chicks to contract farmers, of phytosanitary and veterinary products, to food processing, distribution and retail networks. Livestock farmers are often dependent on a few suppliers for their inputs and a few buyers for their production. The challenge is primarily that the gains from production are increasingly concentrated in the hands of the dominant economic actors, reducing farmer and farm worker income. Other problems arise linked to the narrow profit margins on farm, from neglect of investment in future production and inability to address externalities, for example with strong environmental management. To some extent farmer cooperatives can rebalance the relatively weaker bargaining position of farmers – such cooperatives have been especially successful in the dairy sector, whereas in some livestock sectors the effects appear to be mixed.[21] However, concentrated corporate control over different links of the livestock value chains raises challenges for sustainability in particular in the more intensive production systems.

3.1.3 Social challenges

Providing security and satisfactory working conditions.

Agriculture and food processing are among the sectors that employ the largest share of low-income people. Forty percent of the agricultural workforce is waged, working on someone else's land or with someone else's animals (ILO/FAO/IUF, 2007). The work is physically demanding and repetitive. Although new technologies have reduced the physical strength required for the work, new risks have been introduced and safety measures, information and training are too often lacking. The number of fatal and serious accidents and illness among agricultural workers is high, yet they often have access to inadequate or no social safety nets, even in developed countries (ILO/FAO/IUF, 2007).

According to the International Union of Food, Agricultural, Hotel, Restaurant, Catering, Tobacco and Allied Workers' Associations (IUF)[22], occupational health and safety issues are by no means confined to the Global South. For instance, in the United States of America, there are detailed studies showing that agricultural and food industry workers are among the most disadvantaged groups in the country, with lower than average educational status, greater than average likelihood of being migrants, and more likely than average to speak English as a second language[23] (Maloney and Grusenmeyer, 2005). Some studies focus on the situation of workers in meat and poultry industry, which is considered particularly difficult (see Box 6).

---

[21] See for instance: http://www.fao.org/docrep/T3080T/t3080T0a.htm; http://ec.europa.eu/agriculture/external-studies/2012/support-farmers-coop/leaflet_en.pdf; (accessed June 2016).

[22] See : http://www.iuf.org (accessed June 2016)

[23] See: http://www.ers.usda.gov/topics/farm-economy/farm-labor/background.aspx (accessed June 2016).

Box 6 Occupational health in the meat and poultry industry in the United States of America

According to the US Bureau of Labor Statistics (BLS), although the majority of workers in the US meat and poultry industry are citizens, an estimated 26 percent of them are foreign-born non-citizens. They work in hazardous conditions involving loud noise, sharp tools and dangerous machinery. Many workers must stand for long periods of time wielding knives and hooks to slaughter or process meat on a production line that moves very quickly. Workers responsible for cleaning the plant must use strong chemicals and hot pressurized water. While, according to BLS, injuries and illnesses have declined over the past decade, the meat and poultry industry still has one of the highest rates of injury and illness of any industry in the country (US GAO, 2005). An estimated 71 percent of US poultry growers have annual incomes below the US federal poverty limit (NCFH, 2014).

In the framework of the Health Hazard Evaluation Programme, a study conducted in a poultry processing plant of South Carolina by the National Institute for Occupational Safety and Health showed that 42 percent of the workers had evidence of carpal tunnel syndrome, 41 percent performed daily tasks above the thresholds recommended by industry experts and 57 percent reported at least one musculoskeletal symptom, not including hand or wrist symptoms (Musolin *et al.*, 2014)

Alabama produces more than 1 billion broilers per year – ranking it third among states behind Georgia and Arkansas. It is an industry with an USD8.5 billion impact on the state – generating about 75 000 jobs and 10 percent of Alabama's economy – and one that plays a vital economic role in numerous small towns. However, for the poorly paid workers who face the relentless pressure of the mechanized processing line, the jobs come at a high price. Nearly three-quarters of the poultry workers interviewed by the Southern Poverty Law Centre for a recent report described suffering some type of significant work-related injury or illness. In spite of many factors that lead to undercounting of injuries in poultry plants, the US Occupational Safety and Health Administration (OSHA) reported an injury rate of 5.9 percent for poultry processing workers in 2010, a rate that is more than 50 percent higher than the 3.8 percent injury rate for all US workers. (SPLC and Alabama Appleseed, 2013).

Child labour

Agriculture is the largest sector where child labour is found: of the 215 million child labourers worldwide in 2008, about 60 percent (129 million) were engaged in the agriculture sector, including farming, livestock, forestry, fishing and aquaculture (FAO, 2013c). Agriculture is also one of the most dangerous sector in terms of accidents and occupational diseases: almost 60 percent of girls and boys (aged 5–17 years) in hazardous work are found in agriculture (FAO, 2013c). Children can be gainfully employed in agriculture but all too often the work is at the expense of education and in unsafe working conditions. By endangering the health and education of the young, child labour in agriculture is an obstacle to SAD and food security.

Addressing gender inequalities

In many societies, social and cultural norms tend to determine distinct and complementary roles for women and men in livestock production and processing. For example, in the majority of traditional societies, women manage poultry and small animals while men work with the larger animals, such as cattle and camels (FAO, 2012b). Although women's typical roles within livestock production systems vary from region to region, economic, legal, social and cultural factors tend to marginalize women's place in the livestock value chain (IFAD, 2010).

Women account for a significant and growing share of the workforce in agriculture worldwide, as men are much more likely than women to move to non-farm jobs (Agarwal, 2012). In developing countries women comprise approximately 43 percent of the agricultural labour force, ranging from 20 percent in Latin America to 50 percent in South Eastern Asia and sub-Saharan Africa (FAO, 2011a). Despite a determined push to generate disaggregated research – revealing, for example, that female-headed households are as successful as male-headed households in generating income from their animals – the available data remain uneven and inadequate. For example, while the role of women in small-scale livestock production is well recognized, there is much less documentation of their engagement in intensive production and in the market chains associated with large commercial enterprises.

Women face a number of forms of exclusion: they have less access to technologies, extension services, markets, financial services and productive resources, especially land. This discrimination is a result of restrictions imposed through local customs and national laws (FAO, 2011a; Herrero *et al.,* 2012; IFPRI, 2012; Njuki and Sanginga, 2013). The modernization of agriculture and the integration of agricultural systems into international markets have sometimes deepened women's exclusion. For example, new crops may rely on the use of technologies that require capital inputs and some level of education, both of which women have less access to than men. As livestock enterprises scale up, and cash plays a greater role in the farm operation, the control of decisions and income and sometimes of the entire enterprise often shifts to men. There are however some exceptions, for instance in Viet Nam, where women manage many medium-sized duck breeding enterprises (FAO, 2011a). In fact, ownership of livestock is particularly attractive to women in societies where access to land is restricted to men; livestock can provide a relatively simple source of income for resource-poor producers (Bravo-Baumann, 2000).

Male and female livestock producers do not necessarily face the same risks, nor do they experience shared risks the same way. In a recent study, IFAD underlines some of these differences (IFAD, 2010). For example, if women are denied access to externally purchased productive inputs, they may not be able to take advantage of markets for new crops. In many cultures women are not encouraged to participate in collective organizations that can bring economies of scale and a stronger political voice. Women also face specific risks because of their greater vulnerability to sexual harassment and even violent attack, which in many places curtails their freedom of movement in public. The discrimination girls face in education reduces their ability as women to take advantage of new opportunities, and to use support services or adopt new farm technologies. Women and men are likely to be differently affected by household shocks, such as an illness in the family, which may be reflected in their productive activities (for example if a woman gives up paid work to care for a relative).

Constraints from an ageing workforce

In some regions, farmer populations are ageing as rural communities see little future in agriculture (Vos, 2014). This might be the opposite in other regions, like Africa, as a result of demography. In all cases, changing demographics affects agricultural production. Older farmers are for example less likely to introduce new, transformative production techniques (Vos, 2015). In the United States of America, the average age of farmers is now 58 years, while in Japan it is 67 (Jöhr, 2015). Feeding a growing population with an ageing workforce will require radical changes in production technology and/or the need to make farming more attractive to young people. As shown in Chapter 2, rural–urban migration is one of the main drivers of an ageing workforce in some developing countries.

Conflicts and protracted crises

Protracted crises are one of the greatest challenges facing the realization of FSN for all (FAO/IFAD/WFP, 2015). Hunger has always accompanied war. Nor are natural disasters new. However, they have grown more frequent as a result of human activity that has destroyed ecological resilience, including through deforestation, soil and freshwater depletion, and biological diversity loss.[24] Though absolute numbers of hungry people continue to decrease, the number of countries facing food crises has doubled since 1990 (from 12 to 24), while the number facing hunger as a result of protracted crisis has grown from 4 to 19 of that total – an almost five-fold increase. Approximately 19 percent of the food insecure worldwide live in regions affected by protracted crisis (FAO/IFAD/WFP, 2015).

Many studies of livestock farmers living in protracted crisis situations focus on pastoralists. Their vulnerability to drought and forced migration is not new but the evidence suggests that the early warning systems in place are too rarely used to trigger policy responses. Drought is a slow-onset crisis and affects specific regions consistently: it is not unpredictable. And yet government responses continue to be late and inadequate, while urgently needed cross-border strategies for pastoralists remain a critical gap (Levine *et al.*, 2011).

During armed conflicts (see Box 7), farmers' access to fields is greatly reduced, interrupting the production cycle. This has been a feature of the Syrian war (Jaafar *et al.,* 2015). The vicious circle between conflict and drought has also been documented among smallholder livestock producers in eastern Democratic Republic of the Congo, for example, where low livestock numbers and poverty are associated with farmers' vulnerability in violent conflict and their low resilience in the face of a protracted dry season (Maass *et al.,* 2012).

[24] United Nations Office for Disaster Risk Reduction http://www.unisdr.org/we/inform/disaster-statistics

Box 7 Impacts of Conflicts on Pastoralists

Conflicts and wars cause the displacement of millions of people, who live in refugee camps. Lebanon, Iraq, Afghanistan and Sudan are examples of recent conflicts in which displaced peoples have used wood from forests as fuel and for building shelters. About 2.4 million people migrated to the Darfur area and more than 3 million people migrated from Afghanistan to bordering Pakistan. These displacements have led to deforestation and degradation of rangelands around and beyond camps. More specifically, Pakistan has paid an environmental price for accommodating people, along with their animals over the last 15 years. These are environmentally significant displacements occurring under fragile dry land conditions. The national responses to such environmental disasters affecting local pastoral systems were either slow or very limited due to limited capacity. The role of international organizations such as the United Nations Environment Program (UNEP) is significant in assessing the environmental risks, loss of livelihoods, and social stresses in mobilizing resources for post-conflict rehabilitation.

3.1.4 Health challenges

Health is a global public good and must be addressed at the global level, from a comprehensive and cross-cutting perspective, including the links between animal and human health. In September 2004, the Wildlife Conservation Society (WCS) proposed a holistic approach initially called *One World-One Health*, which aimed to better prevent epidemic/epizootic diseases by strengthening the links between human health, animal health and management of the environment, particularly biodiversity and ecosystem services.

In October 2008, six international organizations elaborated a Strategic Framework for Reducing Risks of Infectious Diseases at the Animal–Human–Ecosystems Interface, based on the *One World-One Health* concept (FAO *et al.,* 2008). Now known simply as *One Health*, the initiative promotes coordination between the different health systems, most of which are run separately, to facilitate economies of scale and to foster synergies. This approach has been also endorsed by the Convention on Biological Diversity (through its decisions XII/18 and XII/21), as well as by a number of countries, universities, NGOs and many other stakeholders.

Animal health

Animal diseases reduce productivity and are important causes of shocks that can disrupt food production and markets. Better management of diseases and pests is thus integral to sustainable production. Animal diseases are expensive and threaten human health. The cost of specific disease outbreaks can often run into billions of dollars. Just a few major diseases are responsible for most of the harm.

Animal diseases appear to be decreasing in wealthy countries but are static or increasing in poorer countries (Perry *et al.,* 2011). There have been many studies on the economic costs of disease linked to losses from animal mortality, reduced productivity and control costs. However, only a few studies have attempted to systematically assess the impacts of livestock disease across species or countries. The cost of 32 important diseases in the United Kingdom livestock sector valued in 2001 was estimated at USD1 178 million, or 8 percent of the value of the sector (Bennett and IJpelaar, 2005). In Australia, the top 21 beef and sheep diseases cost the livestock sector AUD 979 million, or 16 percent of the value of the sector (Sackett and Holmes, 2006). Studies on disease incidence and mortality in developing countries are complicated by the lack of good information: Fadiga *et al.* (2013) estimated the annual financial cost of five important animal diseases in Nigeria to be up to 29.2 billion Nigerian Naira (USD185 million in 2013).[25] All five diseases were transboundary in nature. A recent survey from the World Organisation for Animal Health (known as OIE) estimated that, in Africa, the 35 highest priority diseases cost nearly USD9 billion a year, equivalent to 6 percent of the total value of the livestock sector in Africa (Grace *et al.,* 2015).

Although the levels of animal disease are highest in pastoral systems, the overall burden is greatest in smallholder systems, as these systems hold more animals. These include zoonotic diseases (such as salmonella, highly pathogenic avian influenza), and are linked to concerns over animal welfare. Improved conditions for animals are associated with a reduced incidence of zoonotic disease. A meta-analysis by FAO in Africa showed small ruminants have higher mortality than cattle, young animals

[25] Newcastle disease (ND) in poultry, *peste des petits ruminants* (PPR) in sheep and goats, contagious bovine pleuropneumonia (CBPP) in cattle, African swine fever (ASF) in pigs and trypanosomosis in cattle and pigs.

are more vulnerable than adults, pastoral systems have more disease than mixed systems, and traditional systems more disease than modern livestock systems (FAO, 2002).

Human health

Food security, good nutrition and human health can be compromised by a range of food-borne diseases, animal diseases or through antimicrobial resistance. Moving towards sustainability also includes taking care of the health-related aspects of agricultural development.

The relationships between ASF, nutrition and health are complex: if small amounts of meat, dairy and eggs added to grain-based diets have beneficial nutrition effects, excessive amounts of processed meat have been linked to an increased risk of chronic disease. While studies in high-income countries generally support a link between higher ASF consumption, overnutrition and chronic disease, the exact role of specific foods is highly contested and prone to revision. The challenge of the weak evidence base for nutritional guidelines combined with overconfidence in studies that confound correlation with causation is illustrated by major reversals in nutrition advice in some countries. In 2015, for example, the American Dietary Guidelines Advisory Committee abandoned its recommended restrictions on cholesterol and fat intake and recommended against the promotion of artificial sweeteners for weight loss. However, some studies show an association between meat consumption (especially red and processed meat) and cardiovascular diseases (including strokes), some cancers, and diabetes – all of which cause mortality (Micha *et al.,* 2012; Larsson and Orsini, 2014). In 2015, WHO's International Agency for Research on Cancer declared that there is sufficient evidence to support the carcinogenic effect of red meat and processed meat but noted at the same time the nutritional value of red meat and encouraged governments and international regulatory agencies to conduct risk assessments in order to balance the risks and benefits of eating red meat and processed meat and to provide the best possible dietary recommendations (IARC, 2015).

Food-borne diseases (FBD) impact human health globally in ways comparable in scale to that of malaria, HIV/AIDS or tuberculosis (Havelaar *et al.,* 2015), with an estimated 420 000 deaths per year. FBD are primarily the result of microbes (79 percent) and macro-parasites (18 percent). Although public attention, even in developing countries, is much more focused on the relatively much less important causes: chemicals and plant toxins, which account for an estimated 3 percent of FBD[26] (Havelaar *et al.*, 2015). Most of the global burden of food-borne disease (98 percent)[27] is borne by developing countries (Havelaar *et al.,* 2015), where the most risky fresh foods are supplied largely by the informal sector and produced by smallholders (Grace, 2015). Livestock products are the food category most implicated in FBD (Painter *et al.*, 2013; Sudershan *et al.*, 2014; Bouwknegt *et al.*, 2014; Tam *et al.*, 2014; Sang *et al.*, 2014).

Emerging diseases are defined as diseases that have newly appeared in populations, or that are rapidly increasing in frequency or range, while re-emerging diseases are those that were previously under control but have started to reappear. They are mostly zoonotic diseases. Drivers of zoonotic disease emergence include land-use change, encroachment of agriculture on natural ecosystems, urbanization, conflict, travel, migration, global trade, trade in wildlife and changing dietary preferences (IOM & NRC, 2009).

One new human disease emerges every four months. Around 60 percent of all human diseases and 75 percent of all emerging diseases are zoonotic (Woolhouse *et al.,* 2005; Taylor *et al.*, 2001). Historically, most zoonotic diseases emerged in the intensive animal industries of the United States of America and Europe but more recently there has been a shift to developing countries (Grace *et al.*, 2012). Most emerging zoonoses have a wildlife component, and the study of disease emergence has a strong focus on wildlife. However, the most important emerging diseases often involve livestock. Between 1997 and 2009, the economic losses from six major outbreaks of highly fatal zoonoses,[28] involving livestock as a reservoir or a bridge to carry disease to people, amounted to at least USD80 billion (World Bank, 2012). If these outbreaks had been avoided, the benefits would have averaged USD6.7 billion per year (World Bank, 2012). The high density of animals in intensive systems, along

[26] This is an example of where lay perception differs from expert judgment and is probably due to psychological factors that make chemical hazards more frightening for many (Slovic, 2010).

[27] A recent global assessment estimated that the health burden was distributed as follows: 35 percent in South Asia, 35 percent in Africa and 9 percent in Southeast Asia (Havelaar *et al.,* 2015).

[28] Nipah virus (pigs, Malaysia), West Nile fever (horses, United States of America), severe acute respiratory syndrome (farmed civet, Asia, Canada, other), avian influenza (poultry, Asia, Europe), bovine spongiform encephalopathy (cattle, United States of America, United Kingdom), Rift Valley fever (ruminants, United Republic of Tanzania, Kenya, Somalia).

with their genetic homogeneity, exposure to stress and the use of antimicrobials to mask poor husbandry foster disease emergence in these systems (Jones *et al.*, 2013). But although the drivers of disease emergence have been identified (Jones *et al.*, 2013), there is little evidence as to which practical strategies could be best employed to reduce disease emergence from or through a livestock system.

Antimicrobial resistance is considered one of the major public health challenges facing humanity this century in both developed and developing countries (O'Neill, 2015; 2016). Standards and guidelines to address this concern have been recently published by international organizations (WHO, 2015c; OIE, 2015; see also section 3.5.2).

3.1.5 Animal welfare

There are divergent perspectives with respect to animal welfare: as citizens, people tend to support the notion of animals being entitled to a good life, but as consumers they tend to be less careful (Schröder and McEachern, 2004).

Animal welfare conditions currently vary across countries and production systems. Conditions depend on socio-economic and regulatory settings, as well as on religious and cultural traditions, consumer pressure, retailers and civil society organizations. The OIE defines animal welfare with "five freedoms" (Box 8).

In 2016, the International Organization for Standardization (ISO) published general requirements and guidance for organizations in the food supply chain on animal welfare management (ISO/DTS 34700).[29]

Finding an acceptable balance between increasing production, improving efficiency and the welfare of livestock is a challenge for the sector, particularly in the situation of poorly regulated, intensive industrial systems (McInerney, 2004). Maintaining and improving animal welfare can incur higher costs to livestock producers; but these can result in higher returns to producers from more productive animals, as well as price premiums where livestock producers are integrated into supply chains in which animal welfare is differentiated.

In many countries, legislation provides for a minimum standard of animal welfare (Mitchell, 2001; WAP, 2014a; CWF, 2014) and, where these do not yet exist, the OIE provides guidelines. In many low- and middle-income countries, however, even where animal welfare legislation exists, there are insufficient resources and capacity for its implementation.

Especially in high-income countries, consumers may be willing to pay more for livestock products that go beyond minimum standards of welfare, exerting increasing pressure on livestock producers, transporters and slaughterhouses to raise animal welfare standards. Governments, livestock supply industries and consumers can play an important role in triggering or enforcing animal welfare policies and practices (see Chapter 4). Retailers are increasingly demanding production systems that take into consideration animal welfare.

Box 8 OIE principles for animal welfare

OIE's Terrestrial Animal Health Code defines animal welfare as "how an animal is coping with the conditions in which it lives. An animal is in a good state of welfare if (as indicated by scientific evidence) it is healthy, comfortable, well nourished, safe, able to express innate behaviour, and if it is not suffering from unpleasant states such as pain, fear, and distress" (OIE, 2004). The basis is the 'five freedoms' (FAWC, 2011), the principle that animals should have:

1. freedom from thirst, hunger and malnutrition;
2. freedom from discomfort;
3. freedom from pain, injury and disease;
4. freedom to express normal behaviour;
5. freedom from fear and distress.

The OIE develops animal welfare standards, which can guide members and facilitate trade.

[29] See: http://www.iso.org/

The disparities among countries in relation to their interest in animal welfare, their regulation of animal welfare, and their ability to enforce regulations create specific difficulties for trade. ASF poses a range of challenges for sanitary and food safety standards and recent trade negotiations, for example in the Transatlantic Trade and Investment Partnership (TTIP), are at least as concerned with harmonizing regulations as with more traditional trade barriers such as tariffs.[30]

3.2 Key challenges in smallholder mixed-farming systems

In addition to the cross-cutting challenges identified above, smallholder mixed farming systems face specific challenges that include: limited access to resources, market and services; low resource efficiency and resilience; and structural transformations in agriculture and in the economy that leave them at a competitive disadvantage.

3.2.1 Limited access to resources, market and services

Smallholder farmers face a major challenge in their inadequate access to resources and services, including land, water, breeding stock, housing, machinery and equipment, extension and veterinary services, markets, financial services and new technologies. This undermines their ability to improve their production efficiency and resilience, leaving them vulnerable to persistent poverty (HLPE, 2013a).

Lack of tenure and access to land and water: Lack of tenure and property rights is a major disincentive for smallholder investment (Shepherd, 2007; HLPE 2011b; HLPE 2013a) as well as a source of conflict (USAID, 2013). Many developing countries do not have an efficient formal land title and tenure system, while customary tenure systems are not always reliable (FAO/Earthscan, 2011). The problem of accessing adequate land and water is exacerbated by climate change, urban expansion and large-scale land acquisitions (sometimes called land-grabs) by both foreign and domestic enterprises (HLPE, 2011b: Jayne *et al.*, 2014). Smallholders, in particular women, often lack bargaining power in access to natural resources, especially when in competition with large landowners, input suppliers, traders, processors and retailers.

Poor access to markets: Most smallholders have few choices about where to market what they grow. Wiggins and Keats (2013) identified several challenges for smallholders: (a) the state's failure to provide an enabling investment climate (including a stable macro-economy, enforcement of property rights, and clear standards) and rural public goods; (b) a lack of access to inputs, technical advice, insurance, credit and other financial services; (c) the high transaction costs of information about available products and services and on the competence and character of counterparts in transactions; (d) inappropriate top-down approaches that lack flexibility and fail to strengthen adaptive capacity; and (e) the lack of "champions" whether from the private sector, NGOs or government to overcome the diseconomies of scale that smallholders face.

Exclusion from higher value markets: Farmers who supply modern retail chains can benefit from higher value markets but most farmers find it difficult to enter (and stay in) these demanding value chains (Andersson *et al.*, 2015). Those who do benefit tend to be better capitalized, better educated and geographically advantaged (for example, within range of an urban centre). The dissolution of publicly run agricultural extension services in many countries and the proliferation and tightening of private standards have also squeezed smallholders out of a number of export markets. For example, in the 2000s, Kenya and Uganda saw, respectively, a 60 and 40 percent decline in the number of smallholders participating in the export of fruit and vegetables to Europe under Global G.A.P. (Good Agricultural Practices), a privately operated certification programme (Graffham *et al.*, 2007).

3.2.2 Low resource efficiency and resilience

Reducing yield gaps: Most regions have reached their land frontier limits. This implies that, absent radical technological change, almost all increased production must come from yield increases (Vos, 2015) and not expansion. In turn, this gives critical importance to increasing the efficiency of production to close yield gaps (Garnett *et al.*, 2015). There are large livestock yield differences between countries; yields are especially low in sub-Saharan Africa (Tittonell and Giller, 2013). Globally, the gaps are largest for dairy cattle and poultry. Milk yield in sub-Saharan Africa is only 6

[30] See for example the EU's proposal on sanitary and phytosanitary standards from 2014 (available at: http://trade.ec.europa.eu/doclib/docs/2015/january/tradoc_153026.pdf).

percent of that in developed countries (Staal *et al.*, 2009). The yield gap has been attributed to suboptimal use of genetic resources, inadequate feed and high animal disease burdens. However, efficiency assessments are often based on narrow metrics, which may not include non-food outputs (such as manure and draught power), animal welfare, or non-tangible social assets that are often generated at higher levels in systems with lower economic efficiency (Weiler *et al.*, 2014).

Lack of capacity to increase productivity: Some smallholders only engage to a limited extent in commercial agricultural activities (Perry and Grace, 2009; Okali, 2012). One review estimates that 60 percent of smallholders are non-commercial: instead, they are net food buyers who sell small amounts of surplus production (when they have any) in local informal markets (Christen and Andersen, 2013). Livestock keeping is more prevalent among the rural rich and the urban poor. This suggests rural families would use an increase in income to expand their livestock holdings, but that urbanization makes keeping livestock less viable (Pica-Ciamarra *et al.,* 2011).

Lack of resilience: Smallholders are exposed to many risks (including climatic events, animal diseases, pests and plant diseases, price volatility). Some aspects of modernizing production can increase smallholders' vulnerability. For instance, where increased agricultural productivity is the result of increased reliance on external inputs, smallholders' economic resilience may be undermined. For example, studies in Viet Nam found that small-scale pig farms, which made use of household labour and feed resources grown on farm, were less vulnerable to changes in market prices than larger farms that relied on purchased inputs (Tisdell, 2010). Increases in productivity in smallholder systems using modern technologies and techniques have also been associated with de-linking livestock from local ecosystems and with genetic resource loss. Lack of adaptation to local conditions can be a source of vulnerability.

3.3 Key challenges in pastoral systems

As well as the cross-cutting challenges identified above, pastoralists face many of the same challenges as smallholders. Pastoralists are confronted with low resource efficiency and limited access to services, credit and markets. Market access is limited by high transportation costs, poor infrastructure and the lack of quality standards, leading to high transaction costs for goods and services (IFAD, 2009b). Private sector investments in these areas are minimal because pastoralism is perceived to have high risks and low returns.

But in addition, pastoralists in most countries are a vulnerable minority population. They also face conflicts with other users over access to their traditional land and resources; economic and political marginalization, including in their treatment by government; and, social inequity, related to the clash between pastoralists' nomadic lifestyle and the settled nature of most social institutions, such as schools and health centres.

3.3.1 Conflicts for land and water

Pastoralism requires widespread land and water resources to operate efficiently. It has historically developed in areas with low human population and harsh natural resources conditions that require careful use to make the most of limited ecosystem services. Some of the most fragile pastoral ecosystems, however, have seen rapid population growth recently: in pastoral districts in the Horn of Africa, for example, the population has doubled in the past 20 years (Little, 2013), while in the Qinghai-Tibetan Plateau, high population growth has been compounded by a new railway that has encouraged in-migration (Dong *et al.*, 2011).

As noted by de Haan *et al.,* (2010), "*population pressure, arable farming encroachment and government policies to settle mobile pastoral groups are also major sources of soil degradation".* The conversion of pastures and grasslands to croplands or urban settlement infringes on peoples' acquired and inherent rights and access to traditional lands and natural resources. In west and central Africa, traditional herd movements have led to conflicts over access to farmland, grazing areas, water points and stock routes (McDougal *et al.,* 2015). According to ICG (2014), these conflicts are exacerbated by a worsening climate, increasing populations competing for scarce resources, out-dated legal frameworks, and weak governance.

Water is a critical resource that determines the success of pastoralism as a way of life in arid and semi-arid lands. As populations have increased, pastoralists often rely on boreholes during the dry season, leading to overuse and sometimes transboundary conflicts (Omosa, 2005). Population growth also leads to the encroachment of crops onto pasturelands. Erratic rainfall creates periodic declines in availability of feed for livestock, which leads to excess mortality and undermines the basis of pastoralist livelihoods.

Conflicts over resources are expected to be exacerbated by climate change. In the Sahel, the predicted increase of average temperatures and more frequent droughts, storms and floods will have negative effects on animals and the availability of vegetation, accelerating vulnerabilities and weakening the resilience of agricultural systems (Pastoral Platform of Chad, 2015). The effects will also challenge social equity as the available resources are diminished. Some conservation initiatives and policies that favour recreational uses of land have also violated pastoralists' land rights and access to natural resources.

In east Africa, recent decades have seen conflicts in a broad geographical band that stretches from the Kenya–Somalia border to the Central African Republic (Bevan, 2007; Reda, 2015). Violent conflicts result in ineffective resource utilization, reduced mobility for pastoralists, food insecurity and the closure of markets and schools (Schilling *et al.*, 2012).

3.3.2 Economic and policy-related discrimination

In most countries, pastoralists are a minority. They inhabit remote, marginal lands where political borders may not correspond with traditional territory (Nori *et al.*, 2005). Failure to understand pastoralism has led to policies with negative effects. For example, in regions of China and the Andes, policies to promote the settling of nomadic populations and the introduction of modern farming led to the deterioration of environmental, economic and social conditions in pastoral communities (Hesse and MacGregor, 2006; Dong *et al.*, 2011). In central Asia, the transformation of the traditional pasture-use system, driven by population growth and policy reform, has resulted in massive rangeland degradation and increased carbon emissions (Chuluun and Ojima, 2002). In east Africa, pastoralists are settling and diversifying their livelihoods but service provision and infrastructure development remain inadequate (ODI, 2010) or unhelpful. For example, the development of large-scale irrigation along rivers in drylands has reduced pastoralist's access to grazing and water (Galaty, 2014). While communal land rights ensured women's access to land, transition to private land holding often puts the land title in the hands of men, disadvantaging women pastoralists.

Market distortions: Meat produced by pastoralists in a number of countries has been subject to strong competition from products imported from Europe or the United States of America, many of which benefit from substantial direct and indirect subsidies (Moll and Heerink, 1998; Stoll-Kleeman and O'Riordan, 2015). During the 1970s and 1980s, international food aid was the main response to the Sahelian food crisis. Many of the food aid interventions were poorly planned and implemented, leading to the destabilization of markets and increased dependency among some of the recipient populations (Barrett and Maxwell, 2005). Massive shipments of wheat and rice also stimulated a shift in consumer demand from indigenous millet or sorghum to imported grains (FAO, 2006b).

Emergency assistance: The specificities of pastoral systems are still not adequately accounted for in early warning systems and in the plans to prevent and mitigate food crises. Policy-makers need to better understand what makes pastoralists resilient and what makes them vulnerable, whether with regard to technical aspects (health of livestock, social management of water resources and pasture), social aspects (access of pastoralists and agro-pastoral households to basic social services, including health, education, clean water, sanitation, etc.) or economic aspects (linkages between livestock and feed, choice of markets, competition with settled agriculture and with imports, etc.).

Negative impact of some infrastructure developments: Major hydro-agricultural development projects undertaken in the Sahel (for the irrigation of rice cultivation) have excluded pastoralists from valuable land and in particular from areas used during the dry season. This has weakened pastoral societies (Cisse, 2008). The challenge is to enhance social equity and responsibility by integrating transhumance, forestry and agriculture in the development of the territory, and respecting indigenous peoples' rights to commonly-owned land and natural resources.

3.3.3 Social and gender inequity

Pastoral societies are often patrilineal kinship groups with a marked gender division of labour and entitlements that generally favours men. These inequalities are then typically accepted by women and the community at large (Eneyew and Mengistu, 2013). Child labour is common in pastoral areas and herding can start between five and seven years of age. Boys are generally more involved than girls. International experts are concerned that pastoral labour can be harmful to children's health and educational opportunities (FAO, 2013). Social change is also creating new forms of inequity. For example, rural out-migration leads to more households headed by elderly people, who tend to be more vulnerable (Opiyo *et al.*, 2014). Social differentiation is increasing in many pastoral societies. For example, in the Bolivian and Peruvian highlands agrarian reform supporting individual ownership has led to greater inequities between hired herders and herd owners (Dong *et al.*, 2011), and in the Horn of Africa a more capital-intensive pastoral system aimed at production for the market has had similar impacts (Little, 2013). Often these inequities intersect with each other to compound the disadvantages.

Indigenous peoples (see Box 9) face additional challenges. There is a strong link between the presence of pastoralists, the prevalence of indigenous livestock breeds and the provision of supporting, regulating and cultural ecosystem services. These links are found especially in the extensive livestock systems in drylands and mountainous regions. The large areas covered by these production systems, the importance of grasslands to biological diversity and the link between livestock grazing and nature conservation affirm the role of small-scale livestock keepers and pastoralists as guardians of biodiversity beyond the management of their breeds (FAO, 2009a).

Chronic marginalization, non-recognition of rights, poor infrastructure and limited or inappropriate services have resulted in many indigenous peoples having poor socio-economic, education and health (including mental health) status.

Viable FSN approaches need to enable and support community-based traditional knowledge systems and innovations of indigenous peoples and others who are marginalized or negatively affected by the predominant food system. Indigenous peoples' agro-ecological knowledge and practices are valuable in supporting resilience to change, including climate change, and in monitoring livestock diseases or invasive pests that can damage biodiversity and fragile ecosystems.

3.3.4 Human and animal health challenges

Poor animal health: A meta-analysis by FAO in Africa found pastoralist systems had the highest levels of livestock mortality (Otte and Chilonda, 2002). Livestock are also vulnerable to extreme and recurring weather events characteristic of drylands, such as droughts, winter storms and floods. For example, in Mongolia, the 2010 *dzud* (severe winter) was one of the worst ever, resulting in the death of approximately 8.5 million livestock or 20 percent of the 2009 national herd (Rao *et al.*, 2015).

Risks of zoonotic diseases: Because of their close contact with livestock and poor access to health services, pastoralists are at high risk of some zoonotic diseases. For almost all nomadic populations, three zoonoses present a persistent problem: echinococcosis, brucellosis and rabies (Zinsstag *et al.*, 2006).

Box 9 Indigenous peoples and livestock

The UN-system has no formal definition of indigenous peoples but instead works with a series of typical characteristics that include: self-identification as indigenous peoples; historical continuity with pre-colonial and/or pre-settler societies; a strong link to territories and surrounding natural resources; distinct social, economic or political systems; distinct language, culture and beliefs; form non-dominant groups of society; and, are resolved to maintain and reproduce their ancestral environments and systems as distinctive peoples and communities (UN Permanent Forum on Indigenous Issues).[31]

There are around 400 million indigenous peoples in 70 countries, mostly in Asia. Many, though not all, pastoralists consider themselves to be indigenous peoples. Although indigenous peoples account for less than 5 percent of the global population, they comprise about 15 percent of all the poor people in the world and one-third of the rural extreme poor.[32]

[31] See: http://www.un.org/esa/socdev/unpfii/documents/5session_factsheet1.pdf

[32] See: http://www.ifad.org/pub/factsheet/ip/e.pdf

3.4 Key challenges in commercial grazing systems

Beyond the cross-cutting challenges identified above, commercial grazing systems are also vulnerable to some of the same challenges as pastoral systems, including conflicts over resources (particularly land and water).

Natural grassland degradation: The extent of rangelands has changed over time due to the conversion of forested land into grasslands, the conversion of rangeland into cropland, and the replacement of abandoned rangeland with forests (Box 10). Rangeland biodiversity has been reduced by too intensive use for livestock production and the conversion of rangeland into cropland, a situation that is predicted to continue for the foreseeable future (Alkemade *et al., 2013*). Recent assessments predict little future increase in pastureland (Bruinsma, 2003; MEA, 2005). Most land-use models show a minor increase (10 percent or less) in grazing land needed by 2050 (Smith *et al.,* 2010). Deforestation as a result of ranching is a common occurrence in Central and South America (Wassenaar *et al.,* 2006). However, assessing and managing grasslands are complicated by the absence of an international mechanism or organization in charge of their assessment and of reporting on their state, unlike some other biomes (e.g. forests by FAO, wetlands by the Ramsar Convention).

