Government Office for Science

Foresight

The Future of Food and Farming:

Challenges and choices for global sustainability

FINAL PROJECT REPORT

The Future of Food and Farming: Challenges and choices for global sustainability

This report is intended for:

Policy makers and a wide range of professionals and researchers whose interests relate to all aspects of the global food system: including governance at all scales, food production and processing, the supply chain, and also consumer attitudes and demand. It is also relevant to policy makers and others with an interest in areas that interact with the food system, for example: climate change mitigation, energy and water competition, and land use.

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Professor Charles Godfray CBE, FRS and are Professor Ian Crute CBE,
Professor Lawrence Haddad, Dr David Lawrence, Professor James Muir,
Professor Jules Pretty OBE, Professor Sherman Robinson and Dr Camilla Toulmin.

GO-Science would particularly wish to acknowledge the contribution of Professor Mike Gale FRS who was also a member of the Lead Expert Group, but who sadly died during the course of the Project.

Thanks are also due to the UK government departments Defra and DFID who provided support throughout the Project, the Project's High Level Stakeholder Group, the Project Advisory Group and the Economics Advisory Group, as well as the many experts and stakeholders from the UK and around the world who contributed to the work, reviewed the many Project reports, and papers, and generously provided advice and guidance. A full list is provided in Annex A.

Foreword

The case for urgent action in the global food system is now compelling. We are at a unique moment in history as diverse factors converge to affect the demand, production and distribution of food over the next 20 to 40 years. The needs of a growing world population will need to be satisfied as critical resources such as water, energy and land become increasingly scarce. The food system must become sustainable, whilst adapting to climate change and substantially contributing to climate change mitigation. There is also a need to redouble efforts to address hunger, which continues to affect so many. Deciding how to balance the competing pressures and demands on the global food system is a major task facing policy makers, and was the impetus for this Foresight Project.

Foresight has aimed to add value though the breadth of its approach which places the food system within the context of wider policy agendas. It argues for decisive action and collaborative decision-making across multiple areas, including development, investment, science and trade, to tackle the major challenges that lie ahead.

The Project has brought together evidence and expertise from a wide range of disciplines across the natural and social sciences to identify choices, and to assess what might enable or inhibit future change. Building upon existing work, it has also drawn upon over 100 peer-reviewed evidence papers that have been commissioned. Several hundred experts and stakeholders from across the world have been involved in the work – I am most grateful to them, the core team of lead experts, the group of senior stakeholders who have advised throughout the Project, and to the Foresight Project team.

I am delighted that the findings of all of this work are now published in this Final Report which, together with the supporting papers, is freely available to all. I hope that this will help policy makers and other communities of interest to think creatively and decisively about how to address the challenges ahead in a way that is pragmatic and resilient to future uncertainties.

Professor Sir John Beddington CMG, FRS
Chief Scientific Adviser to HM Government, and
Head of the Government Office for Science

Preface

We are delighted to receive this Final Report of the Foresight Global Food and Farming Futures Project from Sir John Beddington on behalf of Government. Its findings have global relevance and remind us of the scale of the challenge facing us. The Project highlights how the global food system is consuming the world's natural resources at an unsustainable rate; failing the very poorest, with almost one billion of the least advantaged and most vulnerable people still suffering from hunger and malnutrition. Despite the considerable progress made in reducing the proportion of people in Asia and Africa living in hunger and poverty, the overall number affected by chronic hunger has scarcely changed for the past 20 years.

Land, the sea and the actions of food producers not only provide the raw materials to the global food system and deliver a range of crucial environmental services, but are in themselves a source of economic growth in the developed and developing world. The evidence presented in this Report highlights the vulnerability of the global food system to climate change and other global threats and emphasises the need to build in greater resilience to future food price shocks.

In doing so this Report makes a strong case for governments, the private sector and civil society to continue to prioritise global food security, sustainable agricultural production and fisheries, reform of trade and subsidy, waste reduction and sustainable consumption.

Addressing the many challenges facing global farming and food will require decision-making that is fully integrated across a diverse range of policy areas which are all too often considered in isolation, and for action to be based on sound evidence. Building on previous international studies including the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD) and the International Fund for Agricultural Development (IFAD) Rural Poverty Report, this Project provides new insight into how different challenges could converge, the strategies and polices needed to address these challenges, and priorities for action now and for the future.