Conflict over land and resources: Conflicts over land and forest resources between large capital enterprises and cattle ranchers have threatened the viability of smallholder agriculture (Guedes *et al.,* 2012) and the livelihoods and cultures of indigenous peoples. This can lead to rural households and rural or indigenous community members being displaced and migrating to cities or to more marginal lands. Inadequate access to land by the poor and insecure land tenure are factors behind rural poverty, violence, human rights abuses and exploitation of rural workers in conditions of servitude (USAID, 2013).

Poor worker conditions: In some countries, particularly in Latin America and southern Africa, workers have lost security as a result of the expansion, encroachment and concentration of large farms, sometimes violating land rights and deepening inequalities. Moreover, employment opportunities and working conditions for landless labourers, including indigenous people in some countries, are often poor and insecure.

Technical inefficiencies: In tropical areas the current methods of livestock production are often inefficient due to poor management, soil quality and high temperatures with limited shade for animals.

Box 10 The challenge of degradation, biodiversity loss and soil erosion on grassland systems in the Southern Cone of America

Historically, natural pastures have been considered as low productive extensive systems.

Natural grasslands are under pressure by demand driven by commercial seed enterprises for land to use for sown pastures (sometimes with foreign species). The dominant research interests of national research institutions also tend to focus on replacing natural grassland systems with what are considered to be more productive crops. The *cerrado* vegetation in Brazil and the Pampa (Argentina) are two examples of natural grasslands that are being converted.

In Brazil, from the 14.1 million ha with natural grasslands in 1970, only 10.5 million ha survived in 1996 (IBGE, 1996). Current estimates place the remaining natural vegetation cover at around 34 percent of the original cover, so natural grasslands now comprise less than 6 million ha (Hasenack *et al.*, 2007). Bilenca and Miñarro (2004) indicated that natural grasslands are also decreasing in Rio Grande do Sul (Brasil), in Pampas (Argentina) and in Uruguay, at rates of 11.9, 3.6 and 7.7 percent, respectively. Considering the census data from 1996 to 2006, the average reduction has reached 440 000 ha per year (Nabinger *et al.*, 2009).

Source: adapted from Carvalho *et al.*, 2008; 2011

3.5 Key challenges in intensive livestock systems

Intensive livestock systems face many sustainability challenges. These challenges are often related to the fact that farmers and other actors in the agri-food chain do not fully take into account environmental and social externalities (costs or benefits). Nor are the externalities reflected in consumer prices. The extent of the negative externalities has sometimes pushed production and consumption into unsustainable patterns.

3.5.1 Environmental challenges resulting from intensification

Water, soil and air pollution: The concentration of farming and intensive livestock production results in high levels of air pollution around the farms, high water use, extensive water pollution and the emergence of green algae in watercourses and beaches (e.g. Matson *et al.,* 1997). These negative impacts on the environment threaten future food and nutrition security (Tilman *et al.*, 2002) and the long-term resilience of intensive systems. The problem is especially significant in areas where intensive farms are concentrated. Some of the major problems associated with water pollution include: eutrophication of surface water; leaching of nitrates and pathogens; release of pharmaceuticals including antimicrobials and anabolic steroids; build-ups of excess nutrients and heavy metals; and the degradation of rivers, lakes, coral reefs and coastal areas (FAO, 2006b).

In developing countries, while the majority of livestock farms is comprised of small-scale integrated farms and low-input extensive systems that do not pollute very much, intensive farms clustered around major urban centres have experienced rapid growth in the recent decades. Many of these are located near lakes, rivers or coasts. Large concentrations of animals and animal waste close to densely populated areas and far from crop fields (where slurry could be used) create considerable environmental problems. Waste is also a problem elsewhere in the livestock production chain, in livestock feed processing plants, agri-chemical plants, tanneries, slaughterhouses, livestock processing plants and wet markets**.**

Water pollution is also associated with the cultivation of feed for livestock (including crop residues and different by-products used as animal feeds), particularly in mono-cropping systems. Effects may be distant from the source of the pollution, as is the case with nitrogen leaching to surface waters from soy and maize farms in the Mississippi River Basin, which is the primary cause of hypoxia in the Gulf of Mexico surface water some 1500 miles down river (Blesh and Drinkwater, 2013).

Concentrated animal feeding operations (CAFOs) create concentrated (point source) pollution.[33] These are often located in rural areas and they typically have relatively strong systems for managing and storing waste, but they still experience problems. For example, in August 2005 a lagoon collapsed at a western New York dairy, sending 3 million gallons of waste into the Black River. As many as 250 000 fish were killed, and residents of Watertown had to suspend their use of the river as a water supply and recreation area (Food and Water Watch, 2007).

Land-use changes: FAO (2012a) estimates that between 2005/2007 and 2050, arable land could increase by 4 percent (net increase of about 70 million ha, comprised of an increase of almost 110 million ha in the developing countries and adecrease of nearly 40 million ha in the developed countries). But this projection does not take into account the need for new arable land to compensate for land degradation. According to other projections, cropland could expand by 5–20 percent till 2050, mainly in Africa and Latin America (Byerlee *et al.,* 2014). Much of the increased crop output over that period will be for livestock feed (Chapter 2). Lal *et al.* (2012) estimate that 20 percent of the world's native grasslands have been converted to cultivated crops and almost 80 percent of the South America *cerrado* has been converted to cropland or urbanized (White *et al.*, 2000).

Loss of genetic diversity: Intensive livestock production systems reduce the available genetic diversity of livestock. FAO (2007) highlights the relationship between the rapid spread of intensive livestock production and the decline of genetic diversity in livestock production systems. In the face of climate change and unpredictable changes in agricultural conditions, the loss of diversity curtails the opportunities for adaptation.

[33] The US Environmental Protection Agency (US-EPA) defines a CAFO as an animal feeding facility that houses more than 1 000 animal units (AU), has 300 to 1 000 AU but meets certain conditions, or is designated a CAFO by the state (US-EPA, 2005).

3.5.2 Health impacts of intensive systems

Antibiotic use in agriculture, mainly in intensive systems, is a major contributor to the problem of antimicrobial resistance. Antimicrobial use in agriculture exceeds use in human medicine and is growing rapidly, raising concerns on the possible impacts of agricultural antimicrobial use on human and animal health (Grace, 2015; Landers *et al.,* 2012). Demand for antibiotics for livestock is growing especially rapidly in the emerging economies of Brazil, India and China. China's livestock industry alone could soon find itself consuming almost one-third of the world's available antibiotics (van Boeckel *et al.*, 2015). Most antimicrobials are often used in intensive livestock production for growth promotion rather than the treatment of disease, while aquaculture is also an important user in some places (especially in Southeast Asia and Chile). There is very little information on the use of antimicrobials in livestock in developing countries and there are important differences among developed countries: some have markedly high amounts of antimicrobial used per animal (for instance Italy, Cyprus, United States of America) while others use very little (for instance Norway, Iceland, Sweden) (Grace, 2015).

Antibiotics, whether for human or animal use, end up in the environment and in the food system. Resistant pathogens can be found in animals, animal food products and the environment. Developing countries in particular lack the surveillance systems that would generate reliable national data on the level of antimicrobial residues or resistant pathogens in animals and their products. While it has been shown that agricultural use of antimicrobials has led to antimicrobial resistant infections in humans, the evidence from the literature is insufficient to draw firm conclusions on the extent of the contribution (Grace, 2015).

CAFOs: Adverse health effects related to exposure to contaminants among CAFO workers have been well-documented; the impact on the health of residents in nearby communities is less well documented but neighbouring residents appear to be at increased risk of developing neuro-behavioural symptoms and respiratory illnesses, including asthma (Greger and Koneswaran, 2010).

3.5.3 Social challenges in intensive systems

Rural abandonment: The social benefits of agriculture can be eroded as production becomes more concentrated and intensive. Intensive agricultural systems are associated with negative effects on employment, wealth distribution, ancillary economic activity in rural areas, service provision in rural areas (such as schools and health facilities), and the maintenance of landscapes and recreational spaces. In the United States of America, a review of studies over the past 50 years found industrialized agriculture resulted in lower relative incomes for farm workers who live in the local community and greater income inequality and poverty. Rural town "Main Street" also suffers as retail trade diminishes and stores close down (Pew Commission on Industrial Farm Animal Production, 2008). Faced with the trends of rural abandonment, the EU Common Agricultural Policy has made the maintenance of viable rural communities one of its three strategic aims.

Unsatisfactory working conditions: Concentration and the intensification of agricultural production change the nature of work. Fewer people are employed in modernized farming systems (such as for milking). Working conditions do not necessarily improve with the industrialization of agriculture, however, and they are often unsatisfactory. The social, political and economic status of workers and their relative autonomy is often less than it is in traditional farming systems. This challenge can be partially offset by stronger enforcement of workers' rights and protections, as well as the creation of opportunities for displaced agricultural workers to find decent work outside agriculture. There are also concerns around contract farming, which, when poorly regulated, can increase the risks and reduce the revenues for the contract farmers (Kirsten, 2009).

Low wages: Around half a billion women and men are employed as agricultural workers. The share of women waged agricultural workers has been rising in all regions, accounting for 20–30 percent of total agricultural wage employment (Hurst, 2007). Especially in developing countries, a large part of wageworkers are employed on a seasonal or casual basis: they do not receive any employment benefits and have long periods (often one-third of a year) of joblessness. Wages are often relatively low and working conditions are unsafe.

Migrant labour (temporary workers who are not settled permanently in a population): In many countries, both developed and developing, migrant workers are common among agricultural workers, including migrants who lack legal status. This makes the sector especially vulnerable to abuse, including poor working conditions, unfair wages, and limited access to social services. In some regions such as California, the proportion of migrant agricultural workers is close to 90 percent. In the Republic of Korea, the number of migrant workers in the livestock agro-industry is higher than the numbers found in construction or the fisheries sector. Migrant agricultural labour has for long been associated with poor working conditions (Svensson *et al.*, 2013).

In the United States, the share of hired crop farmworkers who were born in the United States of America or Puerto Rico fell from about 40 percent in 1989–91 to a low of about 18 percent in 1998-2000, while the share born in Mexico rose from 54 percent to 79 percent over the same period. Since 2000, the United States of America and Puerto Rican share has climbed again to about 29 percent while the Mexican share has fallen to about 68 percent. The share from Central America and other regions has never exceeded 6 percent.[34]

Occupational hazards: Participation in livestock value chains is associated with a relatively high level of occupational health hazards, especially traumatic injuries and infections. Farm machinery, livestock-related injuries and falls are reported to be the main causes of occupational injuries on farms (Douphrate *et al.*, 2009). For example, during a five-year period, 20 percent of Finnish farmers suffered injuries and 2 percent infections severe enough to report to a doctor (Karttunen and Rautiainen, 2013). Slaughterhouse and packing plant workers are exposed to high levels of occupational risk, suffering elevated rates of injury, with a high prevalence of mental disorders (Hutz *et al.*, 2013). In the United Kingdom in 2014, food manufacture had a rate of reported injury more than twice that of manufacturing as a whole (HSE, 2014).

3.5.4 Economic challenges in intensive systems

Market concentration: Competition and downward pressure on producer prices can lead to a reduction in farm-sourced incomes and an increase in debt, a situation often encountered in the industrial livestock sector (Zijlstra *et al.*, 2012). As a consequence, in the absence of support or diversification, larger farms tend to survive, while smaller farms cannot structurally compete in domestic or international markets, leading to further concentration in the sector. This tendency is similar to that experienced in the industrial and manufacturing sectors, with implications that highlight the potential conflict between increasing productive efficiency, low prices for consumers, the difficulty to provide decent income, employment and livelihood, and the devitalization and depopulation in rural areas, as well as the externalization of significant environmental costs.

Distorted price signals: Price signals do not always guide optimal production and investment decisions in intensive livestock systems, and thus do not lead to positive FSN outcomes. Price support policies, which are common for many livestock commodities across both developed and developing countries, distort price signals to producers and consumers. Farmers compete for remunerative farm-gate prices while consumers seek low prices and access to quality food. Food processors, traders and retailers hope to balance those opposing interests with the objective of maximizing profit, which can translate either in low or high pricing strategies, depending on the context and the relative market power of the actors. In the food supply chain, processors and retailers often have sufficient market power to drive prices down, which can have positive effects on access to food but at the same time can undermine the profitability of livestock enterprises, and set up vicious circles of competition among livestock farmers, who have relatively little bargaining power in the supply chain.

Inequitable distribution of value added: The concentration of excessive power by large corporations in the agri-food chain over livestock suppliers and consumers gives rise to the concern that the distribution of value added within the food supply chain is unfair (HLPE, 2013a). There is considerable debate on what mechanisms might address these concerns in the organization of food systems and food chains. Proposals include establishing regulatory and anti-trust frameworks, encouraging collective organization of livestock producers, and promoting greater transparency and information, so that the value added generated along the food chain can fairly remunerate labour, farmers and rural areas (HLPE, 2013a).

[34] See: http://www.ers.usda.gov/topics/farm-economy/farm-labor/background.aspx (accessed June 2016).

Feed and energy dependence: Specialized, intensive livestock farming, in particular intensive pig, poultry and dairy production, are dependent on feedstuffs purchased from specialized crop farms, often via imports. This can trigger remote environmental impacts where feed is produced, such as deforestation, soil and water degradation, and loss of biodiversity. It also exposes livestock operations to international grain trade and energy price risks and volatility. The volatility of prices of feed and energy can affect the profitability of livestock operations, hindering optimal investment decisions.

3.6 Concluding comments

There is a broad consensus that while the livestock sector generates very many health, livelihood, economic and environmental benefits, it also contributes to many nutrition, health, social and environmental challenges.

This chapter has presented some of the challenges that the livestock sector has to address. These challenges can be either global or specific to farming systems, and can cover different dimensions of sustainability (see Table 2).

Progress towards SAD for FSN will require the elaboration of comprehensive pathways at different levels to address these challenges simultaneously, while recognizing the important differences among farming systems so as to reduce unintended consequences. Chapter 4 proposes a common approach to elaborate those pathways, and then suggests possible pathways for each of the four livestock systems in turn.

Table 2 Priority challenges to attain SAD for FSN in different livestock systems

System	Scale and geography	Key health and One-Health challenges	Key social challenges	Key environmental challenges	Key economic challenges
Smallholder mixed farming	Around 600 million persons mainly in south and south east Asia, and Africa Around 30 million small farmers in developed countries	Endemic animal diseases Zoonotic diseases Food-borne diseases Contribution to NCD	***Farm fragmentation*** ***Lack of rights, entitlements, tenure*** Ageing workforce and exodus of young people Rural abandonment	Climate change; ***Land degradation;*** Loss of biodiversity	***Low economies of scale*** ***Exclusion from high-value markets and service*** ***Low productivity and high yield gaps***
Pastoral	Nearly 200 million pastoralists	Endemic animal diseases Zoonotic diseases	***Marginalization: lack of rights, entitlements, tenure*** ***Conflict over land and water*** ***Inequitable norms & institutions***	***Climate Change*** ***Extreme events (droughts, floods)*** ***Water scarcity***	***Lack of access to markets and services*** Low productivity
Commercial grazing	Hundreds of thousands of farmers in Latin America, parts of United States of America, Australia, and southern Africa	Emerging diseases Contribution to NCD	***Displacement of indigenous peoples and local communities*** ***Vulnerable groups*** ***Poor work conditions*** ***Rural abandonment***	***Deforestation;*** ***Contribution to climate change*** ***Land conversion***	Exposure to world price volatility International market access Low economies of scale
Intensive	Around 2 million intensive dairy farmers in United States of America, Brazil, Europe, New Zealand Several million intensive pig, poultry and beef/sheep feedlot farms, mainly in BRICs and high-income countries	***Emerging diseases*** ***Foodborne diseases*** ***Contribution to antimicrobial resistance and NCD***	***Poor work conditions*** ***Poor animal welfare***	***Air, land, water pollution*** High water use ***Contribution to climate change***	Exposure to world price volatility ***Price squeeze from input suppliers, processors and retailers***

Bold italics indicates highest priority; NCD = Non Communicable Diseases; BRIC = Brazil, Russian Federation, India, China

4 PATHWAYS TOWARDS SAD FOCUSING ON LIVESTOCK

Drawing on the trends in agriculture and the challenges for SAD identified in the previous chapters, with regard to livestock systems, reviewed above, this final chapter is focused on action: what should states, intergovernmental organizations (IGOs), the private sector, civil society organizations and other stakeholders in the food systems do to improve the sustainability of agricultural production to ensure food security and nutrition for all?

The chapter suggests a common, three-tier approach to elaborate pathways towards SAD for FSN: first, looking at the operational principles for pathways and the tools for solutions on the ground; second, looking at the enabling environment; and third looking at farm practices of the different livestock farming systems already identified, namely: smallholder mixed farming, pastoral, commercial grazing and intensive livestock systems.

Pathways to SAD need to address multiple challenges simultaneously, taking the benefits that ASF has to offer, respecting the diverse cultures in which livestock systems play a central role, and yet acknowledging the unsustainability of important aspects of modern livestock systems and thus the need for change. The pathways are illustrated throughout the chapter with selected case studies.

4.1 Common approach to elaborate pathways

Pathways combine technical actions, investments and enabling policy instruments. They are context, scale-and time-period specific. They are pursued and supported by various actors at different scales, all undertaken with the aim of advancing the goal of SAD for FSN.

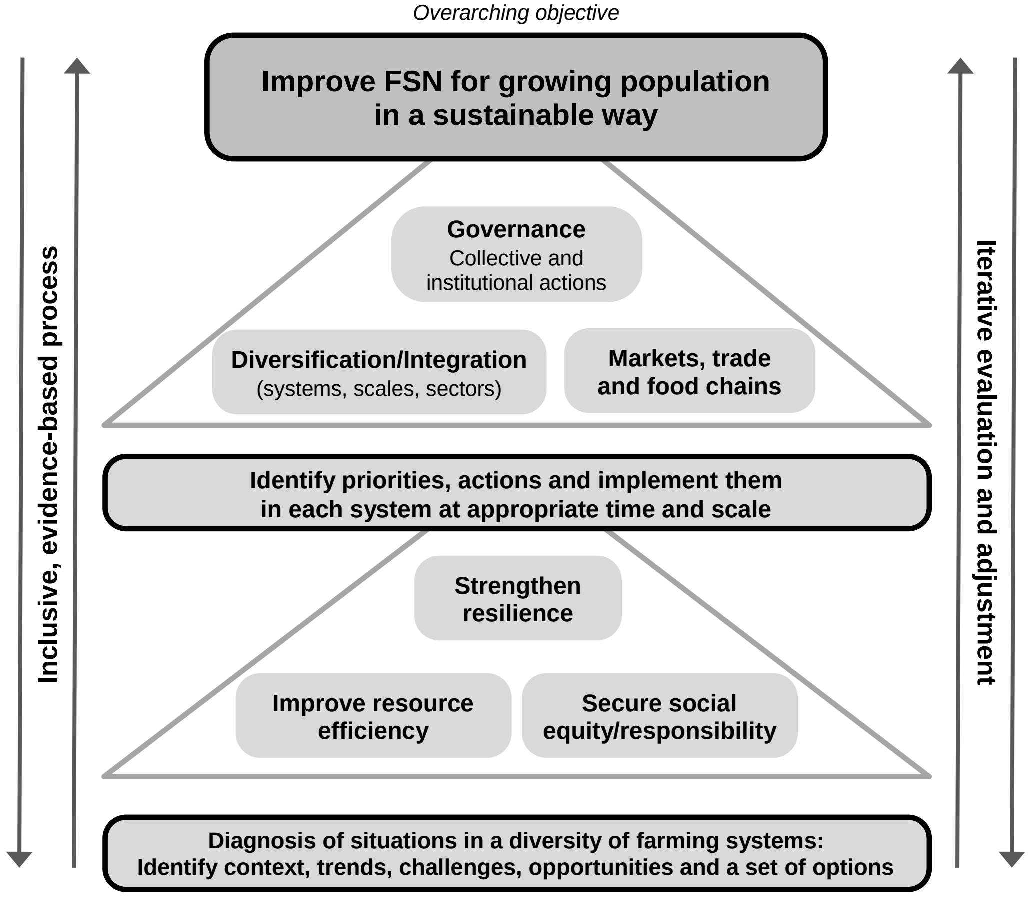
However, the common approach in eight steps described below (and illustrated in Figure 8) can frame processes to identify these pathways and design national SAD strategies:

Common approach to elaborate pathways towards SAD for FSN

1. Describe the **current situation** of the specific farming system in a specific context (for example at country level).
2. Agree on the set of **long-term FSN goals** and measurable targets at national level, in line with the SDGs.
3. Identify the **challenges** to be addressed to move towards SAD for FSN.
4. Define a set of operational **priorities** among these challenges**.**
5. Identify the **possible set of solutions** available that can be mobilized by stakeholders, both in specific farming systems and those that are cross-cutting.
6. Define the **specific responses/solutions** and technical packages that are best suited to address the priorities of the given context. Acknowledging the scope for both synergies and trade-offs, these responses should address three criteria: **improve resource efficiency, strengthen resilience, and secure social equity and responsibility.**
7. Set in place an **appropriate environment for implementation, including policies, laws** and international-level arrangements for agriculture, food security and trade**, to complement and enable the** choice of priority actions at the farm level and along the food chain. This environment comprises choices to be made in three main domains: (i) governance options including the institutional architecture at the appropriate level;[35] (ii) degree of diversification and integration of systems from the farm to the global level in terms of co-existence of different farm types within the overall food system; and (iii) the role and orientation of markets and trade, including preferences for where investment should be directed.
8. Set in place methods to **monitor and evaluate** progress to reinforce positive reactions and responses, to allow the identification of constraints that emerge over time, and to allow for dynamic and iterative adjustments if progress falls short of moving towards the desired goal.

[35] An OECD/FAO/UNCDF report (2016) takes a territorial/regional perspective to approach FSN policy.

Figure 8 Pathways and responses for SAD towards FSN



Pathways to SAD are affected by changes at the farm level, and by changes outside the agriculture sector, such as investment in transportation infrastructure and the development of new technologies off-farm, as well as by a wide range of policies and regulations whether targeted to agriculture or to all sectors of the economy and society.

The imperative of achieving food security and better nutrition is widely accepted and reinforced by the adoption of the SDGs in 2015. Nonetheless, the multiplicity of entry points, perspectives and objectives for the realization of these complex goals has led to the coexistence of differing narratives and evaluations of the state of existing food systems and, most importantly, different recommendations on the directions required to improve sustainability and the policy instruments needed to achieve FSN.

One of the most contested debates over pathways to SAD is that between the “market orientation” versus the “food sovereignty” narratives.

The market-oriented narrative focuses strongly on economic growth and income generation as the basis for food security, relying on economic access to food through purchasing power and on open and deregulated domestic and international agricultural markets to ensure efficiency and competition. In this narrative, market incentives drive the development of productivity-enhancing technologies. Over time, the narrative has progressively adapted methodologies to account for the environmental impacts of agricultural production (“internalizing the externalities”) with the objective of “sustainable intensification”. From a market-oriented perspective, it includes the promotion of market-based instruments such as pollution charges, remuneration for ecosystem provision, better pricing of scarce natural resources, legal frameworks to protect private ownership and tenure of natural resources (especially land and water), environmental legislation, and targeted interventions to address social concerns associated with agricultural development.

In contrast, the "food sovereignty" narrative focuses on the "right of peoples to healthy and culturally appropriate food produced through ecologically sound and sustainable methods, and their right to define their own food and agriculture systems" (Nyéléni Declaration, 2007). This narrative emphasizes the need for a "practical method for building food sovereignty at farm scale" (Shattuck *et al.*, 2015). Pathways to food sovereignty argue for more transformative changes in the structure, production methods and power relationships embedded in industrialized food systems, and promote "localized", just and responsible food production, distribution and consumption in rural and urban contexts (Desmarais *et al*., 2010; Pimbert, 2009; Desmarais *et al*., 2010).

The debate between market-oriented and food sovereignty advocates reveals starkly different perspectives on pathways to sustainable development (and is just one illustration of the differences that exist). This report acknowledges the importance of these differences, and the many "shades of grey" that exist among the narratives as well. It seeks to describe pathways for actors in food systems that acknowledge that decisions about public policies, technologies, private investment and regulation are embedded in assumptions about how food systems work and how they are evolving in the face of different pressures, including ecological, cultural and economic developments. There are rarely perfect solutions but actors in the food systems should make decisions based on an enhanced understanding of the demands of SAD and the obligation to realize FSN for all.

4.2 Operational principles for solutions towards SAD

Solution-oriented pathways towards SAD can be defined according to their compatibility with three broad principles: improve resource efficiency, strengthen resilience and secure social equity/responsibility. The reasons for choosing these criteria is that they seem better suited to concretely outline development options than using the conventional three dimensions of sustainability. They have the potential to better identify win–wins (and trade-offs) in terms of those solutions contributing to positive economic, social and environmental outcomes.

This section lists the main sets of responses with regard to the three criteria of resource efficiency, resilience and social equity/responsibility. In some cases, a solution pertaining to one criterion, such as resource efficiency, can also improve resilience and social equity/responsibility. For instance, there is some evidence that efficiency and resilience to climate change can go together, according to case studies reported in a FAO–OECD workshop (FAO/OECD, 2012).

A particular focus in recent years has been an examination of the various approaches to improve agricultural resource efficiency and to strengthen resilience to climate change, animal diseases and price volatility that, in turn, can facilitate investment and productive efficiency. This synergy is further developed in the next section. This reinforces the importance of acknowledging the interlinkages among the three criteria and the need to adopt an integrated approach.

4.2.1 Improve resource efficiency

Many of the challenges identified in Chapter 3 – economic, environmental and social – call for a better use of resources, to increase economic returns, reduce negative environmental impacts and improve the social situation of smallholders, pastoralists and family farmers who have a limited resource base or who face exclusion for social, cultural or political reasons.

With respect to *resource efficiency*, the potential exists to narrow the yield gap between the highest and lowest agricultural performers in a region and thus increase agricultural production, including livestock and the production of animal feed. This can be achieved through the transfer and adoption of existing practices and technologies as well as the development of new technologies and increasing the participation of stakeholders. Narrowing the yield gap has the potential to improve diets, nutritional status and the health of poor and vulnerable people, as well as to enhance their economic well-being.

Three questions then arise: first, which ways and means are available for farmers to adopt appropriate technologies and approaches to improving yields and ensuring decent livelihoods within their specific contexts; second, how do the ways and means affect (positively or negatively) livestock's environmental footprint (Revell, 2015); and third, which policy measures and actions can most effectively reduce those environmental externalities? A recent OECD report (2016) examined the role of policy in improving resource efficiency.

Narrow yield gaps

Sumberg (2012) notes that several major analytical studies, including the InterAcademy Council's 2004 report, have drawn on yield-gap analysis as a framing device for agricultural policy prescriptions. Focusing on yield gaps is seen as a way to make lasting agricultural productivity improvements in parts of the world where it could make the biggest difference to livelihoods and FSN (Sumberg, 2012; InterAcademy Council, 2004; IAASTD, 2009; Foresight, 2011). Sumberg outlines a range of methodologies used by analysts to estimate the gap between potential and actual crop yield and explores the relative importance of factors and inputs that explain the potential and actual differences.

Box 11 Integrated sustainable silvo-pastoral systems in Colombia

In Colombia, arable lands are estimated to cover 54 060 km^2, and cattle occupy 80 percent of the agricultural area. Extensive grazing has caused soil degradation and deforestation and, in dry areas, has hastened desertification. Moreover, with an equivalent 0.62 livestock unit per hectare (Vera, 2006), cattle ranching has traditionally relied on extensive systems, with few animals per hectare raised on grass. While it has a range of benefits, this type of cattle ranching provides limited feed quality. It also often suffers from challenges during seasonal extremes of temperature and drought, due to limited shade, poor soil quality and access to water.

Silvo-pastoral systems (SPS) have been proposed to increase the efficiency of cattle ranching while reducing its environmental burdens. Intensive silvo-pastoral systems (iSPS) are a type of SPS that combine high-density cultivation of fodder shrubs (4 000 to 40 000 plants per ha) with: (i) improved tropical grasses; and (ii) trees species or palms at densities of 100–600 trees per ha. These systems are managed under rotational grazing with occupation periods of 12 to 24 hours and 40 to 50 day resting periods, including *ad libitum* provision of water in each paddock (Calle *et al*., 2012). iSPS have the potential to deliver much more feed of higher quality from the land. The additional plant matter, plus root density, and biodegradable material can increase soil quality and water retention, as well as increasing carbon content in the soil (Chará *et al.,* 2015). By using animal breeds well adapted to tropical environments, the iSPS have the potential to achieve high levels of production from local feed sources in pasture-based environments. This maintains good health, natural behaviour and ease of animal management (WAP, Agri-benchmark, CIPAV FEDEGAN, 2014). Several studies in Latin America have demonstrated scientifically evidenced benefits of iSPS for productivity, soil quality, GHG mitigation and animal welfare, while boosting rural economies and livelihoods.

A study carried out in three pioneer farms in establishing iSPS showed that both feed production and profit increased when the systems were established: *La Luisa*, a beef finishing farm in the Cesar valley with four groups of beef animals and a total of 500 cattle on the farm; *Petequí*, a dairy farm in the Cauca valley with around 70 crossbred dairy animals; and *El Hatico*, a dairy farm in the Cauca valley, rearing Lucerna breed animals. The herd is divided into five groups ranging from pre-parturition cows, high-, medium- and low-lactation cows.

The results of implemented measures showed that iSPS are:

i. More productive and profitable than extensive cattle ranching systems. Their success is based on good management, extension and access to capital that builds farmers' long-term capacity to deliver efficient and increasingly productive beef and dairy production.

ii. Productivity that goes hand-in-hand with animal welfare.

iii. Responsible investment in sustainable environmental management, with potential climate mitigation benefits.

The study provided evidence for the ability of iSPS to create "triple-win" solutions for sustainable livestock production: productivity and profitability gains; environmental improvements; and animal welfare benefits.

The knowledge developed in these farms is used by the project Colombia Mainstreaming Biodiversity into Sustainable Cattle Ranching led by FEDEGAN-FNG in partnership with CIPAV research institute, The Nature Conservancy and *Fondo Acción*. The project is administered by the World Bank with funding from the Global Environment Facility and the United Kingdom's Department of Energy and Climate Change (DECC) and aims at establishing 10 000 ha of iSPS and 40 000 more of other SPS in the country.

As iSPS are management-intensive, capacity building via extension and advisory services is a key component of successful delivery. Targeted investment early in establishment of the silvo-pastoral system, and an effective capacity building programme, tailoring knowledge development to individual farmers' needs, can provide increased potential for success.

The benefits for productivity and profitability from such investment are clear and this is an area where international and local policy mechanisms, donors and governments can play a crucial role.

Box 12 Improved goat production in Kenya

In Meru district, Kenya, Farm Africa developed a model to improve smallholder goat enterprises (mostly managed by women) and assist them to develop local and regional goat milk markets. The model is suitable for mixed-farming smallholders with up to 2 ha, at least 500 mm/annum rainfall and that grow a variety of crops (Farm Africa, 2007). It includes the establishment of intensive dairy goat enterprises with housed goats, on-farm fodder development and conservation, crossbreeding of local goats with an improver dairy breed, and mapping out market opportunities and developing linkages to viable ones. In the model, farmer groups, community-based private providers and local NGOs manage all the necessary support services and inputs. For example, replacement bucks are bred locally at group-managed breeding units. In the scaled up intervention, 120 000 goat milk enterprises were targeted for assistance over ten years. The intervention has increased mean lactation length from 70 days in local goats to 193 days in crossbred goats, and milk yields from an average of 14 litres to 536 litres per annum. The intervention would increase net annual income from USD55 to USD424 per family, improve child, maternal and invalid persons' milk intake and hence address the widespread vitamin A deficiency among the poorest families.

Promote sustainable intensification

Building on the notion of yield gaps and the scope for sustainable productivity growth, the concept of "sustainable intensification" has gained traction as an approach to tackling the conflicting challenges of producing more food to meet expected demand, while protecting the environment from the consequences of greater agricultural production in the face of increasing competition for natural resources. The broad logic of the approach is that if more food is to be produced to meet burgeoning demand in the face of evident stresses and constraints in the natural asset base, productivity has to be lifted while improving environmental performance. Boxes 11 and 12 show examples of intensification in silvo-pastoral systems in Colombia and in goat production in Kenya.

"Sustainable intensification" has been criticized. One major area of concern is the extent to which this approach fails to adequately address the need to reverse biodiversity loss. This concern is an aspect of the debate often referred to as "land sharing or land sparing". Briefly, land sharing and land sparing sit at either end of a continuum. According to Acton (2014), "a land sparing system involves large, separate areas of sustainably intensified agriculture and wilderness, whereas land sharing involves a patchwork of low-intensity agriculture incorporating natural features such as ponds and hedgerows, rather than keeping agriculture and wilderness separate". According to some experts, "sustainable intensification" is defined too weakly and narrowly, and lacks engagement with the core principle of sustainability, including equitable distribution and individual empowerment (Loos *et al.,* 2014). It is also criticized for its ambiguity over the role of technologies that rely on genetic modification, its lack of focus on social and community cohesion and equity objectives, including the importance of a just allocation of resources, and the extent to which it supports improved animal care. Petersen and Snapp (2015) consider that differences have arisen over the merits of the sustainable intensification concept in part because of differences about the extent to which a profound shift is needed in agricultural production practices. For some, the concept proposes only marginal changes to a system that continues to increase food production without looking at other aspects of the FSN challenge. For others, "sustainable intensification" calls for a more dramatic change to agricultural systems that are responsible for causing significant environmental damage and that leave billions of people mal- or undernourished.

Box 13 Embracing sustainable intensification

Petersen and Snapp (2015) note this concept has been embraced especially in international agricultural development by the work of FAO, the CGIAR system, the United Kingdom's Royal Society, government agencies such as USAID and non-government actors including the Bill and Melinda Gates Foundation. "Sustainable intensification" is also being mainstreamed into thinking in the EU in the context of agricultural policy reform (European Commission, 2015). A recent RISE report provided one definition of sustainable intensification – only focusing on land – as a "means simultaneously improving the productivity and environmental management of agricultural land" (RISE Foundation, 2014). In a practical sense, therefore, the concept is guiding a significant body of research on agricultural development and food security and has been adopted in the design of programme interventions in many countries, including in the developed world.

Godfray (2015) argues that sustainable intensification is essentially “sustainable increases in productivity from existing agricultural land in response to price signals”. He observes that the word “intensification” is off-putting for some who associate it intrinsically with high-input industrial farming.

Box 13 provides examples of organizations that have embraced sustainable intensification. Their support is based on their understanding that encouraging higher productivity is a powerful way to achieve and sustain higher living standards in the long run. Income transfers (such as social payments or production subsidies) do not build the economic foundation to support broadly-based increases in welfare over time; improved productivity does. Sustainable intensification was in fact initially inspired by the collaboration of academic researchers and smallholders in sub-Saharan Africa in the 1990s, who together sought to increase agricultural yields while improving social and environmental outcomes (Pretty, 2007).

Reduce environmental impacts, including GHG emissions

Improving efficiency of resource use will be essential to reduce environmental impacts, including GHG emissions.

The overall global environmental footprint of the livestock sector is set to increase with the expected increase in production to meet expected demand; this growth will increase the global footprint even if the intensity of resource use per unit of output decreases (Revell, 2015).

Mitigation of the livestock sector’s GHG emissions could be achieved by any one or more of the following: a reduction in production and consumption, an increase in productivity, a shift in the structure of production towards less emission-intensive livestock species, or technological innovation. Many technical options to reduce emissions exist, including: better management of feed (see below), energy conservation, careful use of grazing land and recycling of manure; no or minimum till cropping; better animal health; and improvements in genetics and animal husbandry practices. These emissions could be reduced by between 18 and 30 percent if all producers in a given system, region and climate, adopted appropriate versions of the practices now applied by the 10 to 25 percent of producers with the lowest emissions intensity in the same system (FAO*,* 2013a).