The Report also provides valuable insight into how our farming and food industry in the UK can contribute to the transition to a green economy by increasing sustainability, seizing opportunities and providing innovative solutions for the future.

We will be jointly acting on the Project's findings. And we will strongly encourage others to do the same, as it is clear that concerted efforts at national, regional and global levels of government, and close partnership with the private sector and civil society, will be crucial to address the challenges we face.

We would like to take this opportunity to thank Sir John Beddington for this excellent Report, and also the many individuals and stakeholders who have contributed to the Project.

Rt Hon Caroline Spelman MP
Secretary of State for Environment,
Food and Rural Affairs

Rt Hon Andrew Mitchell MP
Secretary of State for International Development

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Executive Summary – key conclusions for policy makers

1 Introduction[1]

Project aim: to explore the pressures on the global food system between now and 2050 and identify the decisions that policy makers need to take today, and in the years ahead, to ensure that a global population rising to nine billion or more can be fed sustainably[2] and equitably.

The global food system will experience an unprecedented confluence of pressures over the next 40 years. On the demand side, global population size will increase from nearly seven billion today to eight billion by 2030, and probably to over nine billion by 2050; many people are likely to be wealthier, creating demand for a more varied, high-quality diet requiring additional resources to produce. On the production side, competition for land, water and energy will intensify, while the effects of climate change will become increasingly apparent. The need to reduce greenhouse gas emissions and adapt to a changing climate will become imperative. Over this period globalisation will continue, exposing the food system to novel economic and political pressures.

Any one of these pressures ('drivers of change') would present substantial challenges to food security; together they constitute a major threat that requires a strategic reappraisal of how the world is fed. Overall, the Project has identified and analysed five key challenges for the future. Addressing these in a pragmatic way that promotes resilience to shocks and future uncertainties will be vital if major stresses to the food system are to be anticipated and managed. The five challenges, outlined further in Sections 4 – 8, are:

A. Balancing future demand and supply sustainably – to ensure that food supplies are affordable.

B. Ensuring that there is adequate stability in food supplies – and protecting the most vulnerable from the volatility that does occur.

C. Achieving global access to food and ending hunger. This recognises that producing enough food in the world so that everyone can *potentially* be fed is not the same thing as ensuring food security for all.

D. Managing the contribution of the food system to the mitigation of climate change.

E. Maintaining biodiversity and ecosystem services while feeding the world.

These last two challenges recognise that food production already dominates much of the global land surface and water bodies, and has a major impact on all the Earth's environmental systems.

In recognising the need for urgent action to address these future challenges, policy-makers should not lose sight of major failings in the food system that exist today.

Although there has been marked volatility in food prices over the last two years, the food system continues to provide plentiful and affordable food for the majority of the world's population. Yet it is failing in two major ways which demand decisive action:

- **Hunger remains widespread.** 925 million people experience hunger: they lack access to sufficient of the major macronutrients (carbohydrates, fats and protein). Perhaps another billion are thought to suffer from 'hidden hunger', in which important micronutrients (such as vitamins and minerals) are missing from their diet, with consequent risks of physical and mental impairment. In contrast, a billion people are substantially over-consuming, spawning a new public health epidemic involving

1 Note: the contents of this Executive Summary closely follow the findings of the Foresight Project's Final Report, although the emphasis here is on the high-level conclusions and priority actions. All the supporting references for the analysis and figures contained in this Executive Summary are provided in the Final Report.

2 Sustainability implies the use of resources at rates that do not exceed the capacity of the Earth to replace them. A more detailed description of the use of this and other terms is provided in the Final Report.

chronic conditions such as type 2 diabetes and cardiovascular disease. Much of the responsibility for these three billion people having suboptimal diets lies within the global food system.

- **Many systems of food production are unsustainable.** Without change, the global food system will continue to degrade the environment and compromise the world's capacity to produce food in the future, as well as contributing to climate change and the destruction of biodiversity. There are widespread problems with soil loss due to erosion, loss of soil fertility, salination and other forms of degradation; rates of water extraction for irrigation are exceeding rates of replenishment in many places; over-fishing is a widespread concern; and there is heavy reliance on fossil fuel-derived energy for synthesis of nitrogen fertilisers and pesticides. In addition, food production systems frequently emit significant quantities of greenhouse gases and release other pollutants that accumulate in the environment.

In view of the current failings in the food system and the considerable challenges ahead, this Report argues for decisive action that needs to take place now.