Carbon sequestration in soil and biomass (by restoring degraded soils, better adjusting stocking density and using legumes) also has an important potential for mitigating net emissions from the livestock sector (Henderson *et al.*, 2015; IPCC, 2014).

Improve animal feed efficiency

Feed is a key limiting factor and often the most expensive input in livestock production. In pre-industrial times, livestock keeping was mainly opportunistic, making use of resources unfit for direct human use, using grazing, crop residues and waste products. With growing affluence and the ability to produce crop surpluses, livestock production has become demand-driven, a process that is still evolving. In the context of growing resource scarcities, it can be argued that livestock need to revert to more resource-driven use, in particular as a converter of by-products and agro-industrial and food waste. With more standardization of these waste products, their use can be combined with modern additives, such as enzymes and synthetic amino acids.

In grassland systems, better management of rangeland and increased cut-and-carry and pasture resources, together with improved feed utilization of crop residues and other agricultural by-products, all have considerable underexploited potential to improve animal productivity, while also contributing to the resilience of agro-ecosystems and environmental sustainability (Smith *et al.,* 2013). Plant breeding technologies can be used to develop faster growing feed varieties as well as dual-purpose varieties with traits such as drought tolerance, pest resistance or tolerance, higher yields and increased nutritional value. A useful development, for example, would be in dual-purpose crops that produce both high grain yields and nutritionally rich residues for livestock.

Apply animal genetic improvement technologies

Technologies to improve management of genetic resources include artificial insemination (AI), which is widely used worldwide to introduce genetically superior male germplasm. Complementary technologies such as heat synchronization and semen sexing can improve the efficiency of AI but are mainly used in developed countries. Multiple ovulation and embryo transfer allow the production of multiple offspring from superior cows and is now a technique in commercial use. In addition, genetic markers can be used to breed livestock for important traits such as disease resistance, product quality and improved productivity. Whole genome sequencing allows the rapid identification and management of genetic defects that compromise health and welfare. It is possible to obtain targeted modifications of genes, using specific enzymes[36] in order to turn it off, turn it on and/or edit it, which paves the road for cost-effective options.

Genomic selection is revolutionary. It allows scientists to predict the genetic value of an animal at birth using DNA array analysis that contains several tens of thousands of genetic markers. It then allows increasing genetic progress by using bulls that are very young but that have undergone testing. The technology bypasses the need for progeny testing on offspring before selection and the renewal of females is improved since their genetic values are better known than having to rely on performance and pedigree.

Close nutrient cycles

According to Peyraud *et al.* (2014), "*the closing of nutrient cycles can be envisaged on various scales, from an individual farm or small agricultural region to the regional or national level. These possibilities need to be explored from an economic, technical and social point of view*".

Animal manure is an important source of plant nutrients in developing countries and in organic farming worldwide. Many smallholders in Africa and Asia rely on manure as their only source of fertilizer. The total amounts of nutrients (nitrogen [N], phosphorus [P] and potassium [K]) in livestock excreta are at least as large as the total amounts of N, P and K in chemical fertilizers used annually (Menzi *et al.,* 2010).

When suitably managed, the manure from intensive agricultural production can be a significant source of nutrients for crop and forage production. In Switzerland, for example, the contribution of livestock manure to total agricultural fertilizer use is about 60 percent for N, 70 percent for P and over 90 percent for K (Menzi *et al.,* 2010). However, poor manure management is a common problem and has serious negative effects on the environment. In many parts of the world, environmentally sound manure management is hindered by the treatment of manure as a waste rather than a nutrient and energy source and by the lack of environmental legislation and its enforcement. Improved environmental performance of intensive livestock production systems requires an integrated whole-farming systems approach, together with enforceable environmental legislation. Menzi *et al*. (2010), drawing from current trends, suggested that without a change in current practices, the projected increases in intensive livestock production would double the current environmental burden and contribute to large-scale ecosystem degradation.

In intensive livestock systems that rely heavily on concentrates, technological advances have the potential to improve the use of by-products, make available novel food sources (including insects, see Box 14), remove contaminants from feed (such as mycotoxins) and increase the nutritional values of feeds.

Reduce food losses and waste (FLW)

It is estimated that nearly one-third of food produced for human consumption is lost or wasted globally, representing 1.3 billion tonnes per year, with a lower proportion for meat and dairy products (FAO, 2011b). Governments, retailers and other actors in the food system are paying increased attention to reducing FLW to cut costs and improve the sustainability of food systems. A number of education campaigns aimed at consumers to reduce FLW in the household have also been launched.

Box 14 The contribution of insects

Insect rearing could be one of the ways to enhance food and feed security (FAO, 2013d). They grow and reproduce easily, have high feed conversion efficiency (since they are cold-blooded) and can be reared on bio-waste streams. One kg of insect biomass can be produced from on average 2 kg of feed biomass (Collavo *et al*., 2005). Although some studies have been conducted on evaluation of insects, insect larvae or insect meals as an ingredient in the diets of some animal species, this field is in infancy. The protein content of insects could range from 40 percent to 60 percent on a dry matter basis, with protein quality as good as muscle protein. These have been found to be good feed ingredients for poultry and pig diets. The studies have confirmed that palatability of these alternate feeds to animals is good and they can replace 25–100 percent of soymeal or fishmeal depending on the animal species.

Source: Makkar *et al.* (2014).

[36] Such as Cas9 (CRISPR associated protein 9), an endonuclease associated with Clustered Regularly Interspaced Palindromic Repeats (CRISPR).

It has been estimated that reducing the food waste rate by half by 2050 would provide one-quarter of the gap between anticipated food demand and projected supply (Lipinski *et al.*, 2013). The HLPE report on FLW in the context of sustainable food systems (HLPE, 2014a) analyses the impacts of FLW across different dimensions of sustainability and the main causes of FLW.

Attention to losses and waste in the livestock sector can make a useful contribution to sustainable development, including by ensuring a more efficient use of natural resources, mitigation of GHG emissions and reducing other environmental damages. It can improve outcomes for FSN. There is also the potential to capture FLW for feed (most smallholder mixed farms rely heavily on reusing as much of the nutrition and energy produced on-farm as possible, using animal manure for fertilizer and household and crop residues for feed).

However, it is important to avoid being too simplistic and promote an understanding of the likely effects of harnessing FLW for FSN: reducing FLW will have ripple effects in the food system, including reducing the demand for purchased food, which could put downward pressure on prices and incentives to produce and invest (Koester, 2015; Revell, 2015).

4.2.2 Strengthen resilience

Strengthening resilience to environmental, economic, financial and animal disease shocks can also improve resource efficiency.

Strengthen resilience through agro-ecological practices

Agro-ecological practices can contribute to strengthened resilience. Though variously defined, agro-ecological approaches are gaining traction among parts of the scientific community, as well as in some developing and developed countries, and in some international agencies, including FAO and UNEP. FAO hosted a series of regional conferences on agro-ecology following a two-day international symposium in Rome in September 2014. A recent report produced by IPES-Food (2016) calls for a necessary shift from "industrial agriculture" to "diversified agro-ecological systems". The worldwide association of peasant organizations, *La Via Campesina (LVC)*, has made agro-ecology a cornerstone of its advocacy and educational work.

Agro-ecology has been articulated as an interdisciplinary field of knowledge involving a set of concepts and principles oriented towards the design and management of sustainable ecosystems (Altieri, 1995). It takes a holistic approach and has become closely, though not systematically, linked to the food sovereignty and rights frameworks, emphasizing the fundamental role of ecosystems in maintaining sustainable agriculture in the long run as well as the importance of connecting rural communities to local food chains.

Agro-ecology starts from a strong critique of the negative consequences of industrial agriculture for the environment and human health, including the degradation of land, the loss of plant and animal species diversity, the increasing susceptibility of crops and animals to diseases, the damage caused by pesticides on soil, water and human health, the strong dependency of industrial food systems on fossil fuels and the loss of livelihoods associated with industrial agricultural systems (Wibbelman *et al.*, 2013). Agro-ecology is oriented towards the social and ecological management of agro-ecosystems based on the principles of sustainability, integrity, productivity, equity and stability (Conway, 1987; Marten, 1988). According to Gliessman (1997), the term agro-ecology arose in the 1930s, coined by researchers who sought to apply ecology to crop production methods. Subsequently, various researchers who sought to establish connections between ecology and agronomy picked up the term (Wezel and Soldat, 2009; Wezel *et al.,* 2009; Gliessman, 1997). Since the 1970s, a conceptual framework and methodological tools for agro-ecology have been developed, drawing on knowledge from farmers, pastoralists, and indigenous people in different environmental contexts (Altieri, 1987; Gliessman, 1997; Hetch, 2002).

Drawing on Altieri (1995) and Gliessman (2014), de Schutter (2010) describes agro-ecology as both a science and a set of practices. "Core principles of agro-ecology include recycling nutrients and energy on the farm, rather than introducing external inputs; integrating crops and livestock; diversifying species and genetic resources in agro-ecosystems over time and space; and focusing on interactions and productivity across the agricultural system rather than individual species. Agro-ecology is highly knowledge intensive, based on techniques that are not delivered top down but developed on the basis of farmers' knowledge and experimentation." According to Francis *et al.* (2003), agro-ecology encompasses "the integrated study of the ecology of the agro-food system as a whole, including their ecological, economic and social dimensions". The social and economic sustainability of agro-ecosystems also depends on the integration of concerns such as population density, gender dynamics, labour availability, human health, social organization, prices and markets, knowledge and technology.

Agro-ecology does not just introduce new substance to the practice of agriculture; it introduces new methodologies and a broad definition of knowledge as well. Agro-ecological research emphasizes the importance of the interfaces between disciplines and the integration of rapidly changing knowledge in many fields (Caron *et al.*, 2014). It is rooted in participatory approaches, and many agro-ecologists see the strengthening of local organizations and of farmer and local community control over the means and processes of production and the organization and dynamics of food systems at different scales as a core component of the science (Anderson *et al*., 2015).

From a scientific and technical perspective, agro-ecology applies ecological concepts and principles to farming systems (Tittonell, 2014), focusing on the interactions between plants, animals, humans and the environment, to foster SAD in order to ensure FSN for all, now and in the future. Today's more transformative visions of agro-ecology integrate transdisciplinary knowledge, farmers' practices and social movements while recognizing their mutual dependence (Anderson *et al.*, 2015; Nyéleni, 2015).

Developments of agro-ecology in selected countries are shown in Box 15.

The concept of agro-ecology invites an interaction among various forms of knowledge, through a transdisciplinary, participatory and action-oriented approach (Mendez *et al.,* 2015), that engages both scientists and practitioners, with special attention to traditional and local knowledge.

An important line of innovation in agricultural research concerns the application of systemic approaches to farming systems evaluation and management at different levels, in an effort to link agriculture, conservation and FSN. This broad category of research includes efforts related to: the conservation and management of biodiversity in agro-ecosystems; participatory plant and animal breeding applied to the development of agro-ecological systems; the ecological intensification of livestock systems; development and application of sustainability indicators and the development of approaches linking biodiversity and nutrition in the construction of local food systems.

Apply novel approaches to animal health

Animal health is a clear area where resilience and efficiency are linked. Technical interventions to improve animal health contribute to increasing productivity. A number of promising innovations exist. For example, technologies that make vaccines heat-stable eliminate the need for a cold storage chain, which improves delivery and increases the uptake of existing vaccines in countries where cold storage chains are expensive or non-existent. Multiple-dose vaccines are another innovation that reduces the cost and increases the protection offered by vaccines.

Intensive systems rely on vaccines to keep animals healthy when they are raised in high-density facilities such as CAFOs, where proximity and genetic similarity create a constant risk for widespread disease outbreaks. However, infectious diseases are still responsible for substantial losses as well as the contamination of livestock products with disease-bearing bacteria such as salmonella. New vaccines could further limit these costs and risks. Recombinant vaccines offer advantages over traditional vaccines in specificity, stability and safety.

Box 15 The development of agro-ecology in selected countries

In France, in the bill for the future of agriculture, food and forestry (law No. 2014-1170 of 13 October 2014), agro-ecology is considered as a way to implement the transition towards agricultural practices that ensures both a better environmental and a better economic performance of the agriculture sector. The bill includes an action plan to implement this transformation of agriculture.

In Brazil, the National Policy of Agroecology and Organic Production has been implemented since 2012, with the participation of producers, government and civil society organizations. The promotion of food sovereignty and FSN, the sustainable use of natural resources, the structuring of sustainable and equitable consumption and distribution systems, the conservation and sustainable use of biodiversity, gender equity and the involvement of rural youth in agro-ecology and organic production are all incorporated as policy goals under the policy. Goals, strategies and investments in different policy areas (including production, knowledge and markets) are monitored through the National Plans of Agroecology and Organic Production, which are renewed every four years.

Vaccination can be more widely employed in disease control if it is possible to distinguish vaccinated from infected animals. New Differentiating Infected from Vaccinated Animals (DIVA) vaccines allow this, which means movement restrictions, necessary for infected animals, can be loosened for vaccinated animals. Disease control is also facilitated by diagnostics. Molecular diagnostics are already widely used in some countries, and further innovations can increase their coverage and decrease their cost. The development of farm-level diagnostics, such as in-line milk testers, can also lead to more timely diagnosis of diseases and more effective treatments for sick animals. Currently, animal therapeutics, especially antimicrobials, are often used prophylactically and with inadequate regulation, and are widely blamed for an increase in resistance.

Adapt to climate change Livestock in itself can be a way to build resilience and adapt to changing conditions. It can be used as a diversification and a risk management strategy in case of crop failure. In some regions, changing systems from crop to mixed crop–livestock or to livestock systems will be a key adaptation strategy (Jones and Thornton, 2009).

The adaptive capacity of livestock systems depend on multiple parameters, including choice of species and breeds, housing, especially for intensive systems, availability of alternative feed resources, the accessibility of animals (health/extension services), the type/efficiency of response to outbreaks (surveillance, compensation schemes, etc.) and the household wealth status (ICEM, 2013).

Selection of livestock but also of feed crops and forages is a major component of building resilience to climate change. Many livestock breeds are already well adapted to high temperatures and harsh environments (FAO, 2016b). They need to be characterized and improved in structured breeding programmes (Madalena, 2008), targeting adaptive traits in high output and performance traits in locally adapted breeds.

Systemic adaptation measures include grassland restoration or diversification in composition, agroforestry with fodder trees and legume shrubs to provide alternate feed resources, shade and retain water, or animal and feed mobility (FAO, 2016b).

Protect and manage genetic resources

Breeding strategies and programmes for plants and animals need to be strengthened (FAO, 2015c). They will have to address multiple objectives: not only improve productivity, but also adapt to climate change and to a wide diversity of feeding resources and, more generally, of environmental, economic and social conditions. Especially for animal genetic resources, which are often more difficult to conserve *ex-situ*, there is a need to expand and diversify conservation programmes both *in-situ* and in gene banks; to recognize and protect traditional and indigenous knowledge; to facilitate creation and transfer of knowledge and technologies relative to the management of livestock genetic resources. Access to genetic resources, and to the related knowledge, should be facilitated, in particular for smallholders, marginalized populations and indigenous people. The development of institutional frameworks at different levels could help to reach those objectives.

4.2.3 Secure social equity/responsibility

The term “social equity-responsibility” as understood in this report includes a wide range of social and ethical issues with varying priority across countries and contexts: income distribution, social protection, human rights, gender, tenure and property rights, social discrimination and marginalization. It includes the responsibility of all actors (individual, corporate, collective) to safeguard the environment, to protect human health and well-being, and improve animal welfare.

Social equity/responsibility, including issues of cultural integrity, is one of the most wide-ranging, challenging and politically sensitive areas of sustainability, although often overlooked. These social and cultural issues are embedded in historical, legal and cultural traditions, and in the overarching notion of universal human rights.

The norms and practices of social equity/responsibility, and the priorities for intervention, differ across countries and communities and over time. They form possibly the most diverse and context-specific of the categories of sustainability attributes. They include norms and practices that relate to issues as sensitive and as wide-ranging as access to land, seeds and other productive resources; the use of child labour; the division of labour by gender or social groups; and attitudes concerning the adoption of new technologies. These norms and practices can be enforced – and also undermined or changed – by regulation and law, by community practice, by informal relationships, by religious institutions, and by political and economic power.

In recent years, international organizations have worked to better define the notion of social responsibility through political guidelines. The CFS has elaborated Principles for Responsible Investment in Agriculture and Food Systems (RAI), and the CFS Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security (VGGT).[37] OECD and FAO, building on those CFS products and other existing international standards and principles, have just released this year a Guidance for Responsible Agricultural Supply Chains (OECD/FAO, 2016) to help enterprises observe existing standards for responsible business conduct along agricultural supply chains.

While it is important, it is also often difficult to evaluate progress towards social equity/responsibility in contributing to SAD in a measurable and comparative way. All actors in the food system must direct themselves to social equity/responsibility issues and to understanding the implications of agricultural development policies and programmes on social outcomes.

Develop social protection systems

The HLPE report, *Social Protection for Food Security* (2012), grounded in a human rights based approach, shows the powerful synergies between social protection and food security, especially for vulnerable people. It reviews a wide range of social protection instruments and calls for comprehensive social protection strategies at household, national and international levels.

The HLPE report*, Investing in Smallholder Agriculture for Food Security* (2013a), also showed the particular importance of social protection programmes for smallholders farmers, which act as a safety net and are a key component in the Right to Food entitlement. They are part of the means of intervention to improve health and nutrition and also allow smallholders to invest more in productive activities with potentially better outcomes. These supports, properly designed and implemented, provide essential services to family farmers and reduce the de-capitalization process, from which it is often difficult to recover. Social protection programmes can contribute to appropriate risk management strategies that will also strengthen the resilience of smallholders and family farms.

Improve working conditions in the agriculture sector

Agriculture is a sector in which a significant proportion of jobs remain informal. Even in the formal sector, progress is still needed to define working conditions and protect workers' rights through formal written contracts. In South Africa for instance, in 2014, while over 92 percent of workers with employment of a permanent nature and 80.8 percent of workers with employment of a limited duration have written employment contracts, only 46.4 of workers were entitled to paid vacation leave, and 35 percent to paid sick leave (Visser and Ferrer, 2015).

Agriculture is one of the most hazardous sectors in both developing and developed countries. Increasing attention is being given to applying practical actions in agricultural and rural settings to reduce work-related accidents and diseases, improve living conditions and increase productivity. Reports from many countries have shown the feasibility and effectiveness of ergonomic innovations that have improved working and living conditions in agricultural and rural settings. Building on these good examples, the International Labour Organization published a manual presenting practical and concrete solutions for improvements in agricultural work and rural life from an ergonomics point of view (ILO, 2014).

Agriculture, in many countries, is historically and traditionally, an under-regulated sector and one in which regulation enforcement is also difficult (FAO, 2013a). In South Africa, it was only after the adoption of the Labour Relation Act (LRA) in 1995 and of the Basic Conditions of Employment Act (BCEA) in 1997 that farmworkers became eligible for the same rights as other workers (Visser and Ferrer, 2015). Nonetheless legislation and law enforcement are major tools to improve the working conditions in the agriculture sector and Box 16 shows that some progress has been made in recent decades in some countries.

---

[37] RAI and VGGT are available on the CFS Web site: http://www.fao.org/cfs/cfs-home/products/en/

Box 16 Working conditions in the meat processing industry

On 19 April 2013, an Ordinance of the Brazilian Ministry of Labour created the Regulatory Standard NR36.[38] The regulatory standard was the result of a long negotiation with Brazilian workers' organizations. This new standard aims to improve workers' safety in slaughterhouses and the processing meat industry. It seeks to prevent and reduce occupational illnesses and accidents through detailed regulation covering workplace infrastructure, ergonomic and temporal organization of the work, environmental conditions in the workplace, risk management and prevention, and occupational health medical control.

In Argentina, ILO conventions No. 155 and 187 (concerning Occupational Safety and Health) have been incorporated in national legislation in 2011 (by laws No. 26693 and 26694). More recently, the government has adopted the "Occupational Safety and Health Argentine Strategy 2011–2015". Concerning more specifically the poultry, cold meat and meat industry, Argentina established a special retirement regime adapted to the hard working conditions in this sector and, for the same reason, a specific Collective Agreement (No. 607/2010) covers the meat and poultry industry workers.

Improve animal welfare

Animal welfare is linked to economic development and the education, cultural practices, religious beliefs and knowledge of farmers. Improving animal welfare can contribute to both resilience and resource efficiency, as illustrated in Box 17.

Innovations around improved housing and care of animals can improve productivity as well as human and animal welfare. For example, robotic milking is in use in thousands of farms and is thought to improve welfare by allowing the cow to choose when to be milked. Financial mechanisms for agricultural funding have begun to endorse the importance of animal welfare: the European Bank for Reconstruction and Development included animal welfare (defined in relation to EU animal welfare legislation) in its lending standards in 2014, while the UN Committee on Food Security's Responsible Agricultural Investment Principles also highlight the importance of animal welfare. The World Bank/International Finance Corporation's Good Practice Note on Animal Welfare provides detailed recommendations (IFC, 2014).

Box 17 Animal welfare: contributing to resilience and resource efficiency

NGOs including World Animal Protection (WAP, 2014b) work closely with the industry to integrate animal welfare into livestock practices, lending their animal welfare expertise and working pragmatically to develop good welfare solutions and promote them within the wider international community.

WAP has worked with major multinational producers to introduce humane slaughter methods in Brazil and China, training over 5 000 professionals to date. Partnerships between WAP and the Brazilian Ministry of Agriculture (MAPA) have been recognized by the European Commission as enabling capacity building to meet European import standards. The reduction of production losses following humane slaughter has delivered benefits for the industry. In one Brazilian slaughter plant, a multinational processor was able to significantly reduce risk of injury and damage and to exceed its targets. In China, one of the largest-scale producers reduced production losses from 12 percent to 8 percent and fractures from 1.7 percent to 1.0 percent of animals, and reduced carcass loss from 0.5 kg to 0.2 kg per carcass. Improving animal welfare throughout production and slaughter has made good economic sense. In Uruguay, research showed that 48 percent of carcasses ended up with at least one lesion, with bruising leading to losses of 2 kg of meat per carcass. If extrapolated across the country, this equated to USD100 million annually, or 3 000 tonnes of meat. In a similar Brazilian study, better handling reduced carcass bruising from 20 percent to 1 percent (Appleby and Huertas, 2011). The biggest welfare wins can be achieved on farm, where animals spend most of their time. For example, moving from close confinement systems such as sow stalls (gestation crates) to group housing systems, and cage-free rather than battery cage layer hen production. Alongside legislative requirements in the EU, many large food companies now require commitments to phase in improved animal welfare in their supply chains, including major food service multinationals and producers.

---

[38] Regulatory Standard NR36 - Health and Safety at work in slaughter houses and processing meat and derivatives. Available at: http://www.braziliannr.com/brazilian-regulatory-standards/nr36-health-and-safety-at-work-in-slaughter-houses-and-processing-meat-and-derivatives/ (accessed June 2016).

4.2.4 Controversies around solutions

Choice of solutions from a wide range of competing concepts

Solutions to contribute to SAD have been variously encapsulated in a range of approaches, some of which are reviewed above, including sustainable intensification, save and grow, climate-smart agriculture, biotechnologies, conservation agriculture, ecological intensification, agro-ecology and organic farming. They differ in their degree of prescription as to the technical orientation they entail (some of them are more focused on practical solutions). They all derive from the need for a shift towards more resource efficiency and care for natural resource use, and a greater reliance on natural processes for farming, such as plant, field and landscape level ecosystem processes. However, while some approaches take a narrow, farm-centred approach, others look at farming systems within a wider socio-economic-environmental context. This multiplicity of seemingly competing concepts can entail confusion and debate, for instance between sustainable intensification and agro-ecology. But in terms of practical action at the farm level, there might be considerable overlap among these approaches.

Farm scale and appropriate technological options

The issue of the farm scale that is best suited to sustainable solutions is a recurring debate (HLPE, 2013a). Some argue that small-scale, mixed-farming systems using traditional practices and knowledge, strongly integrated with rural communities and respecting natural resource cycles (such as for nitrogen and carbon), are more sustainable in the long run. Others argue that sustainability is enhanced on large-scale farms, which benefit from economies of scale in their use of resources and are better able to harness the latest knowledge and technologies and to address environmental problems. For them, the viability of livelihoods on small-scale farms is precarious, especially in competition with larger farms in an open market system while efforts to cut costs on large-scale farms often target labour costs to the detriment of available employment (for example, with the adoption of fully automated milking or meat packing).

This report argues that technologies for sustainable agriculture need to cover the whole spectrum of farming systems and be tailored to particular circumstances and contexts. According to an OECD study, "*All farming systems, from intensive conventional farming to organic farming, have the potential to be locally sustainable. Whether they are in practice depends on farmers adopting the appropriate technology and management practices in the specific agro-ecological environment within the right policy framework. There is no unique system that can be identified as sustainable, and no single path to sustainability…However, it is important to recognise that most sustainable farming systems – even extensive systems – require a high level of farmer skills and management to operate"* (OECD, 2001).

Many of the actions require knowledge and financial resources by farmers, and infrastructure to protect against collective shocks (such as drought and flooding). However, the "tipping points" beyond which the ecosystems on which agriculture depends cannot recover, are not always clearly known. Nor are the long-term impacts of new technologies easy to predict. There are trade-offs, encapsulated in the debate on the application of the precautionary principle, in finding a balance between risk-averse caution and risk-taking, as well as striking a balance between maintaining farmers and rural communities and facilitating adjustment over time to contribute to FSN. But, in all cases, risk assessment and impact evaluation are necessary to better inform possible technological choices.

Risks and benefits associated with technological developments presented in this section are controversial issues. Arguments in defense of a strong interpretation of the precautionary principle to technological innovations in agriculture and food processing relate to potential uncertainties and knowledge gaps with regard to the impacts of technological innovations, including genetic engineering, on ecosystems and human health. In this perspective, the possible hazardous effects of discrete technologies should be evaluated through the application of systemic approaches to risk assessment (weighing benefits and harm) in the context of the wide variability of ecosystems and social settings.

Production methods unacceptable to some stakeholders

Recent decades have seen a growth in ethical consumerism, especially in developed countries, whereby consumers are encouraged to use their purchasing habits to express their beliefs, values and preferences. In response to this, various initiatives have arisen to provide, advertise and sometimes certify ASF that meet given criteria. Such criteria include for instance: fair trade; locally produced; animal welfare friendly; organic; GMO-free; antibiotic free; bird friendly; or respectful of the deforestation moratorium. Most people would argue that the public should make informed choices about issues that are of concern to them. A challenge is that the proliferation of labels, many of them managed by the private sector, can confuse consumers and can have unwanted negative effects, including excluding smallholders from markets because they are unable to afford certification.

As shown in Chapter 2, while there is still a long way to go to eliminate hunger and malnutrition, the world has substantially reduced the incidence of hunger over the last decades. That progress can largely be attributed to scientific and technological advances applied to agricultural and food production, including irrigation, hybrid seeds and the application of inorganic fertilizers, together with advances in medicine and sanitation. Proponents of biotechnology foods argue they are similarly placed to increase agricultural productivity, improve the nutritional quality of food, reduce environmental harm, rehabilitate degraded lands and reduce waste. A number of impact assessment studies of these technologies have been largely positive (Klümper and Qaim, 2014). At the same time, however, critics of biotechnologies cite concerns about currently unknown cumulative or long-term harmful effects, including the implications of genetically modified organisms (GMOs) "escaping" into the environment through cross-pollination and the unintentional transfer of allergens into new foods (Buiatti *et al.*, 2013).

The IAASTD (2009) concluded – controversially in the view of some governments – that the biotechnologies now in commercial distribution are not designed to solve the problems faced by the majority of the world's farmers. The technologies are expensive, and linked to specific inputs that have to be purchased off-farm. The extensive use of private patents – and the companies' rigid enforcement of those patents – precludes the possibility of collective learning and adaptation, unlike the experience with the green revolution technologies, which were developed in the public domain.

Consumers may have a greater fear of novel technologies used in food value chains than most experts consider warranted by the actual health risk. These technologies include: the addition of chemicals in food, for example as preservatives; the use of GMOs; and the use of irradiation for food preservation. Risk perception is complex and driven only partly by factual evidence. Food technologies often involve "fear factors" that make them seem more worrisome than other much greater risks – for example, travelling by car (Slovic, 2010). The factors include distrust of large companies, dislike of "unnatural" processes and uncertainty over unfamiliar dangers. The tension between consumer and expert opinions and between food access, quality and preferred production methods are also areas where risk assessment and impact evaluation can help to inform the debate on sustainable agriculture.[39]

4.3 Enabling SAD solutions and responses

An enabling environment for SAD is crucial. This environment includes formal and informal governance and institutions, legal arrangements, infrastructure, research and development, and the respective roles assigned to markets, public policies and regulations. This complex environment varies hugely across countries, reflecting different histories, cultural norms and expectations for the future. The solutions and responses to move towards SAD involve not only policies and actions that are targeted to the agriculture sector, but also those that are cross-sectoral and economy-wide.

4.3.1 Investing in agriculture as an overall economic priority

Many studies have shown agricultural growth to be more effective than growth in other sectors for reducing extreme poverty (Christiaensen *et al*., 2011; Fan *et al*., 2007, Anderson *et al.,* 2011).

The WDR 2008 (IBRD/World Bank, 2007) observed the past neglect of the agriculture sector as a driver of growth and poverty reduction in developing countries. The WDR focused strongly on investing in agriculture to sustain economic growth and generate employment, including outside of agriculture, as a key driver to benefit the poor and ensure their access to adequate food. Given that most of the poor people live in rural areas, in particular in low-income countries, integrating agriculture and the food sector into rural development strategies is seen as an essential pre-condition for food

[39] Expert opinion is generally the result of scientific consensus that, although the best guide for evidence-based advice, is liable to revision as the result of new research. For some issues (e.g. vaccination) there is no scientific justification for the public concern over safety. For other important issues, including chemicals and GM foods, a minority of the science community shares the concerns over safety commonly held by non-experts. In this report, we have followed the prevailing scientific consensus, while recognizing that this can evolve in line with newer evidence.

security. The last food price crisis (2007–2008) raised awareness of the importance of private and public investments in agriculture and in rural infrastructures to foster agricultural development.

The HLPE (2013a), focusing on the specific roles of smallholder agriculture in achieving food security and sustainable development, explains why investment in agriculture should not neglect smallholder farming systems, which produce a significant part of the food consumed in developing countries and provide jobs to many rural poor.

4.3.2 Role and limits of markets

Two contrasting and overarching approaches to improve SAD for FSN are market orientation and food sovereignty.

Market orientation

Orienting agricultural development and food policy towards markets is the approach reflected in much of the mainstream economic and scientific literature, in the policies and investments of international governmental organizations, and in the agricultural policies and development programmes of many governments.

The WDR (IBRD/World Bank, 2007) recommended stimulating growth in poor rural communities by harnessing markets to lift productivity on farms and in associated rural enterprises. At the same time, the WDR report proposed a major role for governments as providers of support for public infrastructure, investors in human capital and environmental improvements, and providers of targeted social protection for the most vulnerable people.

Anderson *et al*. (2011) undertook exhaustive research that showed a strong positive relationship at the national level between trade liberalization and income growth. The same research showed an even stronger relationship between trade liberalization and poverty reduction in developing countries. The research suggested that the benefits for developing countries in global trade liberalization would come from reducing domestic subsidies and border protection measures (such as tariffs), especially in developed countries. Such findings support the argument that access to food would be strengthened by reforms of export and import measures to further open markets. A study by several IGOs (FAO/OECD, 2014) – which included contributions from the Asian Development Bank, IFAD, the International Labour Organization (ILO), the International Food Policy Research Institute (IFPRI) and WTO – focused specifically on the links between growth and food security. That study found that “food security is causally linked to economic growth and employment and the two-way linkages are mutually reinforcing”.

Nonetheless, there is strong evidence that a good outcome for poverty and FSN requires policy measures to deal with externalities, market failures and to compensate the losers from liberalization, especially in the short term and for groups directly hurt by relative price changes (Ravallion and Datt, 1996; HLPE, 2011a, 2012; Fan, 2010). Trade liberalization does not necessarily result in national welfare increases, especially in very-low-income countries. It can have mixed impacts on poor households even when it leads over time to higher incomes and poverty reduction on average (World Bank, 2005). Other research points to the importance of taking account of the specific circumstances of countries in designing growth strategies and policy reforms (Hausmann *et al.,* 2005). Most economic schools of thought that are favourable to market orientation nevertheless favour phased liberalization in agriculture to boost growth, employment and incomes. They suggest governments invest in complementary policy measures that are targeted closely to those who are most vulnerable to the changes. They also recommend public investment in research and extension, transport and market infrastructure, and access to credit at reasonable rates of interest. Social protection, education and health services targeted directly to the poor are all also important to support equitable distribution of any gains from trade.

The contested policy arena that surrounds trade and FSN is not short of studies. Researchers have explored how various degrees of trade openness perform against various indicators of well-being, including FSN. Reviews of studies (e.g. FAO, 2006d; McCorriston *et al*., 2013) have shown mixed results as to the linkages among trade liberalization, economic growth and FSN. Out of 34 studies reviewed, 13 reported that trade liberalization and economic growth would improve food security, 10 that it would lead to FSN decline, and the remaining 11 reported mixed outcomes. The results depend very much on the nature and extent of trade liberalization, the socio-economic context, and the assumptions made by the researchers in the modelling exercises.

Díaz-Bonilla (2015) points to the variety and complexity of the links between trade and FSN. His work shows the importance of the contextual and structural characteristics of national economies as well as the need to understand the global economy. A number of factors need to be understood to develop good policy, including land use, gender differences, concentration levels in product and input markets, and trade patterns. Promising policy responses include attention to opportunities for smallholders and family farms, and interventions to promote social equity, to protect rights to land and water, and to support the proper functioning of land, credit, input and product markets.

While there is wide agreement that market liberalization alone will not suffice and that governments should also implement carefully designed, context-specific supporting measures for FSN, there are also different views about which policies will have the best results. Among the most controversial interventions are those that have a significant effect on prices, such as public procurement at administered (rather than market) prices. The difficulty of reaching agreement in the WTO negotiations is a reflection of the different positions among countries on whether and how trade rules should be adapted to allow for various support and protection measures that governments consider to be important for their national FSN strategies.

Food sovereignty

Food sovereignty is a term first widely used by LVC, which defines itself as a movement of peasant and farmers organizations that rejects the orientation towards agricultural trade liberalization taken by government negotiators in the General Agreement on Tariffs and Trade (GATT) Uruguay Round (Wittman *et al*., 2010). Food sovereignty asserts the right of nations to control their food systems, including whether and how to engage in international markets (though very few food sovereignty advocates reject trade *per se*). LVC first attracted international attention to the term “food sovereignty” at the World Food Summit in Rome in 1996.

An extensive academic literature on food sovereignty has developed since 1996, building on the ideas pioneered by LVC. The food sovereignty movement anchors its vision for the sustainable development of agriculture in an agro-ecological interdisciplinary approach; agro-ecology is “now considered a twin pillar of food sovereignty … a practical method for building food sovereignty at farm scale” (Shattuck *et al.,* 2015). The food sovereignty movement has come to include a broad network of civil society organizations around the world, as well as local governments and some national governments that have enacted legislation embracing the principles of food sovereignty (Bernstein *et al.*, 2009; Lambek *et al.,* 2014).

There are diverse views and continuing debates within the food sovereignty movement, which spans political activists, academics and practitioners who seek to apply a food sovereignty approach to sustainable agriculture in rural communities across the world. At its centre, food sovereignty is committed to radical change in the structures and power relationships embedded in current agri-food systems, including industrial methods of production. Food sovereignty favours localized food production and markets with short distribution chains, supports an ethics of responsible production and consumption, and promotes agro-ecological agricultural practices that draw from traditional knowledge and practices while not rejecting modern science. This vision for agro-ecology prefers to limit the use of externally purchased inputs and is critical of biotechnology-driven innovations, in particular the use of genetic modification.

In contrast with the market-oriented framework, proponents of food sovereignty tend to be sceptical about the role of markets in driving SAD, especially international markets (Burnett and Murphy, 2014). They put less emphasis on the “productivity revolution” and the structural transformation described in Chapter 2 and envisage the retention or recovery of traditional farming structures. They also favour technologies that enhance ecologically-based productivity growth that evolve through participatory engagement between farmer networks and external experts, with the possibility of scaling up of results (Lee, 2013; Shattuck *et al*., 2015; Edelman *et al*., 2014; Bernstein, 2014; Wittman *et al*., 2010). While food sovereignty advocates see opportunities to increase production sustainably using agro-ecological practices, they favour techniques that make use of the abundant labour in many developing countries. They tend not to measure productivity on a per hectare output of a single crop basis but rather to look at the overall diverse productivity of a given area of land. Food sovereignty discourse emphasizes the need for policies and programmes that distribute food more fairly within and between countries and communities, as well as a transition to healthier diets with a lower environmental footprint and less food losses and waste. There is also a strong emphasis in food sovereignty writing on the social and cultural dimensions of sustainable development, including the rights of women and disadvantaged groups, the role of community organizations and more “direct democracy and greater citizen participation in framing policies” (Pimbert, 2009).

Beyond those core concepts, there is a proliferation of definitions of food sovereignty. A founding member of LVC, Paul Nicholson, describes food sovereignty as the “principal alternative presented against capitalism” (Shattuck *et al.,* 2015). Bernstein (2014) describes the movement’s framing as a “comprehensive attack on corporatized agriculture and its ecological consequences”. There are also challenges to food sovereignty. Recent food sovereignty thinking focuses on local or community rights to self-determination about what food is produced and how, potentially creating tensions with national authorities about which level of government should have the primary role and raising the challenge of how to settle differences among communities in a movement with no formal organizational structure (Agarwal, 2014; Patel, 2009). Others have raised questions about the practicality of achieving desired increases in food production through small-scale, labour-intensive and low-input agriculture and the claimed merits of “the peasant way” in the context of globalization and incorporation of agriculture into more industrial systems (Bernstein, 2014; Collier, 2008). Some note the need for food sovereignty to engage in debates on international trade regulation given the importance of trade for most small states, whether agricultural exporters, food importers, or – as is the case of many LDCs – both at the same time (Burnett and Murphy, 2014).

4.3.3 Diversification and integration

Diversity in agriculture is the result of the co-evolution, in time and space, of human societies and ecosystems (Ploeg and Ventura, 2014). The heterogeneity of farming systems reflects the diversity of social, economic and ecological responses to changing conditions in different geographical and political settings over time (Ploeg, 2010). In the past 50 years or so, however, there has been a strong trend towards the specialization of agricultural production systems. Since the 1900s, some 75 percent of plant genetic diversity has been lost as farmers worldwide have discarded their multiple local varieties and landraces for genetically uniform, high-yielding varieties. Seventy-five percent of the world’s food is generated from only 12 plants and five animal species (FAO, 1999). Despite greater awareness of the risk that biodiversity loss poses today, the trend has not stopped. The proportion of the world’s livestock breeds classified as being at risk of extinction increased from 15 percent to 17 percent between 2005 and 2014 (FAO, 2015c).

The loss of biological diversity and the knowledge systems linked to agriculture based on multiple crops puts farming systems at increased risk of failure in a context of global environmental and economic changes, including climate change. It also undermines the potential to achieve diverse, nutritious diets worldwide. Diversification strategies are necessary to rebuild resilience in the face of this uncertainty and to ensure SAD for FSN for all.

Diversifying production from farm- to system-level

In 2013, at the global level, maize, wheat and rice, the three major crops, represented 40 percent of the total arable land (FAOSTAT). Yet the world has at least 12 650 edible plant species, about 7 000 of which having been used to a significant extent by humans at some point in time (Kahane *et al.*, 2013). Several crops of great nutritional and economic importance, especially for smallholders, are on the decline and receive little attention from commercial plant breeders, including: cereals such as sorghum and millets; roots and tubers including cassava, yam and sweet potato; and pulses including cowpea, common bean, chickpea, pigeon pea, and groundnut. These are often referred to as “orphan crops”. Breeding for orphan crops is lagging behind major crops although they are staple food crops in many low-income countries.

Crop diversification can improve resilience and resource efficiency, yield stability and productivity. Diversified production, including with local varieties or multiple cropping at farm level, can also provide ecological and economic resilience. It constitutes a hedging strategy in the face of multiple risks, including the risk of crop failure and of uncertain prices. The instability created by climate change increases the importance of such resilience. Crop rotations and diversity on farm can be used to control weeds, pathogens and insect pests. Pulses in particular bring several benefits when introduced in crop rotations or in intercropping, such as increased soil fertility and nutrient cycling, due to their ability to fix nitrogen and free phosphorus in the soil. Optimum diversity may be obtained by integrating both crops and livestock in the same farming operation. Evidence from smallholder farm households in Indonesia, Kenya, Ethiopia and Malawi shows that diversifying production on smallholder farms significantly contributes to dietary quality and diversity, complementing the core strategy of improving small farmers’ access to markets (Sibathu *et al*., 2015). Agricultural policies, and public support for farm investments and market development, should take these findings on the importance of production diversity into account.

Integration of crop and livestock was the common practice for centuries until the mid-1900s when technology, government policy and economics pushed farms to become more specialized. Mixed crop and livestock operations have several advantages. First, growing row crops only on more level land, with pasture or forages on steeper slopes, will reduce soil erosion. Second, pasture and forage crops in rotation enhance soil quality and reduce erosion; livestock manure, in turn, contributes to soil fertility. Third, livestock can valorize crop residues and buffer the negative impacts of low rainfall periods by consuming crops that in "plant only" systems would have been considered crop failures. Finally, opportunistic systems can benefit from flexible sources of feed and, to a certain extent, buffer volatility. This can help cushion farmers against trade and price fluctuations and, in conjunction with cropping operations, can help make more efficient use of farm labour.[40] As it can be difficult for specialized crop farms to revert to more integrated, mixed systems, given the daily work constraints related to livestock, crop–livestock integration can also, in some regions, be considered and implemented at a broader landscape or territorial level.

Internalizing externalities

The practices actually adopted on farm will be primarily driven by the farm household's need for financial viability, as well as long-term survival and the need to comply with regulations and with behavioural norms. Farmers, however, often fail to take into account the effects of their farm practices for which there is no financial remuneration. This is true for many public goods, such as carbon sequestration in soils, or preserving habitats for wildlife, as well as for public bads, such as polluting watercourses or harming biodiversity, for which there is no penalty. These market failures compromise SAD.

Many on-farm practices implicitly acknowledge the need to protect and conserve natural resources and ecosystems. Market-oriented approaches have proposed methodologies to create market-based instruments such as pollution charges, remuneration for ecosystem services provision, and better pricing of scarce natural resources to better internalize negative environmental externalities in agriculture. Other policy options to internalize externalities associated directly or indirectly (through land-use change and feed production) with livestock production include: implementing the "polluter pays" principle through taxes, charges and regulations; water pricing to encourage efficient water use (HLPE, 2015); payments to encourage biodiversity and carbon sequestration; and fines and controls to prevent deforestation. Current schemes, however, rarely account for all the environmental damage or benefits of livestock farming. Moreover, many of the natural resources targeted with these policies can be common pool resources, such as land and water, in particular for smallholders, indigenous peoples and pastoralists. Many of the policy options most widely considered assume private ownership; communal ownership also needs to be considered in policy design and implementation.

Integration of sustainable agricultural development with food policy

Governments and experts are increasingly paying attention to the need for consistency among agriculture, nutrition and health policies. (FAO/WHO, 2014). This entails a reorientation of policy objectives in all three areas, as well as multidisciplinary research, institutional change and collaborative initiatives. Ultimately, the objective is to ensure compatibility between SAD on the production side and FSN on the demand side.

There is almost universal agreement – as shown by national dietary guidelines across many countries – that the basis of a healthy diet is fruits, vegetables, grains (particularly whole grains) and legumes, in addition to some ASF. The livestock sector can contribute to these optimal dietary patterns by increasing the accessibility of nutrient-dense foods rich in high-quality proteins and a range of micronutrients such as iron, zinc and vitamins. Indeed, an accumulating body of research has shown that the addition of small amounts of dairy and meat, in particular, to the diets of preschool-aged children and pregnant women has improved the nutritional status of these vulnerable groups. But, as discussed in Chapter 3, ASF, and in particular processed meat, may also in some cases have some negative impacts on nutrition and health.

These positive as well as negative health implications of dietary patterns highlight the challenge of promoting healthy diets both in the composition of food groups and the quantities of individual foods. Despite isolated areas of improvement, and in part probably because the advice given to consumers

[40] See: http://asi.ucdavis.edu/programs/sarep/about/what-is-sustainable-agriculture (accessed June 2016).

can be contradictory, there has been little overall progress in shifting “Western-style” diets to healthier alternatives or decisively reversing overweight trends (Roberto *et al*., 2015).

In recent years much of the advice given by nutritionists has centred on adopting the so-called “Mediterranean diet” (Box 18), which is arguably better for health and for the environment. According to Willett *et al.* (1995), who proposed the first “Mediterranean diet pyramid” (MDP), the highly publicized MDP defines a model for healthy eating. Based on epidemiological evidence, the MDP is related to high life expectancy, low rates of coronary heart disease (Estruch *et al*., 2013) and of certain forms of cancers, as well as of other diet-related chronic diseases. It reflected the food habits of habitants of Crete and Southern Italy in the early 1960s described by Keys (1970). This diet is characterized by a basis of food from plant sources (fruits, vegetables, cereals, potatoes, beans, nuts, seeds), olive oil as the principal source of fat, some dairy products, low to moderate amounts of fish and poultry (including eggs), low and infrequent amounts of red meat, and wine consumed in low to moderate amounts, principally with meals. Soon after, and although different regions in the Mediterranean basin have their own specific diets, Trichopoulou and Lagiou (1997) proposed that these be considered as variants of a single entity, namely, the “Mediterranean diet”.

Box 18 The evolution of diets in the Mediterranean area during the last 50 years

The evolution of the food system of the North Africa–Middle East region has been studied recently by INRA-DEPE (INRA’s Office for Scientific Expertise, Foresight and Advanced Studies), on behalf of the PluriAgri association: Le système alimentaire de la Région Afrique du Nord - Moyen-Orient à l’horizon 2050 : projections de tendances et analyse de sensibilité (The food system in the North Africa–Middle East region in 2050: trend projections and sensitivity analysis) (INRA-DEPE, 2015).

Much of the data gathered for this retrospective study described the evolution of food availability (kcal/capita) of countries around the southern (Morocco, Algeria, Tunisia, Egypt) and eastern (Israel, Lebanon, Syrian Arab Republic, Turkey) edges of the Mediterranean. These “food availability” data serve as popular proxies for actual consumption at the national level[41]. The aggregated data provided in the synthesis report (Marty *et al.,* 2015) of the INRA-PluriAgri study for the period 1961–2012 provide an approximate picture of the evolution of the diet in the region for that period.

The two main trends noted over time in the diet are a radical change in the types of consumed oil, and a strong growth in the consumption of sugar products. Marty *et al*. (2015) noted that: “These two developments in the average diet are largely responsible for the significant increase in non-communicable chronic diseases and obesity in the region (Popkin *et al*., 2012), increase which is all the more worrying as nutritional deficiencies persist in the region (Fahed *et al*., 2012).”

In the early years of the study period, the highest consumption of oils was traditional and local: olive and cottonseed oils. These were replaced, in the 1970s, by palm oil, soya oil and sunflower oil, which are increasingly imported. Concerning sugar products, consumption almost doubled over the period 1961–2012, from 160 to 300 kcal/capita/day. The share of sugar products in plant food availability amounted, by the end of the period studied, to around 10 percent in all sub-regions of North Africa and the Middle East region.

These various trends in dietary change are consistent with a "Westernization" of diets. However, the region still seems to follow, at least to date, a particular pathway of nutritional transition, by maintaining the strong characteristics of the Mediterranean diet: the share of plant products remains high (circa 90 percent on average), and cereals continue to play a leading role (wheat accounts for 40 to 50 percent of total food availability in kcal/capita/day). Another characteristic of the Mediterranean diet that has been important over the period is the high level of fruits and vegetables consumed. The share of animal products in food availability has remained almost constant, at around 10 percent on average (measured in kcal/capita/day). The main feature is the substantial increase in poultry meat consumption: its share in the animal food availability increased from 4 to nearly 20 percent on average in the region over the period. Overall, food availability has increased from 2 000 to 3 000 kcal/capita/day between 1961 and 2012.

In summary, the North Africa–Middle East region has undergone a nutrition transition (increase of daily calories and increase in the share of oil and sugar in food availability), but the changing diet differs from the "Western" model by the very low growth of the share of animal products and the persistence of high levels of plant products, including cereals, fruits and vegetables.

[41] See http://www.ers.usda.gov/data-products/food-availability-(per-capita)-data-system.aspx

Since then the MDP has been adapted to the different nutritional and socio-economic contexts of the Mediterranean region, with updated recommendations considering the lifestyle, dietary, socio-cultural, environmental and health challenges that the current Mediterranean populations are facing (Bach-Faig *et al.,* 2011). The Mediterranean diet has also been recognized as an *Intangible Cultural Heritage of Humanity* by UNESCO (2010).

In many rich and some emerging economies, as well as among some classes of poorer countries, food consumption is in excess of recommended levels. This focus on changing diets is driven by interests outside the farming system and is primarily focused on improving health. But changing diets, as well as efforts to reduce food losses and waste, has consequences throughout the agri-food chain. A number of organizations and experts have made the link between reduced consumption of ASF and smaller environmental footprints, and reduced natural resource use and GHG emissions (Revell, 2015; The Royal Institute of International Affairs, 2015).

Dutch researchers presented the public with their USD330 000 burger grown from *in-vitro* cattle stem cells in 2013. Since then production costs of the so-called *schmeat* have been cut to USD11 (Dorsey, 2015). A shift to inexpensive, acceptable meat substitutes would have profound implications for the livestock industry. However, given that the main driver in the increased demand for meat is projected to occur among the still very large populations who consume relatively little meat per person, the impact of reduced meat consumption among richer consumers, where demand is stagnant, is likely to be muted.

Integration of farm sector action with other economic sectors

Not all of the policy responses necessary to address the livestock sector challenges lie within the agri-food sector. Other important challenges include the need for better (and more equitable) economic outcomes, equitable access to resources, less income inequality, a well-functioning trade system, broad-based and effective social safety nets, investment in public infrastructure, improved educational outcomes and R&D. SAD also depends on effective environmental regulation, throughout the whole economy (not just in agriculture). There is also a difficult balance to be struck between attracting young people into viable and sustainable jobs and livelihoods in agriculture and providing young people with choices that allow those who want to move out of agriculture to take advantage of employment and income opportunities in other sectors.

4.3.4 Gender

The feminization of agriculture (defined as a rise in the proportion of women in the total agricultural workforce) is an observed feature of the agrarian transition that moves workers from agriculture into industry and services, and from rural to urban areas.

UN SDG 5 (Achieve gender equality and empower all women and girls) includes the objective to "End all forms of discrimination against all women and girls everywhere …and ensure women's full and effective participation and equal opportunities for leadership at all levels of decision-making in political, economic and public life …and to undertake reforms to give women equal rights to economic resources, as well as access to ownership and control over land and other forms of property, financial services, inheritance and natural resources". Besides the benefits for SAD, addressing women's empowerment also has nutrition benefits for young children. Smith and Haddad (2015) show that investments in women's education, increasing gender equality and increasing national food availabilities can be expected to have an impact on national child stunting rates even in the short run (over roughly five years), while investments in health environments and improving the dietary diversity of food available in countries have their impacts only over longer periods.

Within pastoral and smallholder mixed farming systems, livestock play an important role in supporting women and in improving their financial situation, and women are heavily engaged in the sector. Particular species and types of livestock activity are more associated with women than men. For example, women often have a prominent role in managing poultry (FAO, 1998; Guèye, 2000; Tung, 2005) and dairy animals (Okali and Mims, 1998; Tangka *et al.,* 2000) and in caring for animals that are housed and fed within the homestead. When tasks are divided, men are more likely to be involved in constructing housing for and herding grazing animals. Where women's mobility is constrained by social norms or the risk of violence, men will undertake the marketing of products. The influence of women is strong in the use of eggs, milk and poultry meat for home consumption and they often have control over marketing and the income from these products. Perhaps for this reason, poultry and small-scale dairy are popular investments for development projects aiming to improve the lot of rural women. In some countries women also dominate small-scale pig production.

4.3.5 Institutions and governance

Successful realization of SAD depends on the processes by which knowledge is exchanged, policy priorities and approaches are decided, and the level at which decisions within the food system are taken, as well as how decisions are made and to whom actions are targeted. This section gathers the main approaches to improve institutions, including capacity-building initiatives and knowledge and research-oriented institutions, to strengthen governance for SAD.

Enabling stakeholder engagement and collective action

Food systems are shaped by the collective effects of thousands of decisions taken by many actors, some of whom are outside the food chain, and many of whom are not operating in the same geographical space. Engaging stakeholders in the process of developing policies and actions for SAD, learning from experience, communicating best practices, drawing on traditional knowledge and adapting policies and programmes to specific local contexts can all help support positive environmental and social outcomes. Reporting progress and relevant research findings in a transparent manner can encourage debate on further actions and appropriate fine-tuning of policies.

As underlined by HLPE (2013a), cooperation in buying, processing and selling, exchange of new knowledge, skills, services and seeds, shared investment for equipment and machinery, are only a few of the many examples of the role that collective action can play to build capacities, promote the participation of smallholders in political decision-making processes, facilitate their access to market, enhance productivity and resilience of farming systems (in particular, pastoral and smallholder mixed farming systems).

Enabling greater access to investment

Significant investment in R&D and technology to improve sustainable productivity in different farming systems is essential. R&D investments in the past played an essential role in developing innovations, changing farm practices and raising productivity; they will be even more crucial in the future to address a more complex and wider set of sustainability objectives, and to ensure SAD for FSN. Investment in R&D for SAD will need to be accompanied by mechanisms to disseminate the knowledge and to provide capacity building for all.

There is now a considerable shift in power between private and public actors as far as agricultural R&D investments are concerned (FAO, 2012a). The private sector now plays a leading role in technological development in food and agriculture, and large corporations are increasing their investment in R&D. A study conducted by the Economic Research Service of the United States Department of Agriculture (USDA), focusing on the 1994–2010 period, estimated that in the year 2000 the private sector already accounted for 45 percent of the total food and agriculture research spending worldwide (Fuglie *et al.,* 2011). Since the R&D undertaken by private companies is protected by patents, this trend raises challenges related to the dissemination, access and uptake of new technologies.

Intellectual property rights frameworks can adversely affect smallholders' access to agricultural knowledge (Gura, 2008). The IAASTD (2009) recommended that farmers be able to manage their seeds and germplasm resources according to their needs. Risks and opportunities associated with technological developments and applications need careful assessment, including the social, economic, cultural, health and environmental implications of different technologies in different contexts. This assessment should be accompanied by regular monitoring and evaluation. Principle 10 of the Rio Declaration calls for enhanced public participation and awareness on environmental issues, while Principle 15 states that "where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost effective measures to prevent environmental degradation" (UNCED, 1992; UNDESA, 2011).

Greater application of communication technologies for all

The application of information and communications technology (ICT) in agriculture is increasingly important, through new innovations that can empower farmers, including smallholders. This extends to the emergence of a number of innovations such as the use of big data, drones, smartphones, social media and other innovative digital technologies. These can improve the efficiencies of the overall food system by guiding production decisions through to reducing waste in supply chains and on consumers' tables.

The "digital revolution" has had significant and wide-ranging implications and applications in agriculture, from decision-making on a single field to informing national policy and corporate objectives, and in global monitoring. The role that ICT can play as an instrument of change is potentially transformative, as digital technologies become increasingly accessible and affordable in the developing world (Kashturi Rangan *et al.,* 2007).

Some of the applications that can have a role in enhancing SAD for FSN include:

- *Precision technologies*: using mobile telephone apps, sensors and satellites to boost the productivity of both smallholder farmers and agriculture value chains (i.e. health of animals on farms or targeting animal feeding regimes more precisely to raise yields and reduce waste).
- *Precision agriculture*: site-specific farming that matches natural variability in soils, microclimates, plants and other factors with customized, location-specific inputs of seeds, fertilizers, pesticides, water, etc. Precision agriculture can reduce costs, increase yields and profitability, and improve environmental outcomes and climate-resilience simultaneously.
- *Digital financial services*, agribusiness ICT systems and extension agent support technologies.
- *Real time market information systems,* including reporting of transboundary animal diseases.
- *Traceability* systems for monitoring compliance with quality, environmental and other product and/or process attributes related to food.

Several emerging trends that are reducing barriers to mature-market technologies and opening new opportunities for local agricultural stakeholders include: the increasing uptake and sophistication of mobile devices; radical price decreases in new remote sensing technologies (including low-cost soil, air, water and plant sensors); the use of unmanned aerial vehicles (drones); the availability of near-free, near-real time satellite and GIS data; greater processing power and connectivity of GPS-enabled mobile devices; and greater geolocation data and possibilities for modelling becoming available to researchers, farmers and extension agents.

There is still unused potential for ICTs in agriculture to improve productivity and reduce environmental harm. Some of the most visible and well-known experiences in developing countries have been on: (a) access to daily weather information and forecasts, and "nowcasts" (three hours) at hyper-local levels – including early warning and weather-based alerts (i.e. FEWSNET); (b) disease surveillance through SMS reporting (i.e. Health Map); (c) market information systems; and (d) traceability (Botswana, Namibia and Uruguay). ICTs are also widely used in agricultural research and academia in developing countries with good success.

Improve international level governance and foster multistakeholder partnerships

Beyond intergovernmental organizations (such as FAO or WHO), platforms (such as the CFS), which works on policy convergence for SAD and FSN, research communities and networks (such as the Global Research Alliance on agricultural GHG that gathers 46 countries) build and share scientific knowledge on SAD, including livestock. There is also a wide range of international multistakeholder partnerships (MSP) specifically focused on sustainability of the livestock sector. These include, for instance, the Global Agenda for Sustainable Livestock (see Box 19).

There are also different initiatives towards sustainability driven by private stakeholders of the livestock sector (see Box 20).

Box 19 The Global Agenda for Sustainable Livestock development

In 2010, the FAO Committee on Agriculture recommended that FAO actively engage in consultations on how to accommodate livestock sector growth in a socio-economic and environmentally sustainable manner. Subsequently, a number of countries and international organizations, called the Dialogue group, initiated the process. They recommended the development of a Global Agenda to shape the sector's role in future global food production systems.

The Global Agenda for Sustainable Livestock (GASL), facilitated by FAO, brings together small- and large-scale producers. It is a partnership composed of seven cluster groups: governments, civil society organizations, the private sector, donors, research/academia, NGOs, intergovernmental and multilateral organizations. Around 200 participants gather once a year in a multistakeholder partnership meeting to address existing and new challenges. Partnerships at regional, national and local levels respond to specific development priorities. A Guiding Group composed of five representatives from each cluster is responsible for the appointment of the Chair and the guidance of the partnership.

The Global Agenda supports continuous practice and policy change by:

- facilitating policy dialogue between different stakeholders of the sector and building consensus;
- conducting and supporting joint analysis to inform stakeholders, identify entry points for practice change and develop harmonized metrics and methods; and
- promoting innovation and supporting investments.

Its approach to sustainable livestock systems integrates consideration of livelihoods, social impacts, public health, animal health and welfare, environmental impacts, land use and tenure and biodiversity. It does this in three priority areas – food security and health, equity and growth, and natural resources and climate. The GASL consensus includes recognition of the many factors that underpin sustainability (GASL, 2015).

The Global Agenda builds and shares knowledge through thematic and regional action networks, formed by experts from the different clusters. All action networks aim at comprehensive sustainability, but have different thematic entry points and geographic coverage. The action networks are: Closing the efficiency gap, Restoring value to grasslands, Waste to Worth, Global Network on Silvo-Pastoral Systems, Dairy Asia Partnership for Health and Prosperity, and Livestock Environmental Assessment and Performance Partnership (LEAP). Action networks have triggered practice change and supported investments through provision of knowledge.

The partnership has facilitated the development of a number of initiatives such as the Livestock Waste Management and Enteric Methane projects funded by the Climate and Clean Air Coalition, as well as the development of harmonized environmental metrics and guidelines in LEAP.

Box 20 Sustainable livestock – private sector initiatives

During the last decade, some private initiatives have been developed to improve sustainability along the livestock supply chain: to reduce harmful environmental impacts while improving animal welfare and nutritional attributes from increasing production. The International Meat Secretariat representing the global meat and livestock sector, the International Dairy Federation, the International Poultry Council, the International Egg Commission, and the International Feed Industry Federation are the main umbrella organizations that bring together national organizations undertaking sustainability initiatives, mainly in intensive and commercial grazing systems.

Initiatives generally involve reporting and sharing information on best practices drawn from evidence-based scientific studies, pilot schemes on representative farms and enterprises, benchmarking and developing indicators to assess progress. In some cases, livestock farmers are offered certification by independent organizations concerning their sustainability and animal welfare practices. Supermarkets, food outlets and livestock processors often require livestock farmers to enter into contracts whereby they adhere to codes and standards of practice in order to sell their livestock products. Two examples of private sector actions are given below:

The Global Roundtable for Sustainable Beef (GRSB) is the largest global, multistakeholder initiative to advance continuous improvement in sustainability of the global beef value chain. GRSB consists of producers and producer associations, the trading and processing sector, retail companies, civil societies and national or regional roundtables. The major beef producing countries – Australia, Brazil, Canada, New Zealand and the United States of America – are represented. The GRSB has developed a Strategic Plan for 2016–2021 to provide a framework for prioritizing goals and objectives in meeting the ongoing challenges and opportunities. GRSB does not set standards or create a certification programme, but provides a common baseline understanding of sustainable beef that national roundtables and other initiatives can use, recognizing that there is a diversity of beef production systems around the world.

Through the Global Dairy Agenda for Action (GDAA), launched in 2009, the international dairy sector has developed an international platform to develop a common vision of sustainability for the dairy sector and to proactively collaborate to solve the challenges, recognizing the diversity of production systems and of priorities at a local level. The global Dairy Sustainability Framework (DSF), a programme of the GDAA, was launched in November 2013 as a tool to shape, assess and monitor the continuous efforts of the international dairy industry to progress towards sustainability. This DSF defines eleven key sustainability criteria unique to the whole dairy value chain and covering environmental, social and economic aspects of sustainability.[42]

[42] See: http://dairysustainabilityframework.org/the-gdaa/background/, http://dairysustainabilityframework.org

4.4 Pathways in specific farming systems

It is in farming systems that practices are implemented making it particularly important to explore the pathways to SAD for FSN at this level. The following section looks in detail at the possible pathways in the four broad farming systems defined in Chapter 1.

4.4.1 Smallholder mixed farming systems

Current situation

Smallholder mixed farming systems tend to score well in terms of social equity and responsibility in employment creation, particularly of women, as well as with regard to maintaining the social cohesion of rural communities and links to local markets. They are, however, vulnerable where land rights are poorly protected. Resource efficiency in terms of yields can be very low, especially where the scale of enterprise is too small to be economically efficient. In that regard, livestock can play an important role, where land is a constraint, to increase income, such as with poultry and pig farming. The environmental performance of smallholder mixed farms also varies considerably, linked to the level of farmer knowledge, the availability of financial resources, the scale of the farm enterprise, and the extent to which the farm is a mixed enterprise and thus able to recycle waste and produce biomass on-farm. In terms of resilience, their relatively low dependence on purchased inputs means that smallholder mixed farms can be less vulnerable to some external economic shocks. However, low levels of assets can threaten their resilience. They tend to be vulnerable to competition for land from pastoralists and human settlements, however, as well as liable to lose their market share to intensive livestock systems, and to have difficulty accessing credit because they lack collateral. They also bear a high burden of agriculture-associated human and animal disease.

Box 21 Smallholder pig production in Viet Nam

Viet Nam is a southeast Asian country, with a population of 91 million, of which two-thirds live in rural areas. Population is predicted to increase to 105 million by 2100. As incomes have increased, so has consumption of ASF and vegetables. Pork comprises nearly three-quarters of total meat consumption and one-third of the household expenditure on food and drink. Most pork is sold in traditional wet markets because of consumer preference for fresh meat, lower price and greater convenience. More than 99 percent of pig farms are small-scale and produce 83 percent of total pork production. Smallholders remain competitive in Viet Nam because they are more efficient users of farm resources such as using their own produced feed and household labour, thus giving them a market advantage over large producers. Women contribute a substantial amount of labour in pig raising, so that technology interventions need to consider this aspect in the technology development and dissemination process.

Although smallholder pig production is successful in Viet Nam, it faces several challenges:

- Environmental. The demand for livestock has led to dramatic increases in maize production in the uplands of North Viet Nam. This generates rural income but maize cultivation on steep slopes has led to massive erosion and declining soil fertility. Livestock production contributes about 45 percent of GHG emissions, and most comes from pig production.
- Health: There have been several major pig epidemics in recent years including foot and mouth disease and blue ear. There is little control of veterinary drugs, including antibiotics and growth promoters. Pork meat often contains food safety hazards such as salmonella and there is increasing concern over food safety.
- Economic: Smallholders face difficulties in obtaining state-owned loans. Most producers do not use extension services and around one-third do not use veterinary services. The high dependence of the domestic feed industry on imported feed ingredients such as maize, soybean meal and pre-mixes creates volatility in feed markets.
- Social: Viet Nam is experiencing rural to urban migration as opportunities increase in cities; this can reduce the smallholder advantage resulting from on-farm labour.

Currently, there are opportunities for efficiency gains for sustaining smallholder competitiveness. Effective provision of services (credit, veterinary, extension) to improve capacity to deal with production and market risks can help smallholder pig producers remain competitive. Policies that enhance productivity across all producer types will be preferable to policies focusing on developing large, industrial farms. Effective control of animal disease, traceability and credible assurance of food safety are needed to improve consumer confidence in the quality and safety of pork.

Box 22 Empowering rural women artisans through improved production, processing and export of wool and mohair in Tajikistan and Kyrgyzstan

Since 2009, the International Center for Agricultural Research in the Dry Areas (ICARDA) with support from IFAD has launched a four-year project aiming specifically to improve the livelihoods and income of rural women artisans processing wool and mohair and small livestock breeders of goats and sheep in Tajikistan and Kyrgyzstan where productivity of local breeds is extremely low and access to market limited. The initiative established innovative community-based breeding programmes, involving over 2 500 farmers from eight villages, using selective crossbreeding (with Altai cashmere bucks known for their higher quality fibre) and artificial insemination techniques with imported frozen semen from highly productive rams to improve the flock productivity and quality. The improved cashgora goats produced 15 percent more fibre compared with local goats, while the percentage of animals producing white fibre (easier to dye) increased by 20 percent. In Kyrgyzstan, the project improved sheep breeds using high quality Tian-Shan rams, which led to improved wool, along with increased yields of fibre and meat.

The project worked with livestock producers to develop a model for processing mohair and cashmere into high-quality yarn suitable for export, and with spinners and weavers to develop new technologies for processing the yarn into finished products, designed for replication and scaling up. The project helped to increase processing efficiency and produced higher-quality products that are generating additional income, incentivizing all stakeholders along the value chain, many of whom are women, and acted as a catalyst for the reorganization of the angora goat sector in the region.

With the help of the project, more than 250 women processors and about 150 goat and sheep farmers, owning a total of nearly 10 000 animals, benefited from the community-based innovation project (as of September 2013); on average, the annual income of the Kyrgyz women increased by 2.3 times; and the monthly income of Tajik women increased by 1.3 times.[43]

Operational priorities for action

In moving towards SAD for FSN, the priority responses for smallholder mixed farming systems are to improve access to resources and services that will enable them to improve productivity, prevent and control diseases, improve access to markets, address poverty alleviation, and reduce environmental damages, as well as build resilience to environmental and climatic impacts. In this perspective, stakeholders at different levels should recognize and leverage the huge potential of livestock, in its different roles (as an asset and a safety net, as draught power, as a provider of ASF and other products, including skin, wool or manure), as a means for improved livelihoods in smallholder mixed farming systems.

At the household level, five major strategies to improve livelihoods, all of them closely related to food security, can be identified: intensification of existing production patterns; diversification of production and processing; expanded farm or herd size; increased farm income (agricultural and non-agriculture) and increased choices to allow a complete exit from the agriculture sector.

Agriculture's role in national development is reflected in a much-described and widely accepted evolution, from *agriculture-based* societies through a transition phase to *urbanized* status (see Box 1 in Chapter 1). Population and income growth and increasing urbanization provide opportunities for smallholders to join this evolutionary path and increase their engagement with markets, to access inputs and increase production and sales, and hence enhance their livelihoods. This structural transformation can alleviate rural poverty and food insecurity, as smallholders improve their economic position. It can also contribute to the emergence and development of rural economic activity through wage labour, food processing and marketing initiatives, as well as the provision of non-agricultural services for rural communities. Although there is limited empirical data on the benefits of such market engagement (Wiggins and Keats, 2013), there is sufficient evidence to support the contention that the multiplier effects of growth in smallholdings will create on-farm and downstream jobs in processing, trading, transport and storage, and will increase economic activity through consumption effects related to increased farm income, consumption which is likely to be on local goods and services.

In the past, government agriculture policies, particularly in OECD and emerging economies, tended to provide public support based on a farm's output level, which favoured large-scale farms over smallholders. More recently governments have increased the emphasis on the role of smallholder agriculture in their policies, recognizing the importance of small-scale producers in food production

[43] See: http://asia.ifad.org/web/1107-icarda/about, http://www.icarda.org/features/creating-opportunities-vulnerable-women#sthash.4Xv8SiN7.dpbs, http://cac-program.org/news/detail/456

and employment generation. The dramatic reduction of poverty in Asia in recent decades was largely the result of providing smallholders with access to improved seeds and fertilizer. In addition, in the case of China and parts of Southeast Asia, government policy decollectivized farmers, allowing the establishment of smaller farm sizes and stronger individual land rights. MERCOSUR countries have focused on family farming from the early 2000s, providing targeted services such as extension, access to credit and rural insurance. In Brazil, 30 percent of the budget of the National School Feeding Programme must be invested in the direct purchase of family farm products. The programme feeds around 45 million pupils each day in Brazilian public schools and has an annual budget of approximately USD1.75 billion; as such it is a significant market for family farms and contributes directly to FSN through improved child nutrition. The Comprehensive Africa Agriculture Development Programmes (CAADP) developed since the African Union summit in Maputo, Mozambique, in 2003 also emphasize the role of small-scale producers (CAADP, 2015).

Public policy has also begun to put more emphasis on policies and institutional reforms to enable the coordination and integration of policies so that they support (rather than hinder) each other (HLPE, 2013a) and support SAD in all three dimensions of sustainability.

The priorities for action are:

- *Better access to markets and more diversified market opportunities:* Smallholder producers often have good access to local markets but less so to longer market chains, so small-scale and large-scale pig and poultry farming will continue to co-exist in "multi-track" development pathways (FAO, 2008, 2014e). Smallholders need to be supported to gain improved market access, supply-chain integration and marketing. Diversification of markets can also enhance the diversification and sustainability of farming systems.
- *Secure tenure rights and equitable access to land* for smallholders and indigenous peoples should be promoted and upheld, reducing land concentration trends. Land redistribution to enhance the social space of sustainable smallholder agriculture is needed (policies are crucial to guide this process of change).
- *Design feasible growth pathways:* a number of development pathways are possible for small-scale poultry and pig producers (FAO, 2008, 2014e) depending on factors such as available resources, choice of markets, and the capacity of farmers to invest in their enterprises. Where industrial commercial operations have encroached on local markets, small-scale intensive livestock producers could work with them as contract suppliers (FAO, 2014d). Contract farming has had mixed outcomes; the experiences of poultry farmers in the United States of America (Domina and Taylor, 2010) and in South Africa (Bolton, 2015; Visser and Ferrer, 2015) show that small profit margins, exclusive dependence of the farmer on the supplier, highly variable feed prices and low economies of scale for small-scale intensive poultry producers are all significant barriers to SAD. HLPE (2013a) provides insight on the economic and institutional conditions to make contract farming benefit smallholders.
- *Recognize, empower and enable the role of women:* Gender-sensitive participatory development processes are essential. These should enhance women's self-determination (Njuki and Sanginga, 2013; Njuki *et al.,* 2014). In efforts to quantify and overcome obstacles to women's' empowerment, useful new tools have been developed to measure women's empowerment through indices, such as the Women's Empowerment in Agriculture Index (WEAI)[44] and the Gender Parity Index (GPI)[45] (IFPRI, 2012).
- *Improve animal health management:* Animal disease is a major cause of reduced productivity in smallholder systems. For example, chick mortality may be as high as 80 percent in family poultry systems (de Bruyn *et al*., 2015). The losses have been reduced through simple interventions such as vaccination of the flock (Pym and Alders, 2012). Such interventions could use locally available resources, such as training local women to be vaccinators, encouraging the use and improving the quality of locally produced feed, and using local materials and service providers for the construction of appropriate animal housing.

---

[44] The Women's Empowerment in Agriculture Index (WEAI) measures the roles and extent of women's engagement in the agriculture sector in five domains: (1) decisions about agricultural production; (2) access to and decision-making power over productive resources; (3) control over use of income; (4) leadership in the community; and (5) time use. It also measures women's empowerment relative to men within their households.

[45] Gender Parity Index (GPI), is a subindex of WEAI and reflects the percentage of women who are as empowered as the men in their households. It shows the gap that needs to be closed for women to reach the same level of empowerment as men.

- *Encourage the use of local, more resistant, breeds:* Use and improve local breeds, which are hardy, disease-resistant and are able to cope with harsh environmental conditions in low-cost (Ahuja and Sen, 2008) extensive scavenging systems (de Bruyn *et al.,* 2015). Use locally available feeds for extensive scavenging systems. Use the manure from small-scale intensive systems as fertilizer in neighbouring farms, which will dispense with the need for on-farm manure disposal systems and contribute to environmental sustainability. Feed shortages may need to be addressed by increasing the use of fodder and crop by-products and adding appropriate supplements. In intensive small-scale production systems with good management and nutrition, access to breeds with high feed conversion ratio and a regular supply of suitable feed and pharmaceuticals is essential. The conservation of local breeds can improve resilience to climate change and safeguard genetic resources (Mtileni *et al*., 2012; Pym, 2010).
- *Implement appropriate, tailored and participatory programmes that respond* to specific farmers' needs, perceptions, constraints, priorities and local conditions (FAO, 2014a). Policies and programmes should be developed with full and direct participation of the people who will be affected. Policies that promote productivity growth and investment need to go hand-in-hand with social protection interventions that target nutrition, health and education.
- *Facilitate smallholder participation in the political process* of identifying, prioritizing and implementing responses. Smallholders' organizations need to be recognized and supported to increase their voice in policy-making platforms and processes. An example of this approach is the use of innovation platforms (IPs) by the International Livestock Research Institute (ILRI). In IPs, multiple stakeholders (including farmers) collaborate in the identification, design and implementation of actions towards the realization of agricultural development outcomes. IPs have proven effective in redressing unequal gender dynamics (Mulema *et al.,* 2015) and solving natural resource management problems in smallholder agricultural development (Misiko *et al*., 2013).
- *Provide good quality training programmes and information*, which are relevant to smallholders' level of education and circumstances, including "hands-on/learning by-doing" with follow-up by technical agents (FAO, 2014a). This entails R&D of new technologies and production models that are appropriate for the small-scale systems, as well as having in place appropriate extension and advisory systems that can facilitate the adoption of the new technologies.
- *Redirect development policies and tax incentives* towards the design of diversified and resilient farming and food systems.

4.4.2 Pastoral systems

Current situation

Pastoral systems score well in terms of social/responsibility in so far as they conserve traditional practices and cultures, and employment; however, women suffer from structural inequity and access to health, education and other services is low. Moreover, pastoralists are vulnerable to insecurity, marginalization and inadequate access to land and resources in many countries. They often have little access to social services, health and education. Resource efficiency tends to be low in terms of yields, although they use land that has low value in alternative uses. They tend to be adaptive to often-harsh natural conditions and so are often very resilient, but face challenges of pressure from other economic activities on land and water resources in many countries. Their relatively low dependence on purchased inputs means that these systems can be more resilient in adjusting to some external shocks, but are vulnerable to climate change and scarce water availability and bear relatively high burdens of human and animal disease.

Operational priorities for action

While pastoralism and agro-pastoralism might exhibit apparent low levels of production, they can be economically efficient in so far as they use resources that have low value in alternative uses (low input–low output). Moreover, they embody cultural and traditional knowledge and values, and after centuries of experience they are skilled at adapting to harsh conditions. However, to be sustainable going forward, pastoral systems need to better integrate all of the dimensions of sustainable development: pastoralists' rights need to be strengthened, animal health and welfare conditions need to be improved, and the value-added of pastoralist activities needs to be improved by better connections to markets. In this perspective, the dialogue between applied research and pastoral organizations should be strengthened; on the one hand, to improve pastoralists' knowledge of how to improve productivity and profitability and, on the other, to encourage exchanges of experience and to ensure pastoralists' expertise is not lost or ignored. Most regions need to work much harder on making their policies and actions coherent, requiring cross-border cooperation.

The pressure on water, land resources and on the corridors for transhumance is very strong. This generates significant conflicts for access to pasture and water between crop farmers and pastoralists.

Climate change will exacerbate these tensions and make access to resources more difficult. In the Sahel, an increase of average temperatures and more frequent droughts, storms and floods will have negative effects on animals and the availability of vegetation, weakening the resilience of agricultural systems (Pastoral Platform of Chad, 2015), and challenging social equity/responsibility. Policies to support silvo-pastoral systems where appropriate is a promising way to restore soil and pasture quality, to improve resource efficiency, to strengthen the resilience of animals and agro-ecosystems in the face of climate change, harsh weather and poor soil conditions.

Box 23 Improving pastoral systems in the Sahel and the Sahara

Pastoral systems in the Sahel and the Sahara are widespread in the arid zones with low and irregular rainfall, water and natural forage resources. They cover several types of animals and shape the mode of life of pastoral societies. They are often mobile where men and herds follow water and pastures on very broad availability spaces. Livestock plays a central role in the economy of Sahelian countries with a contribution to the agricultural GDP sometimes ranging up to 44 percent (SWAC-OECD/ECOWAS, 2008). Livestock is also one of the main economic activities, on which the poorest populations are dependent as a source of food and cash income.

According to most studies (Pastoral Platform of Chad, 2015; FAO/CIRAD, 2012) on the issues of the development of pastoralism, there are a set of related challenges especially in: mitigating conflicts between pastoralists and other farmers; improving penetration in urban markets; facilitation of access to water and land; and better targeting of emergency programmes to better adapt to the sustainable development of pastoralism. Development programmes should target vulnerable pastoral societies by integrating sustainable principles, including strengthening the resilience of pastoralism to climate change.

These challenges require greater participation of nomadic pastoral societies in particular in decision-making in local governance while revitalizing inclusive decentralization policies. This implies fully integrating, establishing and implementing transparent mechanisms throughout the marketing chain, enhancing the role of specific crafts and skills to local societies, especially of women and young people, and promoting the establishment and involvement of representative non-governmental organizations in governance to defend the rights and interests of pastoralists (Cisse, 2008).

The resilience of pastoral societies can also be improved through secure transboundary movements, the development of insurance systems incorporating specificities of pastoralists and nomads, strengthening dialogue between applied research centres and pastoral organizations in order to establish a dynamic transfer of knowledge, and increasing the productivity and profitability of pastoral systems while promoting the exchange of experiences in this field between countries.

This improvement in trade can take the form of encouraging the development of pastoral products and improving coordination, developing secure marketing systems related to transhumance, strengthening the capacity of local organizations to master trade processes and establishing a common pricing system favouring the development of regional clusters of local products, to help them compete with imports.

Social sustainability is one of the major components on which to build the sustainable development of pastoralism. Improving the access of pastoralists to public human and animal health services, education and training can enhance the socio-cultural ties from sharing common resources.

The implementation priorities start by defining strategic objectives for all policies to reduce the vulnerability of pastoralists and ensure sustainability. Prioritizing policy interventions and planning are then needed in order to protect the livelihoods of the most vulnerable segments of society while seeking to improve the productivity of pastoral production systems and access to food. Finally, strengthening the governance of food and nutritional security policies will contribute to making the whole policy process more efficient.

The priorities for action are:

- *Improve governance and security* by involving pastoral societies in local, national and international participatory governance mechanisms, including: improving land-tenure rights and decentralization to fully integrate nomadic societies in the governance of land; giving a greater role to livestock in development plans; disseminating information on the sustainable management of resources and pastoral land rights.
- *Improve connections to markets* and create diversified market opportunities to better value animal production; promote the development and marketing of domestic production to supply urban markets; improve sanitary, food safety and quality standards; better target investment in market infrastructures; encourage private investment in the production and distribution of livestock feed; improve the transformation of animal products (dairy in particular); and increase the supply and availability of zootechnical and veterinary products and services.
- *Provide and protect the access of pastoralists to public services.* This includes: improved human and animal health services and pursuing innovations in the twinning of the two; intensify research for innovations in public policies for basic education and vocational training of young people in pastoral regions; strengthen the links between policies, culture and management of shared resources; and strengthen the capacity of civil society organizations to participate in the development, implementation and monitoring of policies. The central challenge is to provide social protection programmes and public services (health and education) adapted to the specific needs of pastoral systems and communities.
- *Provide and protect access to pastoral resources* (notably water and land) and ensure that pastoralists' customary land and water rights are protected. Ensure that land management, investments and hydro-agricultural development projects take pastoral concerns into account to build sustainable pastoralism and to enhance social equity/responsibility by integrating transhumance, forestry and agriculture in territorial development, while respecting the rights of indigenous peoples to commonly-owned land and natural resources.
- *Implement a fairer taxation system* on the marketing channels for livestock products, to enhance value-added through the processing and marketing of pastoral products.
- *Better target emergency assistance*, giving consideration to the specificities of pastoralist systems in terms of their resilience and vulnerabilities, with regard to technical needs (health of livestock, social management of water resources and pasture), social aspects (access of families of pastoralists and agro-pastoralists to basic social services: health, education, hygiene-water-sanitation) and economic (linkages between livestock and cereals), all at different scales.
- *Devise development strategies that take into account the specific mobility-related needs of pastoral systems*. Priorities include the need to better secure cross-border trade, to remove illicit levies and more generally reduce the risk of theft in crossing national borders. Governments must also strengthen interstate cooperation to facilitate cross-border movement of pastoralists to promote regional exchanges.

4.4.3 Commercial grazing systems

Current situation

Commercial grazing systems score well in terms of resource efficiency when they use land that has low value for alternative uses. Some systems are able to enhance carbon sequestration, biodiversity and landscape benefits. Other commercial grazing systems, however, are associated with deforestation, polluted watercourses and soil erosion that is a result of overstocking. Their relatively low dependence on purchased inputs means that these systems are relatively resilient to external shocks but they remain vulnerable to climate change. In addition, ruminant animals are significant contributors to GHG emissions. Moreover, where the expansion of such systems displaces smallholders and where hired farm worker conditions are not protected, social equity/ responsibility outcomes are compromised.

Operational priorities for action

In moving towards SAD for FSN the priorities for commercial grazing systems are: to achieve a better balance between the natural resource base, maintenance of ecosystems and the stocking rate of livestock; to improve genetic diversity and feeding practices; to protect and promote the land rights and natural resource rights of indigenous peoples; and to improve working conditions and security of employment (social equity and responsibility), while raising overall productivity (resource efficiency).

The priorities for action are:

- *Maintain and improve grassland management practices.* Recent experiences have shown that different levels of intensification can hugely enhance livestock production on natural grasslands. As illustrated with some beef production systems, livestock production can, in some cases, quadruple without any recourse to external inputs, relying instead on controlling stocking and managing natural vegetation (Carvalho *et al*., 2008, 2011). Additional benefits include improved soil health.
- *Contribute to climate change mitigation and adaptation through pasture management.* Enhancing cattle diets can reduce GHG emissions from enteric fermentation and increase carbon stocks in soils. Better pasture management can increase grazing efficiency, which ensures more forage is available during periods of climate variability (Herrero *et al.,* 2016).
- *Improve the stocking and management of grassland–ruminant ecosystems* (see Box 24) as an efficient, sustainable method of producing high-quality protein with minimal (or even positive) environmental impacts. As argued by Tilman *et al*. (2002), ruminant production on grasslands can take advantage of the high efficiency of ruminant guts to convert low-quality forage into high-protein human foods, including dairy products and beef.
- *Develop a crop–livestock–forestry integration* system (CLFIS) (see Box 11) that involves the integration of three production activities on the same land: agriculture, livestock and forestry. Cattle benefit by the availability of shade from trees, losing less fat in hot weather. They also benefit from better quality pastures, which improves farming capacity and reduces slaughter age. Furthermore, crop rotation applied with direct tillage reduces soil degradation, generating positive effects on the environment. Annual crops provide quick returns to producers that redeem the cost of adapting degraded areas into a CLFIS. In the medium term, the producer makes a profit from livestock, while forestry provides longer-term yields in addition to being an important source of energy, which can be extracted from the associated biomass. The system also generates employment for skilled and qualified employees, improving socio-economic conditions for rural workers (Ortiz and Alfaro, 2014).
- *Protect native forests from deforestation.* Grasslands, other native ecosystems and high conservation value areas are protected from land conversion and degradation (see Box 25).

The principal merits of commercial grazing systems are in the use of pastures that can have relatively low value for alternative activities, the maintenance of soil quality, and the relatively light environmental footprint of extensive systems. Nonetheless, the contribution to GHG emissions per ruminant animal is relatively high, there are risks of too-high stocking rates on fragile land, and deforestation and displacement of indigenous peoples from their lands (particularly their customary use areas) is too common, as are poor conditions for hired workers. In many countries, the livestock sector itself has voluntarily started to take action to improve environmental sustainability, albeit still most often at the pilot project level. Policies have varied considerably across different countries. In the case of the New Zealand sheep meat sector, the policy was to reduce support and protection to the sector, which resulted in farmers being exposed to market forces, thereby requiring farmers to make changes in their farm practices and marketing, but complemented by environmental legislation. In many countries the focus has been on improving resource efficiency, including the reduction of GHG emissions, through the dissemination of information on the adoption of best management practices (optimal stocking, improved pastures, grazing management, genetic improvements) and on improving resilience by adapting to droughts and floods (adaptation and preparedness), as well as some limited progress in addressing rights of workers in some countries.

Box 24 Sustainability in the New Zealand sheep meat sector

Sheep numbers in New Zealand reached a high point of 70.2 million in 1982, bolstered by a range of subsidies and support to farming at that time. From 1984, in a widespread economic reform process, these assistance measures were fully removed, so that by 1990 the effects of support had essentially dissipated. At this point the national sheep flock had adjusted to 57.9 million. Over the following 25 years sheep numbers have halved (to 29.8 million in 2014), but the total production levels of lamb meat have reduced only marginally (minus 7 percent).

From 1984, with low world prices for sheep meat and high budgetary costs to the government, a reforming government removed financial support measures, including to other agricultural commodities and implemented other economy-wide reform measures. Farmers were thus faced with exposure to market forces, without support measures. This market-orientation forced farmers to make changes in their farm practices and marketing.

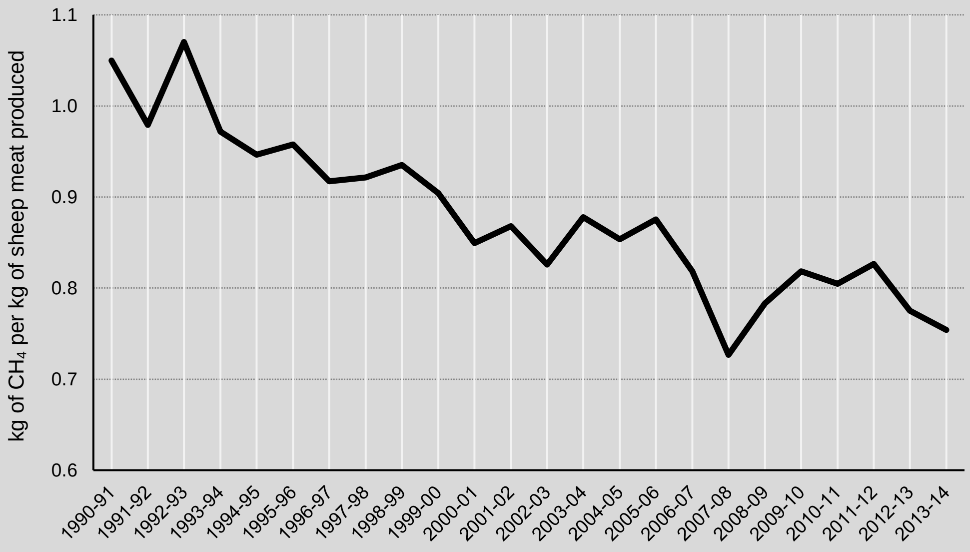
Farmers adjusted their management systems to improve productivity of their sheep flock and the profitability of their operations. The new market-oriented regime revealed that many sheep were being farmed on land that was too marginal to be economic. Also, in many areas the stocking rate (sheep per hectare) was too high to provide optimum performance: this overstocking led to lower lambing percentages, lower growth rates in lambs, lower carcass weights at slaughter, soil erosion on fragile land and contributed to pollution of watercourses. Experience revealed that improved grazing management could have positive effects on these performance measures.

The industry used various approaches, such as: reducing sheep numbers, at the unprofitable margin; ceasing farming on marginal lands (too steep, too remote, too dry or low fertility soils); improving performance of the flock (fertility, growth rate, slaughter weight), by enhanced pasture content and production; improved grazing management (fencing, rotational grazing); genetic improvement; and reducing stocking rates (to an optimal level).

Production performance improved and results showed a return to profitability for most farmers in most years, after the initial and, in some cases, difficult transition period.

A life cycle assessment study (LCA) that estimated the emissions of GHGs from sheep production showed that methane (a major GHG from ruminant animals) emissions per kilogram of lamb meat processed reduced over a 23-year period (see figure), due to the productivity improvements outlined above.

Total New Zealand sheep farming methane emissions per kg of processed meat



New Zealand sheep farmers are also implementing practices directed at environmental improvement and hence enhanced sustainability of production. Beef and Lamb New Zealand, an industry organization, has developed an environmental strategy to enable sheep and beef sector efficiency and profitability, while sustainably managing air, soil and water, and natural resources. Mechanisms include provision of tools and services that assist sheep and beef producers, and development of an on-farm measurement tool to track the effectiveness of initiatives directed at achieving environmental goals.

Source: Beef + Lamb New Zealand Economic Service, Ministry for Environment.

Box 25 Livestock and deforestation: pathways for sustainable beef in the Brazilian Amazonia

According to the Ministry of Agriculture, Livestock and Food Supply (MAPA), Brazil, the second largest producer of beef in the world, will account for an estimated 44 percent of global meat production by 2020. Over the past 20 years, about 10 percent of the Brazilian Amazon forest has been lost, and more than half of this loss was due to the conversion of the forest to cattle pasture (Faminow and Vosti, 1998).

During the last decade, there have been strong actions to reduce deforestation through two key areas of intervention:

(i) Public policies for reduction and monitoring of deforestation to enhance environmental governance (Forest Code Compliance) and improvement of governmental technical capacity (federal, state and municipal) in order to help cattle ranchers, retailers and other stakeholders in the beef value chain in the preservation of the natural ecosystems and thus to improve the productivity of cattle production.

(ii) Development and adoption of new technologies to intensify production and improve pasture quality to increase the efficiency of cattle ranching and consequently to reduce deforestation.

Since 1965, the Brazil's Forest Code requires Amazonian landowners to set aside between 50 to 80 percent of their property under natural vegetation cover. With the approval of the new Brazilian Forest Code in January 2010, and the mandatory environmental registry of rural farms (*Cadastro Ambiental Rural*, CAR Forest Code), compliance has increased. The new system requires landowners to participate in a registry, which enables monitoring of legal and illegal deforestation and to track compliance with environmental regulations and more responsible production. As of 2014, most ranchers in the Amazonia are at or very close to the 20 percent limit that the legislation permits to be converted into pasture.

At the 2009 Copenhagen Climate Conference (COP15), Brazil pledged to voluntarily reduce GHG emissions in the range of 36–39 percent by 2020. The actions include, among other measures, the reduction in deforestation in the Amazonia (80 percent) and the *cerrado* (40 percent), restoration of degraded pastures (about 80 million ha), wide implementation of Brazilian good agricultural practices, reduction in energy consumption, stabilization of the share of renewable energy sources in the energy matrix, and increased use of biofuels.

To fulfil its commitment of reducing GHG emissions, Brazil launched the ABC programme in 2010 to fund low-interest loans for those activities including the promotion of more sustainable cattle ranching practices, with three specific credit lines to support rehabilitating degraded pastureland, crop–livestock–forestry integration and treating cattle waste to generate energy.

The Brazilian Roundtable on Sustainable Livestock (GTPS – *Grupo de Trabalho da Pecuária Sustentável*), a multistakeholder partnership initiative, which covers 900 farmers on one million hectares in five Brazilian States (Mato Gosso, Mato Grosso do Sul, Pará, Rondonia and Bahia) is promoting principles, standards and common practices to be adopted by its members to contribute towards sustainable cattle ranching systems that are environmentally friendly, economically viable and socially acceptable.

4.4.4 Intensive livestock systems

Current situation

Intensive livestock farming systems score well in terms of resource efficiency when measured by conventional productivity indicators (output per unit of input or inputs) and for some environmental impacts in terms of per kilogram produced (such as GHG emissions). But in general, intensive livestock systems score less well when measured more broadly, taking into account overall environmental impacts. Moreover, the high degree of specialization and dependence on purchased inputs that typify intensive production make these systems less resilient and more vulnerable to some economic external shocks, while social equity/responsibility can be compromised. For example, some aspects of hired farm worker conditions as well as animal welfare need to be improved. Intensive systems are also implicated in high levels of antimicrobial use and increased risk of animal disease emergence.

Box 26 Changing structure of the pig sector in China

China's livestock was dominated by pig production in agricultural regions, with a small contribution from non-pig production in pastoral areas. In 1980, the total meat production was 12.05 million tonnes (mt), among which pork accounted for 94 percent at 11.34 mt. However, the relative importance of pork production gradually decreased while the total meat production showed strong growth for more than three decades. By 1990, total meat production had increased to 28.6 mt, or more than doubled in 10 years, while the share of pork declined to 80 percent (22.8 mt). During the last ten years of the twentieth century, the total meat production increased to 60.1 mt, more than double in ten years again, with the share of pork declined further to 66 percent (39.7 mt). The growth of total meat production slowed down a little during the first 13 years of the twenty-first century, standing at 85.4 mt by 2014, while the share of pork production maintained at about the same level of 65.1 percent (State Bureau of Statistics, 2015).

Pork production was dominated by backyard pig raising; almost every farmer household raised one pig or two in a year. Backyard pig production was essential to the survival of small farm holders, as it was not only the main source of badly needed cash income, but also the main source of manure necessary to grow crops. Backyard pig production was cost efficient, not only because opportunity cost for labour was low or even negligible, but also as the use of commercial feed was very limited due to wide use of domestic wastes. More importantly, manure generated from backyard production was crucial to growing crops on the farm as in the past. In many cases, the value of manure from backyard pig production was as much as the value of the pig itself.

The situation has changed dramatically in the last three decades. More than 300 million rural workers have found off-farm jobs, often far away from their homes, and the level of chemical fertilizer use per hectare of sown areas has increased from 86 kg in 1980 to 359 kg in 2013. The backyard pig production has lost its importance to small farm holders: they have found better opportunities to use their labour, and they no longer depend on manure. Following huge rural–urban migration, opportunity costs in raising pigs, in collecting plant materials for manure, and in application of manure, have all increased dramatically. According to the Department of Prices of the State Development and Reform Commission (2015), the wage rate in agricultural production in 2014 was four times as high as that in 2004. And as household size has reduced with some members working at least partially away from home, the quantity of domestic wastes has also reduced and become uneven, so the feed availability for backyard pig production has also declined.

As a result, pig production has experienced a shift from backyard-based to large-scale commercial production. According to the *Animal Husbandry Yearbook*, the number of households/firms with annual production of more than 50 000 pigs has increased from 16 in 2001 to 187 in 2012, those with annual production between 10 000 to 50 000, between 3 000 to 9 999 and between 500 to 2 999 have increased from 747 to 4,363, from 2 798 to 19 735, and from 22 956 to 231 271, respectively, during the same time period. As a comparison, the number of households who raise less than 50 pigs in a year was only 51.9 million, less than 20 percent of the total rural households. The statistics indicate that about 30 million farm households abandoned pig production in the five years during 2007 to 2012 (Editing Committee of Animal Husbandry Yearbook, 2014). It could reasonably be assumed that those households that abandoned pig production were originally engaged in traditional backyard pig production, i.e. raising one or two pigs a year with spare time and domestic waste.

The changing structure of the livestock sector in China may have led to serious problems in non-point pollution, as manure is no longer used as a fertilizer, and as the large and intensive pig farms may not necessarily be located in major agricultural regions. The proper treatment of manure is very costly if the intensive farms cannot use up all the manure generated by themselves, and their scale is not big enough to process the manure for commercial use. Following strengthened environmental regulation in the worst polluted regions, many intensive pig farms in Zhejiang province closed down in early 2015, which led to a significant increase in pork price. It is hoped that tightening environmental regulations may lead to further restructuring of the sector: further expansion and concentration of pig production may lead to the processing of manure as a commercial fertilizer and be profitable due to economy of scale, and relocation of large-scale pig production may reduce the costs of collecting manure and distribution of fertilizer produced from manure.

If this turns out to be the case, further restructuring of the pig sector may reduce the level of non-point pollution due to better utilization of manure and possible reduction in chemical fertilizer application.

Box 27 Intensive livestock systems in Europe

Intensive systems are typical of the majority of pig, poultry and, to a much lesser extent, dairy cows in Europe. These systems show an increasing concentration in size and location, high productivity, maximizing financial margins, integration into supply chains, and a development model driven by mainstream research and multinational food-processing groups. For example, in 2010, 43 percent of all pigs in France were reared in farms with over 1 000 fattening pigs, against 81 percent in Denmark, 63 percent in the Netherlands, 75 percent in Spain and 44 percent in Germany. A French farmer today produces an average of 100 kg of pig carcass per hour worked (50 minutes per pig), similar to what farmers in Spain or Germany produce but much less than what farmers in Denmark or the Netherlands produce (135 to 140 kg, 35 minutes per pig) (IFIP, 2013). Southern and eastern Europe countries are still dominated by small-scale farming, although intensive farms are found in pig and dairy production in Spain, and in the reconversion of old state or collective farms in the east.

Dairy farming is slowly moving towards greater intensity, with some resistance, particularly in France. The average herd size remains low in Europe: 60 dairy cows in France, very similar to Ireland and slightly lower than the Netherlands (80 cows). The largest herds are found in Denmark (150 cows on average) and in the northern and eastern states of Germany where several farms have more than 2 000–3 000 cows. The number of dairy farms has fallen annually despite the introduction of milk quotas in 1984: by 13 percent in Spain, 8 percent in Denmark, 7 percent in Italy and in the United Kingdom, 6 percent in the Netherlands, and, 5 percent in France (Institut de l'élevage, 2007, 2013). The removal of milk quotas in 2015 is likely to increase concentration in both dairy farm size and location.

Nevertheless, three important characteristics of European livestock systems should be noted. First, there is great diversity, in particular in dairy systems, ranging from the largely confined operations in the Netherlands and Denmark, to mainly grazing systems in France and Ireland. Second, there is an increasing emphasis on quality labelling of production in both poultry and pig meat production. For example, in France, 30 percent of chicken sold is certified with a quality label, concerning the method of production. Third, there is growing attention to global and local environmental issues, animal welfare and concerns that technical progress is generating “animal producing machines” and “factory farms” (Porcher, 2011). These issues are also fuelled by pressure from NGOs appealing for a reduction in meat consumption on the grounds of animal welfare, production methods or environmental impacts as well as on the grounds of the impacts on health. One result has been the reduction in the use of antibiotics in the Danish and Dutch pig farming sectors (see in the text below).

Even though intensive systems lead to low consumer prices, and consistent supplies and quality, the European Union, national governments and supermarkets have imposed or require strict standards and regulations concerning production methods, which has given rise to concerns that the European production is less competitive due to higher costs.

In addressing the challenges of intensive livestock systems the Animal Task Force (ATF), a European think tank bringing together most of the large animal husbandry research organizations, has proposed ways to meet the challenges of competitiveness, the reduction of environmental impacts, and improving animal welfare through the development of alternative eco-efficient technical models with multicriteria appraisal variables. Others propose the development of precision livestock farming (Lokhorst and Groot Koerkamp, 2009), which can generate gains in terms of work productivity (robotics) with the ability to track the vital parameters and technical efficiency and health of individual animals (decision support software and sensors).

Three principles underlie these challenges: exploring alternative hybrid production models with broader objectives than competitiveness and price; developing participative research, involving farmers, other stakeholders and NGOs, local and regional authorities, to define scenarios for livestock farming regionally and nationwide (Darnhofer *et al.*, 2012); and developing methodologies to design innovative systems at the farm and regional levels (Bos *et al*., 2012) and identify resources to help transition pathways (Elzen *et al*., 2012; Coquil *et al.*, 2014).

Operational priorities for action

In moving towards SAD for FSN, intensive livestock systems will have to internalize the externalities so as to improve their environmental impact. The priorities for intensive livestock systems are: to reduce environmental damages, especially water pollution and GHG emissions, including through improving feeding and breeding practices; to raise animal health status and to improve animal welfare; to reduce the risks of antimicrobial resistance; to encourage international agreements to facilitate less risky trading conditions; to address market concentration; and to improve working conditions. Raising productivity remains important. Addressing these priorities implies a degree of transformation of intensive farming systems, which will not be easy to achieve at an individual farm level, although there is generally some margin of adjustment for change. Most of these priority areas will require system-wide interventions.

The priorities for action are:

- *Invest in R&D* along the complete food chain that strikes a balance between increasing production and reducing environmental harms, including the need to reduce food losses and waste.
- *Expand precision livestock farming* (Lokhorst and Groot Koerkamp, 2009), with the ability to track the technical efficiency of individual animals.
- *Implement policy changes to reduce the prophylactic use of antibiotics in animal care*. The examples of Denmark (51 percent decrease in antimicrobial use for swine between 1992 and 2008 and 90 percent between 1995 and 2008 for poultry) and the Netherlands (56 percent decrease in antibiotic sales to livestock farms between 2007 and 2012) show that important improvements are achievable and can build on concrete examples (O'Neill, 2015; O'Neill, 2016).
- *Improve animal welfare* in intensive livestock systems, in line with OIE guidelines and best practices and national standards, drawing on the latest scientific research.
- *Reduce the environmental impact of intensive livestock systems by:*
    - Encouraging the recycling of nutrients and animal waste, for example to fertilize pastures, and using forage and grain legumes to increase the nitrogen in soils (Peyraud *et al.,* 2014) in order to reduce the need for mineral nitrogen; explore possibilities to export animal waste as fertilizer to other farms or other agricultural regions; take advantage of the possible coupling of carbon and nitrogen cycles in grasslands and crop–livestock systems (Soussana and Lemaire, 2014).
    - Encouraging the transformation of intensive systems through: the integration of livestock and crop production (e.g. Smith *et al.,* 1997; Devendra and Thomas, 2002; Lemaire *et al*., 2014; Peyraud *et al.,* 2014); the adoption of agronomic practices used in those mixed-farming systems that are the most efficient in the use of nutrients.
    - Increasing the sustainability of feed production. For example, soybean production has expanded significantly due to the growing demand for livestock feed. Soybean production is associated with high levels of pesticide use and large GHG emissions, linked in part to land-use change with the expansion of production. No-tillage systems reduce GHG emissions, and together with diversified farming systems, careful use of fertilizers and a rotation of low-stubble crops (soybean) with high-stubble crops (wheat, maize), there are opportunities to limit the environmental harm from soybean production (World Bank/CIAT/CATIE, 2014).

The principal merits of intensive systems are that they are associated with lower real prices over time for consumers, consistent quality, year-round reliability and thus they make a notable contribution to FSN. This is due to their high productivity, linked to their reliance on innovative technologies and mechanization but also their systematic externalization of costs. Given that there are concerns as to the sustainability of the resources on which the livestock sector depends, the environmental footprint of intensive systems and their impacts on zoonoses, animal health and welfare, governments have increasingly imposed standards, regulations and financial penalties on the production, confinement methods, location and environmental impacts of intensive livestock operations. The livestock sector itself has also voluntarily started to take action to improve environmental sustainability and animal welfare. However, the sustainability of production is especially compromised in countries where producers are not held accountable for negative environmental externalities, including where production-linked subsidies are not conditional upon environmental performance.

4.5 Concluding comments

This chapter demonstrates that there are potential pathways towards SAD, with proven solutions, in all the farming systems. Even if SAD pathways must be adapted to each context, a solution used in a given region or system can also inspire stakeholders when elaborating SAD pathways in another context.

The diversity of farm types across the world cautions against making generalizations with respect to the pathways and responses towards SAD, even when they may be faced with similar challenges. There are also differences within particular farming systems, so the context is a key consideration. No pathway offers the “silver bullet” for all countries and farming systems. But it is crucial that pathways chosen are based on scientific evidence and experience-based knowledge.

Countries are not starting from a “clean sheet”, having the luxury of choosing pathways that would be optimal in terms of SAD for FSN. They must work from where they are now and in the political and institutional landscape through which decisions will be taken and implemented for the foreseeable future. All stakeholders will need to improve situations progressively, using the instruments and approaches likely to lead to high-impact outcomes for FSN, and remembering the importance of long-term change and dynamic effects.

Responses, in a given context, region or system, will need to simultaneously address multiple challenges, both at the global and farming system levels. In an ideal world, the aim would be to find and deliver win–win solutions across all the dimensions of SAD. But in practice trade-offs have to be made, implying difficult choices. For example, the pursuit of economic efficiency may be at the expense of preserving a way of life for smallholders across the three dimensions of economic, environmental and social sustainability.

CONCLUSION AND WAYS FORWARD

Agricultural development is a particularly complex issue because it requires a long-term, integrated and broad perspective. It means that a very wide vision of the sector itself is needed, including dynamic links to overall economic development, natural resources, demographic and social issues, and the trends affecting these aspects in the long term. This report has addressed the issues of agricultural development from the perspective of FSN in all its dimensions (availability, access, utilization and stability). It aims at proposing pathways for sustainable agricultural development to confront the many challenges in order to enhance its contribution to food security and nutrition.

Livestock plays a critical role as an engine for the development of the agriculture and food sector, as a driver of major economic, social and environmental changes in food systems worldwide, and is central to understanding the issues around SAD.

The relationships between ASF, nutrition, and health are complex. While small amounts of meat, dairy and eggs added to grain-based diets have beneficial nutrition effects, excessive amounts of red and processed meat have been linked to an increased risk of chronic disease. In general, consumption levels of some ASF needs to contract in some places and among some populations, while increasing in others. Such a shift would allow for greater convergence of consumption at the global level.

The report recognizes that all the farming systems are under stress and face cross-cutting or specific challenges that need to be urgently addressed – but that they all have the potential, in different ways, to progress towards SAD and better contribute to the ultimate goal of FSN for all, now and in the future.

For some of the challenges identified in this report, there is a considerable body of scientific knowledge and practical experience available as to *what* could be done. But there is much less agreement on *how* to actually realize the shifts in practices and behaviour needed to address global and local challenges simultaneously, *when* actions should be taken, over which period of time, in what sequence, and by *whom*. Crucially, many require more knowledge and data, implementation of better-targeted policies, international cooperation and an institutional architecture to engage stakeholders in identifying priorities for collective action, addressing trade-offs, while avoiding "free riders" who can benefit from others' actions but do not bear the costs of contributing to the solution.

Pathways and operational priorities for actions will, of course, differ across regions, countries and across farming systems: smallholder mixed, pastoral, commercial grazing, intensive livestock systems, as well as plant-based systems. Nevertheless, this report suggests a common approach to elaborate those pathways drawing on three operational principles (improve resource efficiency, strengthen resilience and secure social equity/responsibility) that both show the direction towards sustainability and propose concrete ways forward. SAD strategies and policies for FSN have to organise transitions, starting from the current situation in a given country or farming system, proposing pragmatic and implementable solutions and ways forward, resulting from political consensus that can be reached among the different stakeholders involved. Pathways are needed for all farming systems and one of the critical challenges is to consistently manage the co-existence of systems and their pathways at supra levels.

In considering innovative pathways to SAD, there are many hurdles to overcome, not least the inertia of existing food systems and institutional frameworks that can favour the status quo. Alternatives and transitions may also be constrained by production and consumption path-dependency and technological lock-in. To change direction is costly, with uncertain results, and takes time. Moreover, the direction of change can be controversial, in part because it will impact the patterns of distribution of power, costs, benefits, and risks along the food chains. Different pathways also imply different requirements of knowledge and resource needs, and challenge the resilience of systems (Thompson and Millstone, 2011).

This report highlights operational priorities for action, taking into account the constraints and perspectives of different policy makers and stakeholders. It acknowledges that there could be two kinds of priority areas of intervention: the most critical which are often also the more difficult to implement, and those that could show quick progress. In some cases, the most pragmatic way to move forward to SAD is to begin by actions that are easy to implement, backed not only by strong scientific evidence but also by sufficient political support and interest from stakeholders. Success in this first step could be catalytic in the sense that it will not only change the orientation of agricultural development but also the perspectives of different stakeholders. This could help to build a political consensus allowing the implementation, in a second step, of more ambitious actions.

Within this perspective, building on the main findings of this report, the HLPE has proposed a short set of recommendations for policy-makers and stakeholders with the view to inform political debates in the CFS and at the national level.

ACKNOWLEDGEMENTS

The HLPE warmly thanks all the participants who contributed with very valuable inputs and comments to the two open consultations, first on the scope of the report, and second, on an advanced draft (V0). All contributions are available online at www.fao.org/cfs/cfs-hlpe.

The HLPE thanks the 16 peer-reviewers for their review of a pre-final draft (V1) of the report. The list of all HLPE Peer Reviewers is found online at www.fao.org/cfs/cfs-hlpe.

The following individuals are thanked warmly for their contributions, suggestions and inputs to the work of the panel:

Robyn Alders, Jonathan Brooks, Benoît Dedieu, Eugenio Díaz-Bonilla, Bruno Dorin, Adrienne Egger, Catherine Esnouf, Hubertus Gay, Maggie Gill, Vincent Gitz, Dominic Glover, Michael Griffin, Hans Herren, Hsin Huang, Abdulai Jalloh, Josef, Kienzle, Chantal Le Mouël, Philippe Lecomte, Stewart Ledgard, Gilles Lemaire, Jonathan Levin, Harinder Makkar, William Masters, Holger Matthey, Alexandre Meybeck, Jean-Marc Meynard, Lesley Mitchell, Anne Mottet, Joseph Mpagalile, Baldwin NkhanedzeniNengovhela, Carolyn Opio, Jean-Louis Peyraud, Ugo Pica-Ciamarra, Graham Pilgrim, Nitya Rao, Brian Revell, Fabio Ricci, Walter Rossing, Bertrand Schmitt, Sérgio Schneider, Simbarashe Simba Sibanda, Ralph Sims, Jean-François Soussana, Henning Steinfeld, Gerard Sylvester, Pablo Tittonell, KunioTsubota, Steve Wiggins.

The HLPE process is entirely funded through voluntary contributions. HLPE reports are independent collective scientific undertakings on topics requested by the CFS Plenary. HLPE reports are global public goods. The HLPE thanks the donors who have contributed since 2010 to the HLPE Trust Fund, or provided in-kind contributions, thereby enabling the process of work of the panel, while fully respecting its independence. Since the creation of the HLPE, it has been supported by Australia, the European Union, France, Ireland, Norway, Russia, Spain, Sweden, Switzerland, and the United Kingdom.

REFERENCES

Acton, J. 2014. *Land sharing vs land sparing: can we feed the world without destroying it?* The Royal Society, 3 December 2014 (available at http://blogs.royalsociety.org/in-verba/2014/12/03/land-sharing-vs-land-sparing-can-we-feed-the-world-without-destroying-it/).

Agarwal, B. 2012. *Food insecurity, productivity, and gender inequality*. Institute of Economic Growth Working Paper No. 320, University of Delhi.

Agarwal, B. 2014. Food sovereignty, food security and democratic choice: critical contradictions, difficult conciliations. *The Journal of Peasant Studies*, 41(6): 1247–1268.

Ahuja, V. & Sen, A. 2008. Scope and space for small-scale poultry production in developing countries. *In* O. Thieme & D. Pilling, eds, *Poultry in the 21st century: avian influenza and beyond*. Proceedings of the International Poultry Conference, 5–7 November 2007, Bangkok, FAO Animal Production and Health Proceedings, No. 9. Rome. (Extended electronic version).

Alcorn, T. & Ouyang, Y. 2012. China's invisible burden of foodborne illness. *The Lancet*, 379(9818): 789–790.

Alkemade, R., Reid, R.S., van den Berg, M., de Leeuw, J. & Jeuken, M. 2013. Assessing the impacts of livestock production on biodiversity in rangeland ecosystems. *Proc. Natl. Acad. Sci. USA,* 110(52): 20900–20905.

Altieri, M. 1987. *Agroecology: the scientific basis of alternative agriculture*. Boulder, USA, Westview Press.

Altieri, M.A. 1995. *Agroecology: the science of sustainable agriculture.* Boulder, USA, Westview Press.

Altieri, M.A. 1999. The ecological role of biodiversity in agroecosystems. *Agriculture, Ecosystems and Environment,* 74: 19–31.

Anderson, K., Cockburn, J. & Martin, W. 2011. Would freeing up world trade reduce poverty and inequality? The vexed role of agricultural distortions. *Policy Research Working Papers*, http://dx.doi.org/10.1596/1813-9450-5603.

Anderson, K., Pimbert, M. & Kiss, C. 2015. *Building, defining and strengthening agroecology.* ILEIA and Centre for Agroecology, Water and Resilience, Coventry University, UK.

Andersson, C.I.M., Chege, C.G.K., Qaim, M. & Rao, E.J.O. 2015**.** Following up on smallholder farmers and supermarkets in Kenya*. American Journal of Agricultural Economics*. doi:10.1093/ajae/aav006.

Appleby, M.C. & Huertas, S.M. 2011. International issues. *In* M.C. Appleby, J.A. Mench, I.A.S. Olsson & B.O. Hughes, eds, *Animal welfare*, Second edition, pp 304–316. Wallingford, UK, CAB International.

Bach-Faig, A., Berry, E.M., Lairon, D., Reguant, J., Trichopoulou, A., Dernini, S., Medina, F.X., Battino, M., Belahsen, R., Miranda, G. & Serra-Majem, L. 2011 Mediterranean Diet Foundation Expert Group. *Public Health Nutr.,* 14(12A): 2274–2284. doi: 10.1017/S1368980011002515.

Barrett, C.B. & Bellemare, M. F. 2011. Why food price volatility doesn't matter. *Foreign Affairs (available at https://www.foreignaffairs.com/articles/2011-07-12/why-food-price-volatility-doesnt-matter).*

Barrett, C. B. & Maxwell, D. 2005. *Food aid after fifty years: recasting its role.* New York, USA, Routledge.

Bennett, R.M. & IJpelaar, J. 2005. Updated estimates of the costs associated with 34 endemic livestock diseases in Great Britain: a note. *Journal of Agricultural Economics*, 56(1): 135–144.

Bernstein, H., Lenin, V.I., Chayanov, A.V. 2009. Looking back, looking forward. *Journal of Peasant Studies*, 36(1): 55–81.

Bernstein, H. 2014. Food sovereignty via the 'peasant way': a sceptical view. *The Journal of Peasant Studies*, 41(6): 1031–1063.

Bevan, J. 2007. *Between a rock and a hard place: armed violence in African pastoral communities*. Nairobi, UNDP.

Blesh, J. & Drinkwater, L.E. 2013. The impact of nitrogen source and crop rotation on nitrogen mass balances in the Mississippi River Basin. *Ecological Applications*, 23(5): 1017–1035.

Bolton, T. 2015. *The state of the South African poultry industry.* Supermarket and Retailer for FMCG, Retailers, Wholesalers and Suppliers*.* March 2015 (available at: http://www.supermarket.co.za/SR_Downloads/S&R%202015-3%20Poultry.pdf)

Bos, A.P., Spoelstra, S.F., Groot Koerkamp, P.W.G., de Greef, K.H. & van Eijk, O.N.M. 2012. Reflexive design for sustainable animal husbandry: mediating between niche and regime*. In* G. Spaargaren, A. Loeber & P. Oosterveer, eds. *Food practices in transition. Changing food consumption, retail and production in the age of reflexive modernity,* pp. 229–256. London, Routledge.

Bouwknegt, M., Mangen, M.J.J., Friesema, I.H.M., van Pelt, W. & Havelaar, A.H. 2014. *Disease burden of food-related pathogens in the Netherlands*. RIVM Letter Report 2014-0069.

Bravo-Baumann, H. 2000. *Gender and livestock*. *Capitalisation of experiences on livestock projects and gender. Working document.* Bern, Swiss Development Cooperation.

Brown, R. 2012. *Structure & dynamics of the European meat industry: 2010/11-2015.* For UECBV Conference in Brussels, 24 October 2012. GIRA (available at http://ec.europa.eu/dgs/health_food-safety/information_sources/docs/ahw/pres_24102012_opening_4_richard_brown_en.pdf).

Bruinsma J. 2003. *World agriculture: towards 2015/2030, an FAO perspective.* Rome, FAO/Earthscan.

Buiatti, M., Christou, P. & Pastore, G. 2013. The application of GMOs in agriculture and in food production for a better nutrition: two different scientific points of view. *Genes & Nutrition,* 8(3): 255–270. doi:10.1007/s12263-012-0316-4.

Burnett, K. & Murphy, S. 2014*.* What place for international trade in food sovereignty? *The Journal of Peasant Studies*, 41(6): 1065–1084.

Busch, L. & Bain, C. 2004. New! Improved? The transformation of the global agrifood system. *Rural Sociology*, 69: 321–346.
Buse, K. & Hawkes, S. 2015. Health in the sustainable development goals: ready for a paradigm shift? *Globalization and Health*, 11: 13. DOI: 10.1186/s12992-015-0098-8.
Buse, K. & Kent, S. 2015. Health in the sustainable development goals: ready for a paradigm shift? *Globalization and Health*, 11: 13. doi:10.1186/s12992-015-0098-8.
Byerlee, D., Stevenson, J., & Villoria, N. 2014. Does intensification slow crop land expansion or encourage deforestation? *Global Food Securit*y, 3(2): 92–98.
CAADP (Comprehensive Africa Agriculture Development Programme). 2015. *Final Communiqué*. 11th Comprehensive Africa Agriculture Development Programme Partnership Platform (CAADP PP) Meeting. Walking the talk: Delivering on Malabo Commitments on Agriculture for Women Empowerment and Development. 25–26 March 2015, Johannesburg, South Africa.
Calle, Z., Murgueitio, E. & Chará, J. 2012. Integrating forestry, sustainable cattle-ranching and landscape restoration. *Unasylva*, 63: 31–40.
Caron P., Biénabe E., Hainzelin E. 2014. Making transition towards ecological intensification of agriculture a reality: The gaps in and the role of scientific knowledge. *Current Opinion in Environmental Sustainability*, **8** : p. 44-52. http://dx.doi.org/10.1016/j.cosust.2014.08.004
Carpenter, S.R., Pingali, P.L., Bennett, E.M. & Zurek, M.B. 2005. *Ecosystems and human well-being: findings of the Scenarios Working Group of the Millennium Ecosystem Assessment.* Millennium Ecosystem Assessment Series, Vol. 2. Washington, DC, Island Press.
Carvalho, P.C.F., Paruelo, J. & Ayala, W. 2008. La intensificación productiva en los pastizales del río de la plata: tendencias y consecuencias ecosistémicas. In *Anais da Reunião Anual do Grupo Técnico em Forrageiras do Cone Sul – Grupo Campos. Minas*. Uruguay, INIA.
Carvalho, P.C.F., Nabinger, C., Lemaire, G. & Genro, T.C.M. 2011*. Challenges and opportunities for livestock production in natural pastures: the case of Brazilian Pampa Biome* (available at http://www.alice.cnptia.embrapa.br/bitstream/doc/907421/1/CarvalhoEtAl.2011.pdf).
Chará, J., Camargo, J.C., Calle, Z., Bueno, L., Murgueitio, E., Arias, L., Dossman, M. & Molina E. 2015. Servicios ambientales de Sistemas Silvopastoriles Intensivos: mejoramiento del suelo y restauración ecológica. *In* F. Montagnini, E. Somarriba, E. Murgueitio, H. Fassola & B. Eib, eds. *Sistemas agroforestales: funciones productivas, socioeconómicas y ambientales*. Editorial CIPAV, Cali (available at http://www.cipav.org.co/sistagro/descargar.php).
Christiaensen, L., Demery, L. & Kuhl, J. 2011. The (evolving) role of agriculture in poverty reduction - an empirical perspective. *Journal of Development Economics*, 96(2): 239–254.
Chuluun, T. & Ojima, D. 2002. Land use change and carbon cycle in arid and semi-arid lands of East and Central Asia. *Science in China (Series C)*, 45(Supp.): 48–54.
Cisse, S. 2008. The pastoral land in Mali, problematic, management, securing and settlement of conflicts relating thereto, in development and security of spaces Saharo-Sahelian countries: the asset of the pastoral livestock. Njamena colloque on pastoralism, 2013.
Collavo, A., Glew, R.H., Huang, Y.S., Chuang, L.T., Bosse, R. & Paoletti, M.G. 2005. House cricket small-scale farming. *In* M.G. Paoletti, ed. *Ecological implications of minilivestock: potential of insects, rodents, frogs and snails*, pp. 519–544. New Hampshire, Science Publishers.
Collier, P. 2008. The politics of hunger: how illusion and greed fan the food crisis. *Foreign Affairs*, 87(6).
Conway, G. 1987. The properties of agroecosystems. *Agricultural Systems*, 24: 95–117.
Coquil, X, Beguin, P. & Dedieu, B. 2014. Transitions to self-sufficient mixed crop–dairy farming systems. *Renewable Agriculture and Food Systems*, 29(3): 195–205. DOI: http://dx.doi.org/10.1017/S1742170513000458.
Correa, M. & Grace, D. 2014. Slum livestock agriculture. *In* N. Van Alfen, editor-in-chief. *Encyclopedia of Agriculture and Food Systems,* 5: 11–121. San Diego, USA, Elsevier.
CWF (Compassion in World Farming). 2014. *Economic implications of moving to improved standards of animal welfare*. CIWF reports (available at http://www.ciwf.org.uk/media/5885638/economic-implications-of-moving-to-improved-standards-of-animal-welfare-2014.pdf).
Darnhofer I., Gibbon, D. & Dedieu, B., eds. 2012. *Farming systems research into the 21st century: the new dynamic*. Ed. Springer. 490 p.
de Bruyn, J., Wong, J., Bagnol, B., Pengelly, B. & Alders, R. 2015. Family poultry and food and nutrition security. *CAB Reviews*, 10(13): 1–9 (available at: https://www.researchgate.net/publication/280362847_Family_poultry_and_food_and_nutrition_security).
de Haan, C., Van Veen, T.S., Brandenburg, B., Gauthier, J., Le Gall, F., Mearns, R. & Simeon, M. 2001. *Livestock development: implications for rural poverty, the environment, and global food security. Directions in development*. Washington, DC, The World Bank (available at http://documents.worldbank.org/curated/en/2001/11/1631692/livestock-development-implications-rural-poverty-environment-global-food-security).
de Haan C., Gerber P. & Opio, C. 2010. *Structural changes in the Livestock sector*. *In* H. Mooney, L. Neville, H. Steinfeld & F. Schneider, eds. *Livestock in a Changing Landscape, Vol. 1 Drivers, Consequences, and Responses*, pp. 35–50. Island Press.
de Schutter, O. 2010. *Report submitted to the Human Rights Council by the Special Rapporteur on the Right to Food*. New York, UN.

Delgado, C., Rosengrant, M., Steinfeld, H., Ehui, S. & Courbois, C. 1999. *Livestock to 2020: the next food revolution*. Discussion Paper 28. Washington, DC, International Food Policy Research Institute (available at http://core.ac.uk/download/pdf/6337610.pdf).

Department of Price of State Development and Reform Commission. 2015. *National benefit and cost data of farm products.* Beijing, China Statistics Press.

Desmarais, A., Wittman, H. & Wiebe, N., eds. 2010. *Food sovereignty: reconnecting food, nature and community.* Fernwood publishing.

Devendra, C. & Thomas, D. 2002. Crop–animal interactions in mixed farming systems in Asia. *Agricultural Systems*, 71: 27–40.

Díaz-Bonilla, E. 2015. *Macroeconomics, agriculture and food security: an introductory guide for policy analysis in developing countries*. Washington, DC, IFPRI.

Dinsa, G., Goryakin, Y., Fumagalli, E. & Suhrcke, M. 2012. Obesity and socioeconomic status in developing countries: a systematic review. *Obesity Reviews*, 13(11): 1067–1079. doi:10.1111/j.1467-789X.2012.01017.x.

Domina. D.A., Taylor, C.R. 2010. The debilitating effects of concentration markets affecting agriculture. *Drake Journal of Agricultural Law*, 15(1): 61–108 (available at http://heinonline.org/HOL/Page?handle=hein.journals/dragl15&div=7&g_sent=1&collection=journals).

Dong, S., Wen, L., Liu, S., Zhang, X., Lassoie, J.P., Yi, S., Li, X., Li, J. & Li, Y. 2011. *Vulnerability of worldwide pastoralism to global changes and interdisciplinary strategies for sustainable pastoralism*. Ecology and Society. 16(2): 10.

Dorin, B., Hourcade, J.-C. & Benoit-Cattin, M. 2013. *A world without farmers? The Lewis Path revisited* (No. 24-2013). Nogent sur Marne, Centre International de Recherches sur l'Environnement et le Développement (CIRED).

Dorsey, S. 2015. Can 'test-tube meat' cure hunger and agricultural pollution? *TriplePundit* (available at http://www.triplepundit.com/2015/04/will-test-tube-meat-solve-hunger-agricultural-pollution/).

Douphrate, D.I., Rosecrance, J.C., Stallones, L., Reynolds, S.J. & Gilkey, A.P. 2009. Livestock-handling injuries in agriculture: an analysis of Colorado workers' compensation data. *Am. J. Ind. Med.,* 52: 391–407.

Edelman, M., Weis, T., Baviskar, A., Borras, S.M., Holt-Gimenez, E., Kandiyoti, D. & Wolford, W. 2014 Introduction: critical perspectives on food sovereignty. *Journal of Peasant Studies*, 41(6): 911–931.

Editing Committee of Animal Husbandry Yearbook. 2014. *Animal Husbandry Yearbook.* Beijing, Agricultural Press.

Elzen, B., Barbier, M., Cerf, M. & Grin, G. 2012. Stimulating transition towards sustainable farming systems. *In* I. Darnhofer, D. Gibbo & B. Dedieu, eds. *Farming systems research into the 21st century: the new dynamic*, pp. 433–458. Ed. Springer.

Eneyew, A. & Mengistu, S. 2013. Double marginalized livelihoods: invisible gender inequality in pastoral societies. *Societies*, 3: 104–116.

Erb, K.H., Haberl, H., Krausmann, F., Lauk, C., Plutzar, C., Steinberger, J.K., Müller, C., Bondeau, A., Waha, K. & Pollack, G. 2009. *Eating the planet. Feeding and fuelling the world sustainably, fairly and humanely: a scoping study*. Commissioned by Compassion in World Farming and Friends of the Earth UK. Institute of Social Ecology and PIK Potsdam, Vienna, Potsdam (available at http://www.foe.co.uk/resource/reports/eating_planet_report.pdf).

Erb, K-H., Mayer, A., Kastner, T., Sallet, K-E. & Haberl, H. 2012: *The impact of industrial grain fed livestock production on food security: an extended literature review*. Commissioned by Compassion in World Farming, The Tubney Charitable Trust and World Society for the Protection of Animals, UK. Vienna, Austria.

Estruch, R., Ros, E., Salas-Salvadó, J., Covas, M.-I., Corella, D., Arós, F., Gómez-Gracia, E., Ruiz-Gutiérrez, V., Fiol, M., Lapetra, J., Lamuela-Raventos, R.M., Serra-Majem, L., Pintó, X., Basora, J., Muñoz, M.A., Sorlí, J.V., Martínez, J.A. & Martínez-González, M.A., for the PREDIMED Study Investigators. 2013. Primary prevention of cardiovascular disease with a Mediterranean diet. *New England Journal of Medicine*, 368(14): 1279–1290.

European Commission. 2015. *The role of research in global food security*. Expo 2015 EU Scientific Committee Discussion Paper.

Fadiga, M., Jost, C. & Ihedioha, J. 2013. *Financial costs of disease burden, morbidity and mortality from priority livestock diseases in Nigeria: disease burden and cost–benefit analysis of targeted interventions*. ILRI Research Report 33. Nairobi, ILRI.

Fahed, A.C., Abdul-Karim, M., El-Hage, S., Farhat, T.I. & Nemer G. M. 2012. Diet, genetics, and disease: a focus on the Middle East and North Africa Region. *Journal of Nutrition and Metabolism*, 19 p.

Faminow, M. & Vosti, S. 1998. *Livestock – deforestation links: policy issues in the western Brazilian Amazon*. FAO (available at http://www.fao.org/WAIRDOCS/LEAD/X6139E/X6139E00.HTM).

Fan, S. 2010. *Achieving sustainable food security: new trends and the emerging agenda*. Washington, DC, IFPRI.

Fan, S., Thorat, S. & Rao, N. 2007. *Investment, subsidies and pro-poor growth in India.* IFPRI Discussion Paper 00716.

FAO. 1996. *World livestock production systems: current status, issues and trends,* by C. Seré & H. Steinfield in collaboration with J. Groenewold. Animal Production and Health Paper No. 127. Rome.

FAO. 1998. *Village chicken production systems in rural Africa. Household food security and gender issues*, by A.J. Kitalyi. Rome.

FAO. 1999. *Women: users, preservers and managers of agrobiodiversity* (quoted in: http://www.fao.org/docrep/007/y5609e/y5609e02.htm).

FAO. 2001. *Pastoralism in the new millennium*. FAO animal production and health paper 150 (available at http://www.fao.org/docrep/005/Y2647E/Y2647E00.HTM).
FAO. 2002. *Cattle and small ruminant production systems in sub-Saharan Africa - a systematic review*, By M.J. Otte & P. Chilonda,, Rome.
FAO. 2003. *World agriculture: towards 2015/2030. An FAO perspective*, J. Bruinsma, ed. Rome, FAO and London, Earthscan.
FAO. 2005. *Contribution of farm power to smallholder livelihoods in sub-saharan Africa,* by C. Bishop-Sambrook. Agricultural and Food Engineering Technical Report 2. Rome (available at: ftp://ftp.fao.org/docrep/fao/009/a0229e/A0229E00.pdf).
FAO. 2006a. *Farm power and mechanization for small farms in sub-Saharan Africa,* by B.G. Sims & J. Kienzle**.** Agricultural and Food Engineering Technical Report 3. Rome (available at: ftp://ftp.fao.org/docrep/fao/009/a0651e/a0651e00.pdf).
FAO. 2006b. *Livestock's long shadow*. *Environmental issues and options*, by H. Steinfeld, P. Gerber, T. Wassenaar, V. Castel, M. Rosales & C. de Haan. Rome. 464 p.
FAO. 2006c. *The role of agriculture and rural development in revitalizing abandoned/depopulated areas***.** Rome.
FAO. 2006d. *Trade reforms and food security: country case studies and synthesis*. BY H.C. Thomas,. Rome.
FAO. 2007. *The State of the World's Animal Genetic Resources for Food and Agriculture.* Rome.
FAO, 2008. *Poultry in the 21st century: avian influenza and beyond*. Proceedings of the International Poultry Conference, held 5–7 November 2007, Bangkok. O. Thieme & D. Pilling, eds. FAO Animal Production and Health Proceedings, No. 9. Rome. (Extended electronic version).
FAO. 2009a. *The State of Food and Agriculture: livestock in the balance*. Rome (available at http://www.fao.org/docrep/012/i0680e/i0680e.pdf).
FAO. 2009b. *Rural transport and traction enterprises for improved livelihoods,* by P. Crossley, T. Chamen & J. Kienzle. Diversification Booklet Number 10. Rome.
FAO. 2010. *Draught animal power… An overview.* Rome (available at: http://www.fao.org/fileadmin/user_upload/ags/publications/draugth_ap_overview.pdf).
FAO. 2011a. *The State of Food and Agriculture: women in agriculture, closing the gender gap for development*. Rome.
FAO. 2011b. *Global food losses and food waste. Extent, causes and prevention*, by J. Gustavsson, C. Cederberg, U. Sonesson, R. van Otterdijk & A. Meybeck. Agriculture and Consumer Protection Department, Rome (available at http://www.fao.org/fileadmin/user_upload/suistainability/pdf/Global_Food_Losses_and_Food_Waste.pdf).
FAO. 2012a. *World agriculture towards 20130/20150: the 2012 revision*, by N. Alexandratos & J. Bruinsma. ESA Working Paper No. 12-03 (available at http://www.fao.org/economic/esa/esag/en/).
FAO 2012b *Invisible guardians. Women manage livestock diversity*. FAO Animal Production and Health Paper No.174. Rome (available at http://www.fao.org/docrep/016/i3018e/i3018e00.pdf).
FAO. 2013a. *Tackling climate change through livestock – a global assessment of emissions and mitigation opportunities*, by P.J. Gerber, H. Steinfeld, B. Henderson, A. Mottet, C. Opio, J. Dijkman, A. Falcucci & G. Tempio. Rome.
FAO. 2013b. *Agricultural mechanization in sub-Saharan Africa: guidelines for preparing a strategy*, by K. Houmy, L.J. Clarke, J.E. Ashburner, & J. Kienzle. Integrated Crop Management. Vol. 22. Rome (available at http://www.fao.org/docrep/018/i3349e/i3349e.pdf).
FAO. 2013c. *Children's work in the livestock sector: herding and beyond*. Rural employment. Knowledge material. Gender, Equity and Rural Employment Division. Rome (available at http://www.fao.org/docrep/017/i3098e/i3098e.pdf).
FAO. 2013d. Edible insects: future prospects for food and feed security, by A. van Huis, J. van Itterbeeck, H. Klunder, E. Mertens, A. Halloran, G. Muir & P. Vantomme. *FAO Forestry Paper 171*. Rome.
FAO. 2014a. *Building a common vision for sustainable food and agriculture, principles and approaches.* Rome.
FAO. 2014b. *Ecosystem services provided by livestock species and breeds, with special consideration to the contributions of small-scale livestock keepers and pastoralists,* by I. Hoffmann, T. From & D. Boerma, Background study paper No. 66, Rev.1. Rome (available at http://www.fao.org/3/a-at598e.pdf).
FAO. 2014c. *The State of Food Insecurity in the World 2013*. Rome.
FAO. 2014d. *Decision tools for family poultry development.* Animal Production and Health Guidelines No. 16. Rome.
FAO. 2014c. *Family poultry development − issues, opportunities and constraints*. Animal Production and Health Working Paper. No. 12. Rome.
FAO. 2015a. *The State of Food and Agriculture. Social protection and agriculture: breaking the cycle of rural poverty.* Rome.
FAO. 2015b. *The State of Agricultural Commodity Markets*. *Trade and food security: achieving a better balance between national priorities and the collective good.* Rome.
FAO. 2015c. *The second report on the state of the world's animal genetic resources for Food and Agriculture in brief.* FAO Commission on genetic resources for food and agriculture. Assessments 2015 (available at http://www.fao.org/3/a-i5077e.pdf).
FAO. 2016a. *Global Livestock environmental Assessment Model.* Model Description Version 1.0. Revision 3. April 2016 (available at http://www.fao.org/fileadmin/user_upload/gleam/docs/GLEAM_Version_1.0_Revision_3.pdf).

FAO. 2016b. *Climate change and food security: risks and responses*. Rome (available at http://www.fao.org/3/a-i5188e.pdf).
FAO/CIRAD. 2012. *System of information on pastoralism in the Sahel*. Atlas of the developments of the pastoral systems in the Sahel 1970-2012 (available at http://www.fao.org/3/a-i2601f.pdf).
FAO/Earthscan. 2011. *The state of the world's land and water resources for food and agriculture. Managing systems at risk.* FAO (available at http://www.fao.org/docrep/017/i1688e/i1688e.pdf).
FAO/OECD. 2012. *Building resilience for adaptation to climate change in the agriculture sector*. Proceedings of a Joint FAO/OECD Workshop. A. Meybeck, J. Lankoski, S. Redfern, N. Azzu & V. Gitz, eds. Rome.
FAO/OECD. 2014. *Food security and nutrition opportunities for economic growth and job creation in relation to food*. Report by FAO and the OECD (with inputs by ADB, IFAD, IFPRI and WTO) to the G20 Development Working Group.
FAO/IFAD/WFP. 2015. *The State of Food Insecurity in the World 2015. Meeting the 2015 international hunger targets: taking stock of uneven progress*. Rome (available at http://www.fao.org/3/a-i4646e.pdf).
FAO/OIE/WHO/UN System Influenza Coordination/UNICEF/World Bank. 2008. *Contributing to One World, One Health. A Strategic Framework for Reducing Risks of Infectious Diseases at the Animal-Human-Ecosystems Interface.* 14 October 2008 (available at ftp://ftp.fao.org/docrep/fao/011/aj137e/aj137e00.pdf).
FAO/PAR. 2011. *Biodiversity for food and agriculture contributing to food security and sustainability in a changing world.* Outcomes of an Expert Workshop held by FAO and the Platform on Agrobiodiversity Research from 14–16 April 2010 in Rome. Rome, FAO.
FAO/WHO. 2014. *Second International Conference on Nutrition. Conference outcome document: Rome Declaration on Nutrition.* 19–21 November 2014. Rome (available at http://www.fao.org/3/a-ml542e.pdf).
Farm Africa. 2007. *The goat model. A proven approach to reducing poverty among smallholder farmers in Africa by developing profitable goat enterprises and sustainable support services*. Farm-Africa Working Papers No. 9. London. 62 p.
FAWC (Farm Animal Welfare Committee). 2011. *Five freedoms* (available at www.fawc.org.uk/freedoms.htm).
Food and Water Watch. 2007. *Turning farms into factories*. Washington, DC.
Fischer, C., Hartmann, M., eds. 2010. *Agri-food chain relationships*, edited by Christian Fischer & Monika Hartmann. CABI (available at http://www.cabi.org/bookshop/book/9781845936426).
Foresight. 2011. *The future of food and farming: challenges and choices for global sustainability*. Final Project Report. London, The Government Office for Science.
Francis, C., Lieblein, G., Gliessman, S., Breland, T.A., Creamer, N., Harwood, R., Salomonsson, L., Helenius, J., Rickerlg, D., Salvadorh, R., Wiedenhoeftj, M., Simmonsk, S., Allene, P., Altieril, M., Floram, C. & Poincelotn, R. 2003. Agroecology: the ecology of food systems. *Journal of Sustainable Agriculture*, 22(3): 99–118.
Fuglie, K., Helsey, P., King, J., Day-Rubenstein, K., Schimmelpfennig, D. & Wang, S.L. 2011. *Research investments and market structure in the food processing, agricultural input, and biofuel industries worldwide*. USDA Economic Research Service (available at http://www.ers.usda.gov/publications/eib-economic-information-bulletin/eib90.aspx).
Galaty, J.G. 2014. 'Unused' land and unfulfilled promises: Justifications for displacing communities in East Africa. *Nomadic Peoples*, 18(1): 80–93.
Garnett, T., Roos, E. & Little, D. 2015, *Lean, green, mean, obscene…? What is efficiency? And is it sustainable?* Food Climate Research Network Environmental Change Institute & The Oxford Martin Programme on the Future of Food, The University of Oxford.
GASL (Global Agenda for Sustainable Livestock). 2014. *Towards sustainable livestock* (available at http://www.livestockdialogue.org/fileadmin/templates/res_livestock/docs/2014_Colombia/2014_Towards_Sustainable_Livestock-dec.pdf).
GASL. 2015. *Global Agenda for Sustainable Livestock Consensus* (available at http://www.livestockdialogue.org/fileadmin/templates/res_livestock/docs/2015_consensus.pdf).
Gibson, R.S. 2011. Strategies for preventing multi-micronutrient deficiencies: a review of experiences with food-based approaches in developing countries. *In* FAO. *Combating micronutrient deficiencies: food-based approaches*. E. Thompson & L. Amoroso, eds. Rome.
GIPSA (Grain Inspection, Packers & Stockyards Administration). 2011. *2010 Annual Report*. Packers and Stockyards Program. USDA. Grain Inspection, Packers and Stockyards Administration. March (available at https://www.gipsa.usda.gov/psp/publication/ar/2010_psp_annual_report.pdf).
Gliessman, S.R. 1997. *Agroecology: ecological processes in sustainable agriculture*. New York, USA, CRC Press, Taylor and Francis.
Gliessman, S.R. 2014 Agroecology: the ecology of sustainable food systems. Third edition. CRC Press (available at http://chaddyner.com/ebooks/12/07/2015/27443).
Godfray, H.C.J. 2015. The debate over sustainable intensification. *Food Sec.*, 7: 199–208.
Goss, J., Burch, D. & Rickson, R.E. 2000. Agri-food restructuring and third world transnationals: Thailand, the CP group and the global shrimp industry, *World Development*, 28: 513–530.
Grace, D. 2015. Food safety in low and middle income countries. *Int. J. Environ. Res. Public Health,* 12, 1-x manuscripts. doi:10.3390/ijerph120x0000x.
Grace, D., Mutua, F., Ochungo, P., Kruska, R., Jones, K., Brierley, L., Lapar, L., Said, M., Herrero, M., Phuc, P.D., Thao, N.B., Akuku, I. & Ogutu, F. 2012. *Mapping of poverty and likely zoonoses hotspots*, Zoonoses Project 4, Report to the UK Department for International Development, Nairobi, ILRI. 119 p. (available at https://cgspace.cgiar.org/bitstream/handle/10568/21161/ZooMap_July2012_final.pdf).

Grace, D., Bett, B., Lindahl, J. & Robinson, T. 2015. *Climate and livestock disease: assessing the vulnerability of agricultural systems to livestock pests under climate change scenarios*. CCAFS Working Paper No. 116. Copenhagen, CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).
Graffham, A., Karehu, E., & MacGregor, J. 2007. *Impact of EurepGAP on small-scale vegetable growers in Kenya*. London.
Grafton, R.Q., Daugbjerg, C. & Qureshi, M.E. 2015. Towards food security by 2050. *Food Security*, 7: 179–183.
Greger, M. & Koneswaran, G. 2010. The public health impacts of concentrated animal feeding operations on local communities. *Farm Community Health*, 33(1): 11–20. doi: 10.1097/FCH.0b013e3181c4e22a.
Guedes, G.R., Brondízio, E.S., Barbieri, A.F., Anne, R., Penna-Firme, R. & D'Antona, A.O. 2012. Poverty and inequality in the rural Brazilian Amazon: a multidimensional approach. *Hum. Ecol.,* 40(1): 41–57.
Guèye, El H.F. 2000. Women and family poultry production in rural Africa. *Development in Practice*, 10(1): 98–102.
Gura, S. 2008. *Industrial livestock production and its impacts to smallholders in developing countries*. Consultancy Report to the League of Pastoral Peoples and Endogenous Livestock Development.
Harsdorff, M. 2012. *The economics of cow dung - creating green jobs in the dairy sector in India*. Geneva, ILO.
Hasenack, H., Cordeiro, J.L.P. & Da Costa, B.S.C. 2007. Cobertura vegetal atual do Rio Grande do Sul. In *Simpósio de forrageiras e produção animal*, 2., Porto Alegre. Anais, Porto Alegre. UFRGS, pp.15–22.
Hausmann, R., Rodrik, D. & Velasco, V. 2005. *Growth diagnostics*. Manuscript. Inter-American Development Bank (available at http://www6.iadb.org/WMSFiles/products/research/files/pubS-852.pdf).
Havelaar, A.H., Kirk, M.D., Torgerson, P.R., Gibb, H.J., Hald, T., Lake, R.J., Praet, N., Bellinger, D.C., de Silva, N.R., Gargouri, N., Speybroeck, N., Cawthorne, A., Mathers, C., Stein, C., Angulo, F.J. & Devleesschauwer, B., on behalf of World Health Organization. 2015. World Health Organization global estimates and regional comparisons of the burden of foodborne disease in 2010. *PLoS Med*, 12(12): e1001923. doi:10.1371/journal.pmed.1001923.
Havlík, P., Leclère, D., Valin, H., Herrero, M., Schmid, E., Soussana, J.F., Müller, C. & Obersteiner, M. 2015. Global climate change, food supply and livestock production systems: A bioeconomic analysis, *In:* FAO *Climate change and food systems: global assessments and implications for food security and trade*, Aziz Elbehri (editor). Rome.
Heltberg, R., Hossain, N. & Reva, A. 2012. *Living through crises. How the food, fuel and financial shocks affect the poor.* Washington, DC, World Bank.
Henderson, B.B., Gerber, P.J., Hilinski, T.E., Falcucci, A., Ojima, D.S., Salvatore, M. & Conant, R.T. 2015. Greenhouse gas mitigation potential of the world's grazing lands: modeling soil carbon and nitrogen fluxes of mitigation practices. *Agriculture, Ecosystems & Environment*, 207: 91–100.
Hendrickson, M. 2014. T*he dynamic state of agriculture and food: possibilities for rural development?* Statement at the Farm Credit Administration Symposium on Consolidation in the Farm Credit System McLean, Virginia, 19 February.
Herrero, M., Thornton, P.K., Gerber, P. & Reid, R.S. 2009. Livestock, livelihoods and the environment: understanding the tradeoffs. *Current Opinion in Environmental Sustainability*, 1: 111–120.
Herrero, M., Grace, D., Njuki, J., Johnson, N., Enahoro, D., Silvestri, S. & Rufino, M.C. 2012. *The roles of livestock in developing countries*. Nairobi, International Livestock Research Institute.
Herrero, M., Havlík, P., Valin, H., Notenbaert, A., Rufino, M.C., Thornton, P.K., Blümmel, M., Weiss, F., Grace, D. & Obersteiner, M. 2013. Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems. *PNAS*, 110(52): 20888–20893.
Herrero, M., Wirsenius, S., Henderson, B., Rigolot, C., Thornton, P., Havlik, P., de Boer, I. & Gerber, P. 2015. Livestock and the environment: what have we learned in the past decade? *Annu. Rev. Environ. Resour.*, 40:177–202.
Herrero, M., Henderson, B., Havlík, P., Thornton, P.K., Conant, R.T., Smith, P., Wirsenius, S., Hristov, A.N., Gerber, P., Gill, M., Butterbach-Bahl, K., Valin, H., Garnett, T. & Stehfest, E. 2016. Greenhouse gas mitigation potentials in the livestock sector. *Nature Climate Change*. DOI: 10.1038/nclimate2925.
Hertel, T.W. 2015. The challenges of sustainably feeding a growing planet. *Food Security*, 7: 185–198.
Hesse, C. & MacGregor, J. 2006. *Pastoralism: drylands' invisible asset?* Developing a framework for assessing the value of pastoralism in East Africa. London, International Institute for Environment and Development (IIED).
Hetch, S. 2002. The evolution of agroecological thought. *In* M. Altieri, *Agroecology: the scientific basis of alternative agriculture*, pp. 1–19. Boulder, USA, Westview Press.
HLPE. 2011a. *Price volatility and food security*. A Report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. Rome.
HLPE. 2011b. *Land tenure and international investments in agriculture.* A report by the High Level Panel of Experts on Food Security and Nutrition, Rome. 2011.
HLPE. 2012. *Social protection for food security.* A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. Rome.
HLPE. 2013a. *Investing in smallholder agriculture for food security*. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. Rome.
HLPE, 2013b. *Biofuels and food security*. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. Rome.
HLPE. 2014. *Food losses and waste in the context of sustainable food systems*. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. Rome.

HLPE. 2015. *Water for food security and nutrition*. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. Rome.
HSE (Health and Safety Executive). 2014. *Health and safety in manufacturing in Great Britain* (available at http://www.hse.gov.uk/statistics/industry/manufacturing/manufacturing.pdf).
Huchet-Bourdon, M. 2011. *Agricultural commodity price volatility: an overview*. OECD Food, Agriculture and Fisheries Papers No. 52, OECD Publishing (available at http://dx.doi.org/10.1787/5kg0t00nrthc-en).
Hurst, P. 2007. *Agricultural workers and their contribution to sustainable agriculture and rural development*. Geneva, ILO/FAO/International Union of Food, Agricultural, Hotel, Restaurant, Catering, Tobacco and Allied Workers' Associations (available at http://www.fao-ilo.org/fileadmin/user_upload/fao_ilo/pdf/engl_agricultureC4163.pdf).
Hutz, C.S., Zanon, C. & Brum Neto, H. 2013. Adverse working conditions and mental illness in poultry slaughterhouses in Southern Brazil. *Psicologia: Reflexão e Crítica*, 26(2): 296–304.
IAASTD (International Assessment of Agricultural Knowledge, Science and Technology for Development). 2009. *Agriculture at a crossroads: global report.* B.D. MacIntyre, H.R. Herren, J. Wakhungu, R.T. Watson, eds. Washington, DC, Island Press (available at http://apps.unep.org/publications/pmtdocuments/Agriculture_at_a_Crossroads_Global_Report.pdf).
IARC (International Agency for Research on Cancer). 2015. *IARC Monographs evaluate consumption of red meat and processed meat.* WHO Press Release No. 240, 26 October 2015 (available at https://www.iarc.fr/en/media-centre/pr/2015/pdfs/pr240_E.pdf).
IBGE (Instituto Brasilerio de Geografia e Estaística). 1996. *Censo agropecuário de 1995-1996*, pp. 615–622 (available at http://www.ibge.gov).
IBRD/World Bank (The International Bank for Reconstruction and Development/World Bank). 2007. *World Development Report 2008, Agriculture for Development* (available at http://siteresources.worldbank.org/INTWDR2008/Resources/WDR_00_book.pdf).
ICEM (International Centre for Environmental Management). 2013. *USAID Mekong ARCC climate change impact and adaptation on livestock*. Prepared for the United States Agency for International Development by ICEM.
ICG. 2014. *The security challenges of pastoralism in Central Africa Africa.* Report No. 215. International Crisis Group. Brussels, April.
IFAD (International Fund for Agricultural Development). 2009a. *Livestock and pastoralists* (available at https://www.ifad.org/documents/10180/0fbe4134-4354-4d08-bf09-e1a6dbee3691).
IFAD. 2009b. *Livestock and pastoralists.* Livestock thematic papers. Tools for project design (available at https://www.ifad.org/documents/10180/0fbe4134-4354-4d08-bf09-e1a6dbee3690).
IFAD. 2010. *Gender and livestock: tools for design*. Livestock thematic papers. Tools for project design (available at https://www.ifad.org/documents/10180/b5f16410-cf6d-4e63-89e5-fbd64aaa7cb7).
IFC (International Finance Corporation). 2014. *Good practice note: improving animal welfare in livestock operations* (available at http://www.ifc.org/wps/wcm/connect/67013c8046c48b889c6cbd9916182e35/IFC+Good+Practice+Note+Animal+Welfare+2014.pdf?MOD=AJPERES).
IFIP (Institut du Porc). 2013. Competitiveness observatory (available at www.ifip.asso.fr).
IFPRI (International Food Policy Research Institute). 2012. *Women's empowerment in agriculture index*. International Food Policy Research Institute (available at http://www.ifpri.org/publication/womens-empowerment-agriculture-index).
ILO (International Labour Office). 2014. *Ergonomic checkpoints in agriculture.* Second edition. S. Niu, K. Kogi, eds. Geneva. In collaboration with the International Ergonomics Association (available at http://www.ilo.org/wcmsp5/groups/public/---ed_protect/---protrav/---safework/documents/instructionalmaterial/wcms_176923.pdf).
ILO/FAO/IUF. 2007. *Agricultural workers and their contribution to sustainable agriculture and rural development*. Geneva: ILO, (available at http://www.ilo.org/wcmsp5/groups/public/---ed_dialogue/---actrav/documents/publication/wcms_113732.pdf).
INRA-DEPE. 2015. *Le systeme alimentaire de la region afrique du nord – moyen-orient : une analyse retrospectve, 1961-2011*, by P. Marty (available at https://inra-dam-front-resources-cdn.brainsonic.com/ressources/afile/307932-8bf4b-resource-systeme-agri-et-alimentaire-afriquen-moyen-orient-rapport-fr.html).
Institut de l'élevage. 2007. *Work productivity and pay in dairy farms in the north of the EU.* The livestock farming economy file, 364. 83 p.
Institut de l'élevage. 2013. *The dairy economics year. Prospects 2013.* The livestock farming economy file, 432.
InterAcademy Council. 2004. *Realizing the promise and potential of African agriculture: science and technology strategies for improving agricultural productivity and food security in Africa*. Amsterdam (available at http://www.interacademycouncil.net/24026/AfricanAgriculture.aspx).
IOM & NRC (Institute of Medicine and National Research Council). 2009. *Sustaining global surveillance and response to emerging zoonotic diseases.* Washington, DC, The National Academies Press.
IPES-Food. 2016. *From university to diversity. A paradigm shift from industrial agriculture to diversified agroecological systems.* International Panel of experts on sustainable food systems (available at http://www.ipes-food.org/images/Reports/UniformityToDiversity_FullReport.pdf).
IPCC (Intergovernmental Panel on Climate Change). 2014. *Climate change 2014: mitigation of climate change*. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate

Change. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel & J.C. Minx, eds. Cambridge, UK, and New York, USA, Cambridge University Press.

Iversen, J.S. 2006. *Futures thinking methodologies and options for education*. Think Scenarios, Rethink Education. OECD. ISBN: 926402364X (available at http://www.oecd.org/site/schoolingfortomorrowknowledgebase/futuresthinking/scenarios/37246348.pdf).

Jaafar, H.H., Zurayk, R., King, C., Ahmad, F. & Al-Outa, R. 2015. Impact of the Syrian conflict on irrigated agriculture in the Orontes Basin. *International Journal of Water Resources Development*, 31(3): 1–14.

James, H.S., Hendrikson, M.K. & Howard, P.H. 2012. Networks, power and dependency in the agrifood industry. *Department of Agricultural & Applied Economics Working Paper* (available at SSRN: http://ssrn.com/abstract=2004496 or http://dx.doi.org/10.2139/ssrn.2004496).

Jayne, T.S., Chamberlin, J. & Headey, D.D. 2014. Land pressures, the evolution of farming systems, and development strategies in Africa: A synthesis. *Food Policy*. 48: 1–17.

Jöhr, H. 2015. Where are the future farmers to grow our food*? International Food and Agribusiness Management Review*, Volume 15 Special Issue A.

Jones, B., Grace, D., Kock, R., Alonso, S., Rushton, J., Said, M., McKeever, D., Mutua, F., Young, J., McDermott, J. & Pfeiffer, D. 2013. How do agricultural intensification and environmental change affect zoonoses with a wildlife-livestock interface? A systematic review. *Proc. Natl. Acad. Sci. USA*, 110(21): 8399–8404.

Jones, P.G. & Thornton, P.K. 2009. Croppers to livestock keepers: livelihood transitions to 2050 in Africa due to climate change. *Environmental Science & Policy,* 12(4): 427–437.

Kahane, R., Hodgkin, T., Jaenicke, H., Hoogendoorn, C., Hermann, M., & Keatinge, J.D.H.(D), d'Arros Hughes, J., Padulosi, S. & Looney, N. 2013. *Agrobiodiversity for food security, health and income*. Agronomy for Sustainable Development, INRA and Springer-Verlag France (available at http://www.mtnforum.org/sites/default/files/forum_topic/files/03_lectura_2_-_agrobiodiversity_for_food_security_health_and_income.pdf).

Karttunen, J.P. & Rautiainen, R.H. 2013. Distribution and characteristics of occupational injuries and diseases among farmers: a retrospective analysis of workers' compensation claims. *Am. J. Ind. Med.,* 56(8): 856–69. doi: 10.1002/ajim.22194.

Kashturi Rangan, V., Quelch, J.A., Herrero, G. & Barton, B., eds. 2007. *Business solutions for the global poor: creating social and economic value*. Jossey-Bass.

Keys, A. 1970. Coronary heart disease in seven countries. *Circulation*, 41(Suppl. 1): 186–195.

Kirsten, J. 2009. *The impact of market power and dominance of supermarkets on agricultural producers in South Africa: a case study of the South African Dairy Industry*. Pretoria.

Klümper, W. & Qaim, M. 2014. A meta-analysis of the impacts of genetically modified crops. *PLoS ONE*, 9(11): e111629. doi:10.1371/journal.pone.0111629.

Konandreas, P. 2012. *Trade policy responses to food price volatility in poor net food-importing countries* (No. 42). Geneva & Rome, International Centre for Trade and Sustainable Development (ICTSD) & FAO.

Koester, U. 2015. Reduction of food loss and waste: an exaggerated agitation. *EuroChoices*, 14(3): 34–38.

Konefal, J., Mascarenhas, M. & Hatanaka, M. 2005. Governance in the global agro-food system: backlighting the role of transnational supermarket chains. *Agriculture and Human Values*, 22: 291–302.

Lal, R., Lorenz, K., Hüttl, R.F., Schneider, B.U. & von Braun, J. 2012. *Recarbonization of the biosphere: ecosystems and the global carbon cycle.* Dordrecht, Netherlands, Springer.

Lambek, N. C. S. Claeys, P., Wong, A. & Brilmayer, L., eds. 2014. *Rethinking food systems.* Springer Science & Business Media, Dordrecht (available at http://link.springer.com/book/10.1007/978-94-007-7778-1).

Landers, T.F. Cohen, B., Wittum, T.E. & Larson, E.L. 2012. A review of antibiotic use in food animals: perspective, policy, and potential. *Public Health Rep.,* 127(1): 4–22.

Lang, T. 2004. *Food industrialization and food power: implications for food governance*. London, International Institute for Environment and Development.

Lang, T. & Barling, D. 2012. Food security and food sustainability: reformulating the debate. *The Geographical Journal,* 178(4): 313–326. doi: 10.1111/j.1475-4959.2012.00480.x.

Lang, T., Barling, D. & Caraher, M. 2009. *Food policy: integrating health, environment and society*. Oxford, UK, Oxford University Press.

Lapar, M.L., Toan, N.T., Staal, S., Minot, N., Tisdell, C., Que, N.N. & Tuan, N.D.A. 2012. *Smallholder competitiveness: insights from household pig production systems in Vietnam*. Selected Paper prepared for presentation at the International Association of Agricultural Economists (IAAE) Triennial Conference, Foz do Iguaçu, Brazil. 18–24 August 2012.

Larsson, S.C. & Orsini, N. 2014. Red meat and processed meat consumption and all-cause mortality: a meta-analysis. *Am. J. Epidemiol.*, 179(3): 282–289.

Le Cotty, T. & Dorin B. 2012. A global foresight on food crop needs for livestock. *Animal*, 6(9): 1528–1536.

Lee, R.P. 2013. The politics of international agri-food policy: discourses of trade oriented food security and food sovereignty. *Environmental Politics*, 22(2): 216–234.

Leip A., Billen, G., Garnier, J., Grizzetti, B., Lassaletta, L., Reis, S. Simpson, D., Sutton, M.A., de Vries, W., Weiss, F. & Westhoek, H.J. 2015. *Impacts of European livestock production: nitrogen, sulphur, phosphorus and greenhouse gas emissions, land-use, water eutrophication and biodiversity*. IOP Publishing Ltd. doi. 10.1088/1748-9326/10/11/115004.

Lemaire, G., Franzluebbers, A., de Facio Carvalho, P. & Dedieu, B. 2014. Integrated crop-livestock systems: strategies to achieve synergy between agricultural production and environmental quality. *Agriculture, Ecosystem & Environment*, 190: 4–8.

Levine, S., Crosskey, A. & Abdinoor, M. 2011. *Revisiting the problems of timely response to crises in the Horn of Africa.* Commissioned and published by the Humanitarian Practice Network at ODI. Network paper Number 71. November 2011. London, Overseas Development Institute (available at http://odihpn.org/wp-content/uploads/2011/12/networkpaper071.pdf).

Lipinski, B., Hanson, C., Lomax, J., Kitinoja, L., Waite, R. & Searchinger, T. 2013. *Reducing food loss and waste*. Working Paper, Installment 2 of *Creating a sustainable food future*. Washington, DC, WRI.

Little P., 2013. Reflections on the future, *In* A. Catley, J. Lind & I. Scoones, eds. *Pastoralism and development in Africa: dynamic change at the margins.* London, Routledge and Earthscan. p. 294.

Lokhorst, C. & Groot Koerkamp, P.W.P. 2009. *Precision livestock farming '09*. Wageningen University Press. 368 p.

Loos, J., Abson, D.J., Chappell, M.J., Hanspach, J., Mikulcak, F., Tichit, M. & Fischer, J. 2014. Putting meaning back Into "sustainable intensification". *Frontiers in Ecology and the Environment*, 12(6): 356–361 (available at https://ideas4sustainability.files.wordpress.com/2014/06/2014_loos_sust_intensification.pdf)

Losch, B. 2014. *African youth in agriculture and rural development.* Background paper for the FAO Regional Conference for Africa (ARC 2014) 28th session – Tunis, Tunisia, 24–28 March 2014 (available at https://agritrop.cirad.fr/573011/1/document_573011.pdf).

Maass, B.L., Musale, D.K., Chiuri, W.L., Gassner, A. & Peters, M. 2012. Challenges and opportunities for smallholder livestock production in post-conflict South Kivu, eastern DR Congo. *Tropical Animal Health and Production*, 44(6): 1221–1232.

Madalena, F.E. 2008. How sustainable are the breeding programs of the global main stream dairy breeds? - The Latin-American situation. *Livest. Res. Rural Dev.,* 20: 1–10.

Makkar, H.P.S., Tran, G., Heuzé, V. & Ankers, P. 2014. State-of-the-art on use of insects as animal feed. *Anim. Feed Sci. Tech.,* 197: 1–22.

Maloney, T.R. & Grusenmeyer, D.C. 2005. *Survey of Hispanic dairy workers in New York State.* Department of Applied Economics and Management College of Agriculture and Life Sciences Cornell University, Ithaca, New York, USA. February. RB 2005-02.

Marten, G.G. 1988. Productivity, stability, sustainability, equitability and autonomy as properties for agroecosystem assessment. *Agricultural System,* 26: 291–316.

Matson, P.A., Parton, W.J., Power, A.G. & Swift M.J. 1997. Agricultural intensification and ecosystem properties. *Science*, 277(5325): 504–509.

Marty, P., Manceron, S., Le Mouël, C. & Schmitt, B. 2015. *Le système agricole et alimentaire de la région Afrique du Nord – Moyen-Orient : une analyse rétrospective (1961-2012). In* 52ème colloque de l'Association de Science Régionale de Langue Française (ASRDLF), Territoires méditerranéens : agriculture, alimentation et villes, du 7 au 9 juillet 2015 à Montpellier (available at http://asrdlf2015.fr/sites/default/files/programme_detail.pdf).

Mazoyer, M. 2002. *Une situation agricole mondiale insoutenable, ses causes et les moyens d'y remédier.* Mondes en développement 2002/1 (no 117), pp. 25-37. DOI 10.3917/med.117.0025 (available at http://www.cairn.info/revue-mondes-en-developpement-2002-1-page-25.htm).

McCorriston, S., Hemming, D.J., Lamontagne Godwin, J.D., Parr, M.J., Osborne, J. & Roberts, P.D. 2013. *What is the evidence of the impact of trade liberalisation on food security in developing countries?* A Systematic Review. London, EPPICentre, Social Science Research Unit, Institute of Education, University of London.

McDougal, T.L., Hagerty, T., Inks, L., Ugo-Lke, C.-L., Dowd, C., Conroy, S. & Ogabiela, D. 2015. The effect of farmer-pastoralist violence on income: new survey evidence from Nigeria's Middle Belt States. *The Economics of Peace and Security Journal,* 10(1). doi: http://dx.doi.org/10.15355/epsj.10.1.54.

McInerney, J.P. 2004. *Animal welfare, economics and policy*. Report to Defra, (available at http://archive.defra.gov.uk/evidence/economics/foodfarm/reports/documents/animalwelfare.pdf).

McMichael, P. 1993. World food system restructuring under a GATT regime. *Political Geography*, 12: 198–214.

MEA (Millennium Ecosystem Assessment). 2005. E*cosystems and human well-being: synthesis.* Washington, DC, Island Press.

Mekonnen, M.M. & Hoekstra, A.Y. 2012. A global assessment of the water footprint of farm animal products. *Ecosystems*, 15: 401–415.

Mendez, V.E., Bacon, C.M., Cohen, R., Gliessman, S.R. 2015. *Agroecology: a transdisciplinary, participatory and action-oriented approach (available at* https://www.crcpress.com/Agroecology-A-Transdisciplinary-Participatory-and-Action-oriented-Approach/Mendez-Bacon-Cohen-Gliessman/p/book/9781482241761).

Menzi H., Oenema O., Burton C., Shipin O., Gerber P., Robinson T. & Franceschini G. 2010. Impacts of intensive livestock production and manure management on the environment. *In* H. Steinfeld, H. Mooney, F. Schneider & L. Neville, eds. *Livestock in a changing landscape. Vol. 1, Drivers, consequences, and responses.* Island Press

Micha, R., Michas, G. & Mozaffarian, D. 2012. Unprocessed red and processed meats and risk of coronary artery disease and type 2 diabetes-an updated review of the evidence. *Curr. Atheroscler. Rep*., 14(6): 515–524.

Miller, D. 2014. *Presentation on farming systems, diverse diets.* International Symposium on agroecology for food security and nutrition. FAO 18–19 September 2014, (available at http://www.fao.org/about/meetings/afns/).

Minot, N., Rich, K., Que, N. N., and Phong, N. A. 2010. *Transformation of pig markets in Vietnam: will small-scale farmers be squeezed out?* Technical report submitted to ILRI

Misiko, M., Mundy, P. & Ericksen, P. 2013. Innovation platforms to support natural resource management. *Innovation Platforms Practice Brief 13*. International Livestock Research Institute.

Mitchell, L. 2001. Impact of consumer demand for animal welfare on global trade. *In* A. Regmi. *Changing structure of global food consumption and trade*. Economics Research Service/USDA. US Government.

Mtileni, B.J., Muchadeyi, F.C., Maiwashe, A., Chimonyo, M. & Dzama, K. 2012. Conservation and utilisation of indigenous chicken genetic resources in Southern Africa. *World's Poultry Science Journal*, 68: 727–748. doi:10.1017/S0043933912000852.

Moll, H.A.J. & Heerink, N.B.M. 1998. Price adjustment and the cattle sub-sector in central West-Africa. *In* World Bank/FAO. *Livestock and the environment*, pp. 72–87. Proceedings of the International Conference on Livestock and the Environment, June 1997. A.J. Nell, ed. Ede.

Mulema, A.A., Snyder, K.A., Ravichandran, T. & Becon, M. 2015. Addressing gender dynamics in innovation platforms. *Innovation Platforms Practice Brief 14*. International Livestock Research Institute.

Mottet, A., de Haan, C., Falcucci, A., Tempio, G. and Gerber, P. (In press). *Livestock: in our plates or eating at our table? The feed/food debate.* Global Food Security, under review.

Murphy, S., Burch, D. & Clapp, J. 2012. *Cereal secrets: the world's largest grain traders and global agriculture*. Oxfam Research Reports.

Murray, C.J., Atkinson, C., Bhalla, K., Birbeck, G., Burstein, R., Chou, D., Dellavalle, R., Danaei, G., Ezzati, M., Fahimi, A., Flaxman, D., Foreman, Gabriel, S., Gakidou, E., Kassebaum, N., Khatibzadeh, S., Lim, S., Lipshultz, S.E., London, S., Lopez, MacIntyre, M.F., Mokdad, A.H., Moran, A., Moran, A.E., Mozaffarian, D., Murphy, T., Naghavi, M., Pope, C., Roberts, T., Salomon, J., Schwebel, D.C., Shahraz, S., Sleet, D.A., Murray, Abraham, J., Ali, M.K., Atkinson, C., Bartels, D.H., Bhalla, K., Birbeck, G., Burstein, R., Chen, H., Criqui, M.H., Dahodwala, Jarlais, Ding, E.L., Dorsey, E.R., Ebel, B.E., Ezzati, M., Fahami, Flaxman, S., Flaxman, A.D., Gonzalez-Medina, D., Grant, B., Hagan, H., Hoffman, H., Kassebaum, N., Khatibzadeh, S., Leasher, J.L., Lin, J., Lipshultz, S.E., Lozano, R., Lu, Y., Mallinger, L., McDermott, M.M., Micha, R., Miller, T.R., Mokdad, A.A., Mokdad, A.H., Mozaffarian, D., Naghavi, M., Narayan, K.M., Omer, S.B., Pelizzari, P.M., Phillips, D., Ranganathan, D., Rivara, F.P., Roberts, T., Sampson, U., Sanman, E., Sapkota, A., Schwebel, D.C., Sharaz, S., Shivakoti, R., Singh, G.M., Singh, D., Tavakkoli, M., Towbin, J.A., Wilkinson, J.D., Zabetian, A., Murray, Abraham, J., Ali, M.K., Alvardo, M., Atkinson, C., Baddour, L.M., Benjamin, E.J., Bhalla, K., Birbeck, G., Bolliger, I., Burstein, R., Carnahan, E., Chou, D., Chugh, S.S., Cohen, A., Colson, K.E., Cooper, L.T., Couser, W., Criqui, M.H., Dabhadkar, K.C., Dellavalle, R.P., Jarlais, Dicker, D., Dorsey, E.R., Duber, H., Ebel, B.E., Engell, R.E., Ezzati, M., Felson, D.T., Finucane, M.M., Flaxman, S., Flaxman, A.D., Fleming, T., Foreman, Forouzanfar, M.H., Freedman, G., Freeman, M.K., Gakidou, E., Gillum, R.F., Gonzalez-Medina, D., Gosselin, R., Gutierrez, H.R., Hagan, H., Havmoeller, R., Hoffman, H., Jacobsen, K.H., James, S.L., Jasrasaria, R., Jayarman, S., Johns, N., Kassebaum, N., Khatibzadeh, S., Lan, Q., Leasher, J.L., Lim, S., Lipshultz, S.E., London, S., Lopez, Lozano, R., Lu, Y., Mallinger, L., Meltzer, M., Mensah, G.A., Michaud, C., Miller, T.R., Mock, C., Moffitt, T.E., Mokdad, A.A., Mokdad, A.H., Moran, A., Naghavi, M., Narayan, K.M., Nelson, R.G., Olives, C., Omer, S.B., Ortblad, K., Ostro, B., Pelizzari, P.M., Phillips, D., Raju, M., Razavi, H., Ritz, B., Roberts, T., Sacco, R.L., Salomon, J., Sampson, U., Schwebel, D.C., Shahraz, S., Shibuya, K., Silberberg, D., Singh, J.A., Steenland, K., Taylor, J.A., Thurston, G.D., Vavilala, M.S., Vos, T., Wagner, G.R., Weinstock, M.A., Weisskopf, M.G., Wulf, S., Murray & US Burden of Disease Collaborators. 2013. The state of US health, 1990-2010: burden of diseases, injuries, and risk factors. *Journal of the American Medical Association*, 310(6): 591–608. doi:10.1001/jama.2013.13805.

Musolin, K., Ramsey, J.G., Wassel, J.T., Hard, D.L. & Mueller, C. 2014. *Evaluation of musculoskeletal disorders and traumatic injuries among employees at a poultry processing plant.* Health Hazard Evaluation Program. Report No. 2012-0125-3204. March 2014. US Department of Health and Human Services. Centers for Disease Control and Prevention. National Institute for Occupational Safety and Health (available at http://www.cdc.gov/niosh/hhe/reports/pdfs/2012-0125-3204.pdf).

Nabinger, C., Ferreira, E.T., Freitas, A.K. & Carvalho, P.C.F. 2009. Sant`Anna, D.M. Produção animal com base no campo nativo: aplicações de resultados de pesquisa. *In* V.P. Pillar *et al*., eds. *Campos Sulinos: Conservação e Uso Sustentável da Biodiversidade ed. Brasília,* pp. 214–228.Ministério do Meio Ambiente.

NCFH (National Centre for Farmworker Health Inc.). 2014. *Poultry workers.* Agricultural Worker Factsheets (available at http://www.ncfh.org/uploads/3/8/6/8/38685499/fs-poultryworkers.pdf).

Nestlé, M. 2012. *Food politics: how the food industry influences nutrition and health*, 10th edition. University of California Press.

Njuki, J., Baltenweck, I., Mutua, E., Korir, L. & Muindi, P. 2014. *Women's empowerment in collective dairy value chains*. ILRI Research Brief 38. Nairobi, Kenya, International Livestock Research Institute.

Njuki, J. & Sanginga, P.C. 2013. *Women, livestock ownership and markets: Bridging the gender gap in eastern and southern Africa*. London, Earthscan (available at http://hdl.handle.net/10568/34088).

Nori, M., & Davies, J. 2007. *Change of wind or wind of change? Climate change, adaptation and pastoralism*. Nairobi, The World Initiative for Sustainable Pastoralism, International Union for Conservation of Nature (available at http://cmsdata.iucn.org/downloads/c__documents_and_settings_hps_local_settings_application_data_mozilla_firefox_profile.pdf).

Nori. M., Switzer, J., Crawford, A. & International Institute for Sustainable Development. 2005. *Herding on the brink: towards a global survey of pastoral communities and conflict.* An Occasional Working Paper from the International Union for Conservation of Nature (IUCN) Commission on Environmental, Economic and Social Policy. IUCN, Gland, Switzerland (available at http://www.iisd.org/pdf/2005/security_herding_on_brink.pdf).

Notenbaert, A., Herrero, M., Kruska, R., You, L., Wood, S., Thornton, P. & Omolo, A. 2009. *Classifying livestock production systems for targeting agricultural research and development in a rapidly changing world*. Discussion Paper No. 19. Nairobi, International Livestock Research Institute.

Nyéléni Declaration. 2007. *Declaration of the Forum for Food Sovereignty, Nyéléni 2007*. 27 February 2007 (available at http://nyeleni.org/spip.php?article290).

Nyéléni. 2015. *Declaration of the International Forum for Agroecology.* Nyéléni, Mali. 27 February 2015 (available at http://www.foodsovereignty.org/wp-content/uploads/2015/02/Download-declaration-Agroecology-Nyeleni-2015.pdf)

O'Neill, J. 2015. *Antimicrobials in agriculture and the environment: reducing unnecessary use and waste. The review on antimicrobial resistance* (available at http://amr-review.org/sites/default/files/Antimicrobials%20in%20agriculture%20and%20the%20environment%20-%20Reducing%20unnecessary%20use%20and%20waste.pdf).

O'Neill, J. 2016. *Tackling drug-resistant infections globally: final report and recommendatio*ns. The review on antimicrobial resistance (available at http://amr-review.org/sites/default/files/160518_Final%20paper_with%20cover.pdf).

ODI (Overseas Development Institute). 2009. *Pastoralism and climate change. Enabling adaptive capacity.* Humanitarian Policy Group (available at http://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/4317.pdf).

ODI. 2010. *Pastoralism demographics, settlement and service provision in the Horn and East Africa: transformation and opportunitie*s, Humanitarian Policy Group (available at http://www.oxfamblogs.org/eastafrica/wp-content/uploads/2010/09/REGLAP-REPORTv2-fina-Demographic-trends-settlement-patterns-and-service-provision.pdf).

OECD (Organisation for Economic Co-operation and Development). 2001. *Adoption of technologies for sustainable farming systems*. Wageningen workshop proceedings (available at http://www.oecd.org/greengrowth/sustainable-agriculture/2739771.pdf).

OECD. 2005. *Environmentally harmful subsidies: challenges for reform* (available at http://www.oecd.org/tad/fisheries/environmentallyharmfulsubsidieschallengesforreform.htm).

OECD. 2012*. OECD green growth studies* (available at http://www.oecd-ilibrary.org/environment/oecd-green-growth-studies_22229523).

OECD. 2015. *Competition issues in the groceries sector: focus on conduct.* Background paper by the OECD Secretariat (available at https://www.competitionpolicyinternational.com/assets/DAF-COMP-LACF201518.pdf).

OECD. 2016. *Policy guidance on resource efficiency*. Paris, OECD Publishing. DOI: http://dx.doi.org/10.1787/9789264257344-en.

OECD/FAO. 2015. *OECD-FAO Agricultural Outlook 2015*. Paris, OECD Publishing (available at http://dx.doi.org/10.1787/agr_outlook-2015-en).

OECD/FAO. 2016. *Guidance on responsible agricultural supply chains* (available at https://mneguidelines.oecd.org/OECD-FAO-Guidance.pdf).

OECD/FAO/UNCDF. 2016. *Adopting a territorial approach to food security and nutrition policy*. Paris, OECD Publishing. http://dx.doi.org/10.1787/9789264257108-en.

OECD/IEA. 2014. *Renewable energy 2014: market analysis and forecasts to 202,* (available at https://www.iea.org/Textbase/npsum/MTrenew2014sum.pdf).

OIE (World Organisation for Animal Health). 2004. *Global conference on animal welfare: an OIE initiative.* Paris, 23–25 February 2004 (available at http://www.oie.int/fileadmin/Home/eng/Conferences_Events/docs/pdf/proceedings.pdf).

OIE. 2015. *Standards, guidelines and resolution on antimicrobial resistance and the use of antimicrobial agents***.** Paris.

Okali, C. 2012. *Gender analysis: engaging with rural development and agricultural policy processes.* Future Agricultures Consortium. FAC Working Paper 26 (available at http://r4d.dfid.gov.uk/PDF/Outputs/Futureagriculture/FAC_Working_Paper_026.pdf).

Okali, C. & Mims, J. 1998. *Gender and smallholder diary production in Tanzania*. Report to the Livestock Production Programme of the Department for International Development (DFID): Appendix 1 and 2, pp. 37–38.

Omosa, E.K. 2005. *The impact of water conflicts on pastoral livelihoods.* IISD (available at http://www.iisd.org/pdf/2005/security_pastoral_water_impacts.pdf).

Opiyo, F.E.O., Wasonga, O.V. & Nyangito, M.M. 2014. Measuring household vulnerability to climate-induced stresses in pastoral rangelands of Kenya: Implications for resilience programming, *Pastoralism: Research, Policy and Practice*, 4: 10.

Ortiz, R. & Alfaro, D. 2014. *Sustainable agricultural intensification in Latin America and the Caribbean. A synthesis report from an electronic consultation*. CGIAR Consortium, Montpellier, France (available at http://bit.ly/1lwrb3i).

Paillard, S., Treyer, S. & Dorin, B., coords. 2011. *Agrimonde: scenarios and challenges for feeding the world in 2050*. Edition Quae (available at http://www.cirad.fr/en/news/all-news-items/articles/2010/ca-vient-de-sortir/agrimonde).
Painter, J.A., Hoekstra, R.M., Ayers, T., Tauxe, R.V., Braden, C.R., Angulo, F.J. & Griffin, P.M. 2013. Attribution of foodborne illnesses, hospitalizations, and deaths to food commodities by using outbreak data, United States, 1998-2008. *Emerg. Infect. Dis*., 19: 407–415.
Pastoral Platform of Chad. 2015. *Issues and challenges for the pastoral development in Chad and in the sub-region.* Conference organized by the University of Moundou, 17 June 2015 (available at www.plateforme-pastorale-tchad.org).
Patel, R. 2009. What does food sovereignty look like? *The Journal of Peasant Studies*, 36(3): 663–706.
Perfecto, I., Vandermeer, J. & Wright, A. 2009. *Nature's matrix: linking agriculture, conservation and food sovereignty*. London/Sterling, Earthscan.
Perry, B. & Grace, D. 2009. The impacts of livestock diseases and their control on growth and development processes that are pro-poor. *Phil. Trans. R. Soc. B,* 364: 2643–2655.
Perry, B.D., Grace, D. & Sones, K. 2011. Current drivers and future directions of global livestock disease dynamics. *PNAS*, 10(52): 20871–20877.
Petersen, B. & Snapp, S. 2015. What is sustainable intensification? Views from experts. *Land Use Policy*, 46: 1–10. doi:10.1016/j.landusepol.2015.02.002.
Peyraud, J-L., Taboada, M. & Delaby, L. 2014. Integrated crop and livestock systems in Western Europe and South America: a review. *Europ. J. Agronomy,* 57: 31–42 (available at http://www.fao.org/fsnforum/sites/default/files/discussions/contributions/Integrated_corps_livestock_systems_article.pdf).
Pew Commission on Industrial Farm Animal Production. 2008. *Impact of industrial farm animal production on rural communities* (available at http://www.ncifap.org/_images/212-8_pcifap_ruralcom_finaltc.pdf).
Pica-Ciamarra, U., Tasciotti, L., Otte, J. & Zezza, A. 2011. *Livestock assets, livestock income and rural households: cross-country evidence from household surveys*. Rome, FAO (available at http://www.fao.org/docrep/014/am724e/am724e00.pdf).
Pica-Ciamarra, U. 2013. Study presented at the CGIAR Science Forum (available at http://www.slideshare.net/ISPC-CGIAR/ugo-pica-ciamarra-livestock-ownership-and-consumption-of-animalsource-foods-in-subsaharan-africa).
Pimbert, M. 2009. *Towards food sovereignty: reclaiming autonomous food systems*. London, IIED.
Ploeg, J.D. van der. 2010. *Farming styles research: the state of the art* (available at http://www.univie.ac.at/ruralhistory/Melk_Ploeg.pdf).
Ploeg, J.D. van der & Ventura, F. 2014. Heterogeneity reconsidered. *Current Opinion in Environmental Sustainability*, 8: 23–28.
Popkin, B.M., Adair, L.S. & Ng, S.W. 2012. Now and then: the global nutrition transition: the pandemic of obesity in developing countries. *Nutrition Reviews*, 70(1), 3–21. doi:10.1111/j.1753-4887.2011.00456.x.
Porcher J. 2011. The relationship between workers and animal in the pork industry: a common suffering. *Journal of Agricultural and Environmental Ethics*, 24: 3-17
Potter, P., Ramankutty, N., Bennett, E.M. & Donner, S.D. 2010. Characterizing the spatial patterns of global fertilizer application and manure production. *Earth Interactions*, 14(2): 1–22. DOI: 10.1175/2009EI288.1.
Power, A.G. 2010. Ecosystem services and agriculture: tradeoffs and synergies. *Philosophical Transactions of the Royal Society, B Biological Sciences*, 365(1554): 2959–2971.
Pretty, J. 2007. *The earth only endures: on reconciling with nature and our place in it.* London, Earthscan.
Pym, R. 2010. *Poultry genetics and breeding in developing countries.* Poultry Development Review, FAO.
Pym, R. & Alders, R.G. 2012. Introduction to village and backyard poultry production. *In* V. Sandilands & P. Hocking, eds. *Alternative systems for poultry – health, welfare and productivity*, pp. 97–109. Wallingford, UK, CABI.
Quan, J. 2011. *A future for small-scale farming.* Science review: SR25. UK Government's Office for Science. Foresight project on Global Food and Farming Futures. Natural Resources Institute, University of Greenwich, London (available at http://www.nri.org/images/documents/news2011/11-570-sr25-future-for-small-scale-farming.pdf).
Rao, M.P., Davi, N.K., D' Arrigo, R.D., Skees, J., Nachin, B., Leland, C., Lyon, B., Wang, S.Y. & Byambasuren, O. 2015. Dzuds, droughts, and livestock mortality in Mongolia. *Environmental Research Letters,* 10(7): 074012.
Rashid, S., Gulati, A. & Cummings, R.W. Jr, eds. 2008. *From parastatals to private trade: lessons from Asian agriculture*. Washington, DC, IFPRI.
Ravallion, M. & Datt, G. 1996. How important to India's poor is the sectoral composition of economic growth? *The World Bank Economic Review*, 10: 1–26.
Reardon T. & Timmer C.P. 2012. The economics of the food system revolution, *Annual Review of Resource Economics*, 4: 14.1–14.40.
Reda, K.T. 2015. Natural resource degradation and conflict in the East African pastoral drylands. *African Security Review*, 24(3): 270–278. DOI: 10.1080/10246029.2015.1059350.
Reilly, M. & Willenbockel, D. 2010. Managing uncertainty: a review of food system scenario analysis and modeling. *Philosophical Transactions of the Royal Society, B Biological Sciences*, 365: 3049–3063.
Revell, B.J. 2015. One man's meat … 2050? ruminations on future meat demand in the context of global warming. *J. Agric. Econ.*, 66(3): 573–858.

RISE Foundation. 2014. *The sustainable intensification of European agriculture*. A review sponsored by the RISE Foundation.
Roberto, C.A., Swinburn, B., Hawkes, C., Huang, T.T.K., Costa, S.A., Ashe, M., Zwicker, L., Cawley, J.H. & Brownell, K.D. 2015. Patchy progress on obesity prevention: emerging examples, entrenched barriers, and new thinking. *Lancet.*
Robinson, T.P., Thornton, P.K., Franceschini, G., Kruska, R.L., Chiozza, F., Notenbaert, A., Cecchi, G., Herrero, M., Epprecht, M., Fritz, S., You, L., Conchedda, G. & See, L. 2011. *Global livestock production systems*. Rome, FAO, and Nairobi, International Livestock Research Institute (ILRI). 152 p.
Rodrik, D. 2015. *Premature deindustrialization*. Economics Working Papers, IAS School of Social Science. Paper No. 107.
Ruel, M., Haddad, L. & Garret, J.L. 1999. *Some urban facts of life*. Food Consumption and Nutrition Division Discussion Paper 64. Washington, DC, IFPRI.
Sackett, D. & Holmes, P. 2006. *Assessing the economic cost of endemic disease on the profitability of Australian beef cattle and sheep producers*. Meat and Livestock Australia Limited, North Sydney.
Sang, X.L., Liang, X.C., Chen, Y., Li, J.D., Li, J.G., Bai, L. & Sun, J.Y. 2014. Estimating the burden of acute gastrointestinal illness in the community in Gansu Province, northwest China, 2012-2013. *BMC Public Health.* doi:10.1186/1471-2458-14-787.
Schlink, A.C., Nguyen, M.L. & Viljoen, G.J. 2010. Water requirements for livestock production: a global perspective. *Rev. Sci. Tech.,* 29(3): 603–619.
Schilling, J., Opiyo, F.E.O. & Scheffran, J. 2012. Raiding pastoral livelihoods: motives and effects of violent conflict in north-western Kenya. *Pastoralism: Research, Policy and Practice*. 2: 25.
Schröder, M.J.A. & McEachern, M.G. 2004. Consumer value conflicts surrounding ethical food purchase decisions: a focus on animal welfare. *International Journal of Consumer Studies*, 28(2): 168–177.
Seto, K.C., Güneralp, B. & Hutyrac, L.R. 2012. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proc. Natl. Acad. Sci. USA,* 109(40): 16083–16088.
Shattuck, A., Schiavoni, C.M. & VanGelber, Z. 2015. Translating the politics of food sovereignty: digging into contradictions, uncovering new dimensions. *Globalizations*, 12(4): 421–433.
Shepherd, A. 2007. Approaches to linking producers to markets. *Agricultural Management, Marketing and Financial Occasional Paper 13*. FAO, Rome.
Sibathu, K.T., Krishna, V.V. & Qaim, M. 2015. *Production diversity and dietary diversity in smallholder farm households.* B.L. Tumer, ed. Department of Agricultural Economics and Rural Development, Georg-August-University of Goettingen. Germany. Arizona State University, Tempe, USA (available at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4553771/pdf/pnas.201510982.pdf).
Slovic, P. 2010. *The feeling of risk: new perspectives on risk perception*. New York, USA, Earthscan.
Smith, J.W., Naazie, A., Larbi, A., Agyemang, K. & Tarawali, S. 1997. Integrated crop–livestock systems in sub-Saharan Africa: an option or an imperative? *Outlook on Agriculture*, 26(4): 237–246 (available at http://www.ilri.org/InfoServ/Webpub/fulldocs/Integra/integra.htm).
Smith, C.M., David, M.B., Mitchell, C.A., Masters, M.D., Anderson-Teixeira, K.J., Bernacchi, C.J. & DeLucia, E.H. 2013. Reduced nitrogen losses after conversion of row crop agriculture to perennial biofuel crops. *J. Environ. Qual.,* 42: 219–228 (available at http://www.life.illinois.edu/delucia/2014%20Publications/Smith%20et%20al%20JEQ%202013.pdf).
Smith, P., Gregory, P.J., van Vuuren, D., Obersteiner, M., Havl'k, P., Rounsevell, M. & É Bellarby, J. 2010. Competition for land. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 365(1554): 2941–2957. doi:10.1098/rstb.2010.0127.
Smith, L.C. & Haddad, L. 2015. Reducing child undernutrition: past drivers and priorities for the post-MDG era. *World Development*, 68: 180–204.
Soussana, J-F. & Lemaire, G. 2014. Coupling carbon and nitrogen cycles for environmentally sustainable intensification of grasslands and crop-livestock systems. *Agriculture, Ecosystems and Environment*, 190: 9–17.
SPLC (Southern Poverty Law centre)/Alabama Appleseed. 2013. *Unsafe at these speeds: Alabama's poultry industry and its disposable workers* (available at https://www.splcenter.org/sites/default/files/Unsafe_at_These_Speeds_web.pdf).
Staal, S., Poole, J., Baltenweck, I., Mwacharo, J., Notenbaert, A., Randolph, T., Thorpe, W., Nzuma, J. & Herrero, M. 2009. *Targeting strategic investment in livestock development as a vehicle for rural livelihoods*. Bill and Melinda Gates Foundation - ILRI Knowledge Generation Project Report. Nairobi, ILRI.
State Bureau of Statistics. 2015. *China Statistical Yearbook*. Beijing, China Statistics Press.
Steffen, W., Richardson, K., Rockström, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., de Vries, W., de Wit, C.A., Folke, C., Gerten, D., Heinke, J., Mace, G.M., Persson, L.M, Ramanathan, V., Reyers, B. & Sörlin, S. 2015. Planetary boundaries: guiding human development on a changing planet. *Science,* 347(6223).
Stoll-Kleemann, S. & O'Riordan, T. 2015. The sustainability challenges. *Environment,* 57(3): 34–48.
Sudershan, R.V., Kumar, R.N., Kashinath, L., Bhaskar, V. & Polasa, K. 2014. Foodborne infections and intoxications in Hyderabad, India. *Epidemiol. Res. Int*., 163: 1–50.
Sumberg, J. 2012. Mind the (yield) gap(s). *Food Security,* 4(4): 509–518.
Sumberg, J. & Thompson, J. 2012. *Contested agronomy: agricultural research in a changing world*. London, Earthscan.

Svensson, M., Urinboyev, R., Svensson, A.W., Lundqvist, P., Littorin, M. & Albin, M. 2013. *Migrant agricultural workers and their socio- economic, occupational and health conditions – a literature review*. Social Science Research Network.

SWAC (Sahel and West Africa Club)-OECD/ECOWAS. 2008. *Livestock and regional market in the Sahel and West Africa potentials and challenges*. Paris.

Taheripour, F., Hurt, C. & Tyner, W.E. 2013. Livestock industry in transition: economic, demographic, and biofuel drivers. *Anim. Front*., 3: 38–46. doi:10.2527/af.2013-0013.

Tam, C.C., Larose, T. & O'Brien, S.J., on behalf of the Study Group. 2014. *Costed extension to the Second Study of Infectious Intestinal Disease in the Community: identifying the proportion of foodborne disease in the UK and attributing foodborne disease by food commodity*. Project B18021 (FS231043).

Tangka, F.K., Jabbar, M.A. & Shapiro, B.I. 2000. *Gender roles and child nutrition in livestock production systems in developing countries: a critical review*. Socio-economics and Policy Research Working Paper 27. Nairobi, International Livestock Research Institute.

Taylor, L.H., Latham, S.M. & Woolhouse, M.E.J. 2001. Risk factor for human disease emergence. *The Royal Society.* doi10.1098/rstb.2001.0888.

The Royal Institute of International Affairs. 2015. *Changing climate, changing diets: pathways to lower meat consumption,* by L. Wellesley, C. Happer & A. Froggatt. London, Chatham House.

Thompson, J. & Millstone, E. 2011. *Pathways to sustainable food futures in a dynamic world*. Sussex University, Brighton, UK, STEPS Centre.

Thompson, J. & Scoones, I. 2009. Addressing the dynamics of agri-food systems: an emerging agenda for social science research. *Environmental Science and Policy,* 12: 386–397.

Thornton, P.K. 2010. Livestock production: recent trends, future prospects. *Phil. Trans. R. Soc*. *B*, 365: 2853–2867.

Thornton, P.K. & Herrero, M. 2010. *The interlinkages between rapid growth in livestock production, climate change, and the impacts on water resources, land use, and deforestation*. Policy Research Working Paper 5178, World Bank (available at http://research.fit.edu/sealevelriselibrary/documents/doc_mgr/467/Global_Livestock_Production_&_CC_Impacts_-_World_Bank_2010.pdf).

Thornton, P., van de Steeg, J., Notenbaert, M.H, & Herrero, M. 2009. The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know. *Agricultural Systems.* 101: 113–127.

Thornton, P.K., Boone, R.B., & Ramirez-Villegas, J. 2015. *Climate change impacts on livestock*. CCAFS Working Paper no. 120. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Copenhagen, Denmark.

Thow, A.M. 2009. *The implications of trade liberalization for diet and health* (available at www.globalizationand health.com/content/5/1/5 2009).

Thrupp, L.A. 2000. Linking agricultural biodiversity and food security: the valuable role of agrobiodiversity for sustainable agriculture. *International Affairs*, 76(2): 265–281.

Tilman, D., Cassman, K.G., Matson, P.A., Naylor, R. & Polasky, S. 2002. Agricultural sustainability and intensive production practices. *Nature*, 418: 671–677.

Timmer, C. 2007. *A world without agriculture: the structural transformation in historical perspective*, The Wendt Lecture, American Enterprise Institute, Washington, DC.

Tisdell, C. 2010. *The competitiveness of small household pig producers in Vietnam: significant research and policy findings from an ACIAR-sponsored study and their limitations*. Working Paper No. 63. University of Queensland, Australia.

Tittonell P., 2014. Ecological intensification of agriculture — sustainable by nature. *Current Opinion in Environmental Sustainability*, 8: p. 53–61.

Tittonell, P. & Giller, K.E. 2013. When yield gaps are poverty traps: the paradigm of ecological intensification in African smallholder agriculture. *Field Crops Res*., 143: 76–90.

Trichopoulou, A. & Lagiou, P. 1997. Healthy traditional Mediterranean diet: an expression of culture, history, and lifestyle. *Nutr. Rev.,* 55(11 Pt 1): 383–389.

Tschirley D. 2007. *Supermarkets and beyond: literature review on farmer to market linkages in sub-Saharan Africa and Asia*. Paper prepared for the AgInfo Project funded by the Bill and Melinda Gates Foundation. Michigan State University.

Tschirley, D.L., Ayieko, M.W., Hichaambwa, M., Goeb, J. & Loescher, W. 2010. Modernizing Africa's fresh produce supply chains without rapid supermarket takeover: towards a definition of research and investment priorities. *Food Security International Development Working Papers* (available at http://ideas.repec.org/p/ags/midiwp/93030.html).

Tschirley, D., Haggblade, S. & Reardon, T. 2013**.** *Africa's emerging food system transformation*. Global Center for Food Systems Innovation, Michigan State University, USA. White paper 2013 Series (available at http://pdf.usaid.gov/pdf_docs/PA00KB5C.pdf).

Tung, D.X. 2005. *Smallholder poultry production in Vietnam: marketing characteristics and strategies*. Paper presented at the workshop Does Poultry Reduce Poverty? A Need for Rethinking the Approaches, 30-31 August. Copenhagen, Network for Smallholder Poultry Development.

UNCED (United Nations Conference on Environment and Development). 1992. *The Rio declaration on environment and development.* June 1992. Rio de Janeiro (available at http://www.unesco.org/education/nfsunesco/pdf/RIO_E.PDF).

UNDESA (United Nations Department of Economic and Social Affairs). 2011. *Review of the implementation of the Rio Principles.* Detailed review of implementation of the Rio Principles. Sustainable Development in the 21th Century (SD21) (available at https://sustainabledevelopment.un.org/content/documents/1127rioprinciples.pdf, accessed 20 March 2016).
UNDESA (United Nations Department of Economic and Social Affairs). 2014. *World urbanization prospects. Highlights.* ESA/P/WP.241. Population Division. New York, USA, United Nations.
UNDESA. 2015. *World population prospects. Key findings and advance tables. 2015 Revision.* Population Division. New York, USA, United Nations.
UNEMG (United Nations Environment Management Group), 2011. *Global drylands: a UN system-wide response* (available at http://www.unemg.org/images/emgdocs/publications/Global_Drylands_Full_Report.pdf).
UNEP (United Nations Environment Programme). 2007. *Global Environment Outlook. GEO environment for development 4 (a*vailable at http://www.unep.org/geo/geo4/report/geo-4_report_full_en.pdf).
UNICEF (United Nations Children's Fund). 2013. Statistics by area/child nutrition/underweight disparities. *Childinfo: monitoring the situation of women and children* (available at http://www.childinfo.org/malnutrition_ weightbackground.php).
UNESCO (United Nations Educational, Scientific and Cultural Organization). 2010. Nomination File No. 00394. 5th session of the Intergovernmental Committee for the Safeguarding of the Intangible Cultural Heritage.
US GAO (United States Government Accountability Office). 2005. *Safety in the meat and poultry industry, while improving, could be further strengthened*. Workplace safety and health. Highlights of GAO-05-96, a report to the Ranking Minority Member, Committee on Health, Education, Labor and Pensions, U.S. Senate. January 2005 (available at http://www.gao.gov/new.items/d0596.pdf).
US-EPA (US Environmental Protection Agency). 2005. *Detecting and mitigating the environmental impact of fecal pathogens originating from confined animal feeding operations: review*. EPA/600/R-06/021 (available at http://nepis.epa.gov/Adobe/PDF/P10089B1.pdf).
USAID. 2013. *USAID Issue Brief Land and Conflict*. Land Disputes and Land Conflicts, Property Rights and Resource Governance Briefing Paper #12 (available at http://pdf.usaid.gov/pdf_docs/PA00J75F.pdf).
Van Boeckel, T.P., Brower, C., Gilbert, M., Grenfell, B.T., Levin, S.A., Robinson, T.P., Teillant, A. & Laxminarayan, R. 2015. Global trends in antimicrobial use in food animals. *PNAS*, 112(18): 5649–5654.
van Dijk, M. 2012. *A review of global scenario exercises for food security analysis: assumptions and results*. Food Secure Working Paper No. 2 (available at http://www.foodsecure.eu/publicationDetail.aspx?id=9).
van Dijk, M. & Meijerik, G. 2014. *A review of global food security scenario and assessment studies: results, gaps and research priorities*. FoodSecure Working Paper No. 20 (available at http://www3.lei.wur.nl/FoodSecurePublications/20_Dijk_Meijerink_review-global-food.pdf).
Van Vuuren, D.P., Ochola, W.O., Riha, S., Giampietro, M., Ginzo, H., Henrichs, T., Hussain, S., Kok, K., Makhura, M., Mirza, M., Palanisama, K.P., Ranganathan, C.R., Ray, S., Ringler, C., Rola, A., Westhoek, H. & Zurek, M. 2009. Outlook on agricultural change and its drivers, *In* IAASTD. *Agriculture at a crossroads*, pp. 255–305. Washington, DC, Island Press.
Vera, R.R. 2006. *FAO Country Pasture/Forage Resource Profiles* – Colombia (available at http://www.fao.org/ag/agp/agpc/doc/counprof/columbia/colombia.htm).
Visser, M. & Ferrer, S. 2015. *Farm workers' living and working conditions in South Africa: key trends, emergent issues, and underlying and structural problems.* A report based on a research project commissioned by The Pretoria Office of the International Labour Organization.
Von Lampe, M., Willenbockel, D., Ahammad, H., Blanc, E., Cai, Y., Calvin, K., Fijimori, S., Hasegawa, T., Havlik, P., Heyhoe, E., Kyle, P., Lotze-Campen, H., Mason d'Croz, D., Nelson, G.C., Sands, R.D., Schmitz, C., Tabeau, A., Valin, H., van der Mensbrugghe, D., & van Meijl, H. 2014. Why do global long-term scenarios for agriculture differ? An overview of the AgMIP global economic model intercomparison. *Agricultural Economics*, 45: 1–18.
Vos, R. 2014. Is global food security jeopardised by an old-age time bomb. *The Guardian*, 4 February (available at http://www.theguardian.com/ global-development-professionals-network/2014/ feb/04/global-food-security-old-age-timebomb).
Vos, R. 2015. *Thought for food: strengthening global governance of food security*. CDP Background Paper No. 29 ST/ESA/2015/CDP/29.
Wassenaar, T., Gerber, P., Verburg, P.H., Rosales, M., Ibrahim, M. & Steinfeld, H. 2006. Projecting land use changes in the neotropics. The geography of pasture expansion into forest. *Global Environmental Change*, 17(1): 86–104.
WAP (World Animal Protection). 2014a. *Animal Protection Index* (available at http://api.worldanimalprotection.org; http://www.worldanimalprotection.org).
WAP). 2014b. *A case study of high welfare, large-scale chicken and egg production in Brazil* (available at http://www.worldanimalprotection.org/sites/default/files/int_files/high-welfare-large-scale-egg-production-brazil.pdf).
WAP/Agri benchmark/CIPAV/FEDEGAN. 2014. *A case study of triple wins in milk and beef production in Colombia* (available at http://www.agribenchmark.org/fileadmin/Dateiablage/B-Beef-and-Sheep/Misc/Other-Articles-Papers/CO-milk-beef-production-150203.pdf).
Weiler, V., Udo, H.M.J., Viets, T., Crane, T.A. & de Boer, I.J.M. 2014. Handling multi-functionality of livestock in a life cycle assessment: the case of smallholder dairying in Kenya. *Environmental Sustainability*, 8: 29–38.

Wezel, A. & Soldat, V. 2009. A quantitative and qualitative historical analysis of the discipline of agroecology. *International Journal of Agricultural Sustainability*, 7(1): 3–18.
Wezel, A., Bellon, S., Doré, T., Francis, C., Vallod, D. & David, C. 2009. Agroecology as a science, a movement and a practice: a review. *Agronomy for Sustainable Development*, 29: 503–515.
White, R.P., Murray, S. & Rohweder, M. 2000. *Pilot analysis of global ecosystems: grassland ecosystems*. Washington, DC, World Resources Institute.
Wibbelman, M., Schmutz, U., Wright, J., Udall, D., Rayns, F., Kneafsey, M., Trenchard, L., Bennett, J. & Lennartsson, M. 2013. *Mainstreaming agroecology: implications for global food and farming systems.* Centre for Agroecology and Food Security Discussion Paper. Coventry, Centre for Agroecology and Food Security. ISBN: 978-1-84600-0454.
Wiggins, S. & Keats, S. 2013. *Leaping and learning: linking smallholders to markets in Africa*. Agriculture for Impact. London, Imperial College and Overseas Development Institute.
Wiggins, S., & Keats, S. 2014. *Rural wages in Asia*. London, Overseas Development Institute.
Willett, W.C., Sacks, F., Trichopoulou, A., Drescher, G., Ferro-Luzzi, A., Helsing, E. & Trichopoulos, D. 1995. Mediterranean diet pyramid: a cultural model for healthy eating. *Am. J. Clin. Nutr.,* 6(6 Suppl): 1402S–1406S.
Wise, T.A. 2013. *Can we feed the world in 2050? A scoping paper to assess the evidence*. Global Development and Environment Institute Working Paper No. 13-04. Tufts University, Medford, USA (available at http://www.ase.tufts.edu/gdae/Pubs/wp/13-04WiseFeedWorld2050.pdf).
Wise, T.A. & Trist, S.E. 2010. *Buyer power in U.S. hog markets: a critical review of the literature*. Global Development and Environment Institute Working Paper No. 10-04. Tufts University, Medford.
WISP (World Initiative for Sustainable Pastoralism). 2008. *Pastoralists regions* (available at http://www.iucn.org/wisp/).
Wittman, H., Desmarais, A.A. & Wiebe, N. 2010. The origins and potential of food sovereignty. *In* Desmarais, A.A Wittman, H. & Wiebe, N. eds. *Food sovereignty: reconnecting food, nature and community*. Oakland, USA, Food First.
WHO (World Health Organization). 2015a. *World Health Statistics.* Geneva (available at http://apps.who.int/iris/bitstream/10665/170250/1/9789240694439_eng.pdf).
WHO. 2015b. *Obesity and overweight.* Fact Sheet 311, Geneva (available at http://www.who.int/mediacentre/factsheets/fs311/en/).
WHO. 2015c. *Global action plan on antimicrobial resistance* (available at http://apps.who.int/iris/bitstream/10665/193736/1/9789241509763_eng.pdf?ua=1).
Woolhouse, M.E., Haydon, D.T. & Antia, R. 2005. Emerging pathogens: the epidemiology and evolution of species jumps. *Trends Ecol. Evol.,* 20: 238–244. doi:10.1016/j.tree.2005.02.009.
World Bank. 2005. *Economic growth in the nineties, learning from a decade of reforms*. Washington, DC.
World Bank. 2009. *Global economic prospects 2009: commodities at the crossroads.* Washington, DC. 140 (available at http://siteresources.worldbank.org/INTGEP2009/Resources/10363_WebPDF-w47.pdf).
World Bank. 2012. *People, pathogens and our planet: the economics of one health*. Washington, DC.
World Bank/CIAT/CATIE. 2014. *Climate-smart agriculture in Argentina*. CSA Country Profiles for Latin America Series. Washington, DC, The World Bank Group.
World Food Summit. 1996. *Rome Declaration World Food Security*. Rome, FAO (available at http://www.fao.org/docrep/003/w3613e/w3613e00.htm).
Wright, I.A., Tarawali, S., Blümmel, M., Gerard, B., Teufel, N. & Herrero, M. 2011. Integrating crops and livestock in subtropical agricultural systems. *J. Sci. Food Agric.,* 92(5): 1010–1015. doi: 10.1002/jsfa.4556.
Wu, R., Tiessen, H. & Chen, Z. 2008 The impacts of pasture degradation on soil nutrients and Plant Composition in Alpine Grassland, China. *Journal of Agricultural, Food, and Environmental Sciences* 2(2).
Zhang, Z. 1995. The effect and causes of grassland degeneration (In Chinese). *Pratacultural Science,* 12(6): 1–5.
Zijlstra, J., Everdingen, W.H. v., Jager, J.H., Kooistra, S. & van Riel J.W. 2012. *Implications of expansion on financial results of dairy farms in the Netherlands and the EU.* Report Part I of the Project: Expansion with financial return. Lelystad, Wageningen UR Livestock Research 606. 55 p.
Zinsstag, J. Ould Taleb, M. & Craig, P.S. 2006. Health of nomadic pastoralists: new approaches towards equity effectiveness. *Tropical Medicine and International Healt*h, 11(5): 565568.

APPENDIX

The HLPE project cycle

The High Level Panel of Experts for Food Security and Nutrition (HLPE) was created in October 2009 the science-policy interface of the UN Committee on World Food Security (CFS).

The Committee on World Food Security (CFS) is the foremost inclusive and evidence-based international and intergovernmental platform for food security and nutrition, for a broad range of committed stakeholders to work together in a coordinated manner and in support of country-led processes towards the elimination of hunger and ensuring food security and nutrition for all human beings.[46]

The HLPE receives from CFS its working mandate. This ensures the legitimacy and relevance of the studies undertaken, and their insertion in a concrete political agenda at international level. The report elaboration process ensures the scientific inclusiveness and the independence of the HLPE.

The HLPE produces scientific, policy oriented reports, including analysis and recommendations, serving as a comprehensive and evidence-based starting point for policy debates at CFS. The HLPE aims at providing a better understanding of the diversity of issues and rationales when dealing with food and nutrition insecurity. It thrives to clarify contradictory information and knowledge, elicit the backgrounds and rationales of controversies, and identify emerging issues.

The HLPE is not mandated to conduct new research. The HLPE draws its studies based on existing research and knowledge produced by various expertise-providing institutions (universities, research institutes, international organizations etc.), and adding value by global, multi-sectoral and multidisciplinary analysis.

HLPE studies combine scientific knowledge with experiences from the ground, in a same rigorous process. The HLPE translates the richness and variety of forms of expert knowledge from many actors (knowledge of local implementation, knowledge based on global research and knowledge of "best practice") that draw on both local and global sources, into policy-related forms of knowledge.

To ensure the scientific legitimacy and credibility of the process, as well as its transparency and openness to all forms of knowledge, the HLPE operates with very specific rules, agreed by the CFS.

The HLPE has a two-tier structure:

1. A Steering Committee composed of 15 internationally recognized experts in a variety of food security and nutrition related fields, appointed by the Bureau of CFS. HLPE Steering Committee members participate in their individual capacities, and not as representatives of their respective governments, institutions or organizations.
2. Project Teams acting on a project specific basis, selected and managed by the Steering Committee to analyse/report on specific issues.

The project cycle to elaborate the reports (Figure 9) includes clearly defined stages, starting from the political question and request formulated by the CFS. The HLPE institutes a scientific dialogue, building upon the diversity of disciplines, backgrounds, knowledge systems, the diversity of its Steering Committee and Project Teams, and open e-consultations. The topic bound and time bound Project Teams work under the Steering Committee's scientific and methodological guidance and oversight.

The HLPE runs two open consultations per report: first, on the scope of the study; second, on a V0 "work-in-progress" draft. This opens the process towards all experts interested as well as to all concerned stakeholders, which are also knowledge-holders. Consultations enable the HLPE to better understand the issues and concerns, and to enrich the knowledge base, including social knowledge, thriving for the integration of diverse scientific perspectives and points of view.

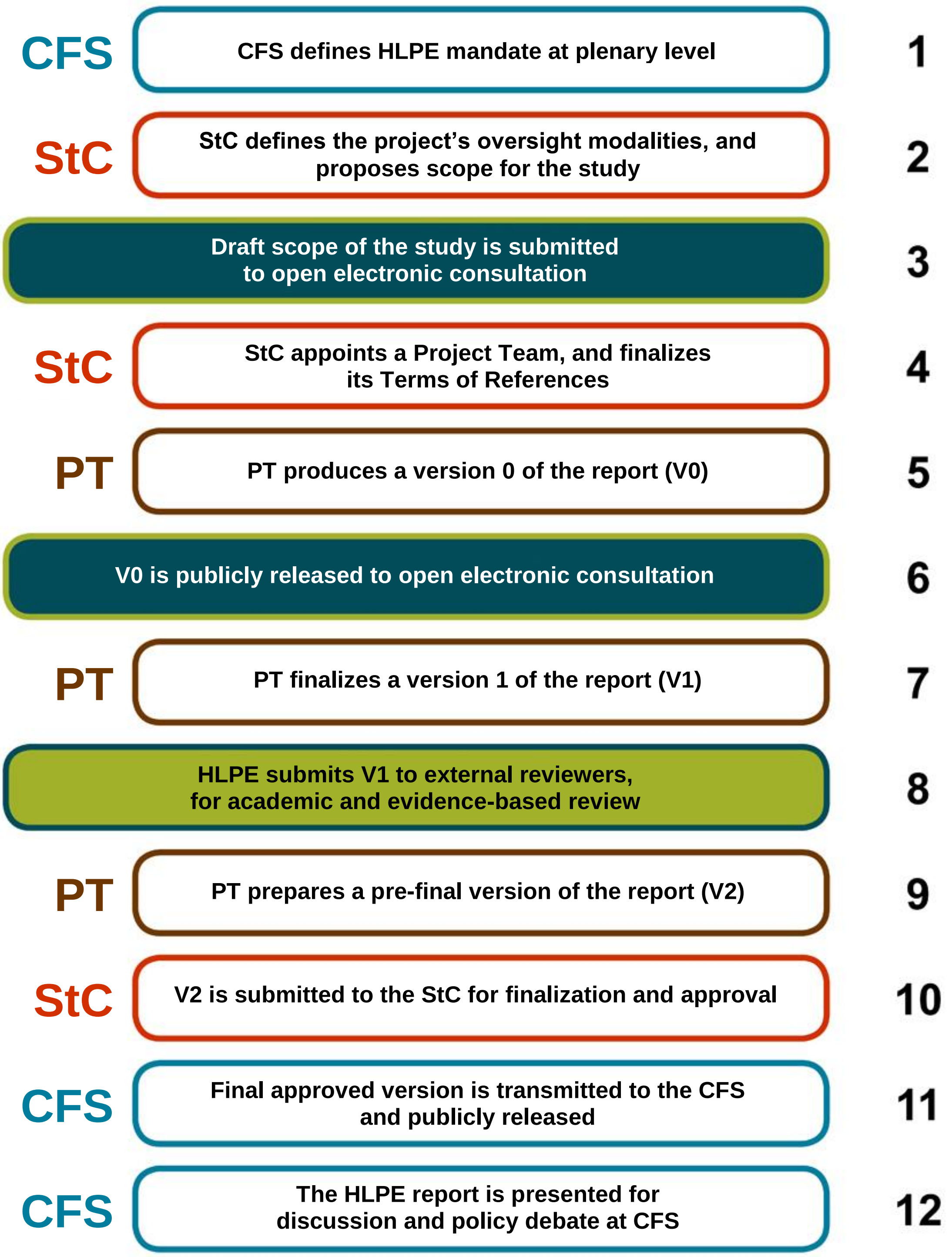
It includes an external scientific peer-review on a pre-final draft. The report is finalized and approved by the Steering Committee during a face-to-face meeting.

HLPE reports are published in the 6 official languages of the UN (Arabic, Chinese, English, French, Russian and Spanish), and serve to inform discussions and debates in CFS.

All information regarding the HLPE, its process and all former reports is available at the HLPE Website: www.fao.org/cfs/cfs-hlpe.

[46] CFS Reform Document, available at www.fao.org/cfs

Figure 9 HLPE project cycle



CFS Committee on World Food Security
HLPE High Level Panel of Experts on Food Security and Nutrition
StC HLPE Steering Committee
PT HLPE Project Team

Cover photo: © ILRI/Stevie Mann

This report addresses the economic, environmental and social dimensions of agricultural development, with the objective of ensuring food and nutrition security, in terms of availability, access, utilization and stability. It focuses on the livestock component of agricultural systems, given the role of livestock as an engine for the development of the agriculture and food sector, and as a driver of major economic, social and environmental changes in food systems worldwide. The report identifies challenges to the achievement of sustainability in livestock systems and possible pathways towards sustainable agricultural development that contribute to current and future food security and nutrition. The report concludes with recommendations for appropriate actions by policy-makers and stakeholders.

CFS
COMMITTEE ON WORLD FOOD SECURITY
HLPE
High Level Panel of Experts

Secretariat HLPE c/o FAO
Viale delle Terme di Caracalla
00153 Rome, Italy

Website: www.fao.org/cfs/cfs-hlpe
E-mail: cfs-hlpe@fao.org

I5795E/1/07.16