The response of the many different actors involved will affect the quality of life of everyone now living, and will have major repercussions for future generations. Much can be achieved immediately with current technologies and knowledge given sufficient will and investment. But coping with future challenges will require more radical changes to the food system and investment in research to provide new solutions to novel problems[3]. This Report looks across all of these options to draw out priorities for policy-makers[4].

The analysis of the Project has demonstrated the need for policy-makers to take a much broader perspective than hitherto when making the choices before them – they need to consider the *global food system* from production to plate.

The food system is not a single designed entity, but rather a partially self-organised collection of interacting parts. For example, the food systems of different countries are now linked at all levels, from trade in raw materials through to processed products. Besides on-farm production, capture fisheries and aquaculture are also important, in terms of both nutrition and providing livelihoods, especially for the poor – about a billion people rely on fish as their main source of animal protein. Many vulnerable communities obtain a significant amount of food from the wild ('wild foods'), which increases resilience to food shocks.

Most of the economic value of food, particularly in high-income countries, is added beyond the farm gate in food processing and in retail, which together constitute a significant fraction of world economic activity. At the end of the food chain, the consumer exerts choices and preferences that have a profound influence on food production and supply, while companies in the food system have great political and societal influence and can shape consumer preferences. All of the above imply the need to give careful consideration to the complex ramifications of possible future developments and policy changes in the global food system.

Policy-makers also need to recognise food as a unique class of commodity and adopt a broad view of food that goes far beyond narrow perspectives of nutrition, economics and food security.

Food is essential for survival and for mental and physical development – nutritional deficiencies during pregnancy and in early growth (especially the first two years) can have lifelong effects. For the very poor, obtaining a minimum amount of calories becomes a dominant survival activity. However, issues of culture, status and religion also strongly affect both food production and demand, and hence shape the basic economics of the food system. Also, food production, cooking and sharing are major social and recreational activities for many in middle- and high-income countries.

3 See Box 1.2 for a brief discussion of the Project's treatment of new technologies in the food system.

4 See Box 1.3 for a list of the Project's high-level conclusions, and Section 8 for a list of priorities for policy-makers.

Box 1.1 The Project's added value

The Project has involved around 400 leading experts and stakeholders from about 35 low-, middle- and high-income countries across the world[5]. Drawing upon the latest scientific and other evidence from many organisations and researchers, it aims to add value by:

- Taking a long-term, strategic outlook at likely challenges over the next 20 years to 2030 and the next 40 years to 2050. It has used futures techniques to embrace the many uncertainties inherent in the future, and to identify choices that are resilient to a range of outcomes.
- Taking a very broad view of the food system and the wider context in which it operates. It has considered the concerns and experiences of many different types of stakeholder, from African smallholder to multinational retailer, from issues of governance to evolving consumer demand.
- Commissioning new economic modelling to explore possible future trends in food prices.
- Involving participants from a very wide range of disciplines: natural and social scientists and experts in risk management, economics and modelling.

Annex E of the Project's Final Report provides an overview of all the Project's evidence and reports. These include commissioned papers and reports synthesising specific aspects of the future challenges affecting the food system.

A word of caution

It is impossible for a broadly scoped project such as this to consider the range of issues and disciplines in the same detail as the more focused work of individual researchers and organisations. Rather, its insights should be seen as complementary, aiming to provide a fresh look and a challenge to existing thinking, as well as providing signposts to the most important issues and promising approaches. It aims to present a framework for thinking about the future, and for more detailed analysis and policy development by others.

Box 1.2 Appraising new technologies in the food system

- New technologies (such as the genetic modification of living organisms and the use of cloned livestock and nanotechnology) should not be excluded *a priori* on ethical or moral grounds, though there is a need to respect the views of people who take a contrary view.
- Investment in research on modern technologies is essential in light of the magnitude of the challenges for food security in the coming decades.
- The human and environmental safety of any new technology needs to be rigorously established before its deployment, with open and transparent decision-making.
- Decisions about the acceptability of new technologies need to be made in the context of competing risks (rather than by simplistic versions of the precautionary principle); the potential costs of *not* utilising new technology must be taken into account.
- New technologies may alter the relationship between commercial interests and food producers, and this should be taken into account when designing governance of the food system.
- There are multiple approaches to addressing food security, and much can be done today with existing knowledge. Research portfolios need to include all areas of science and technology that can make a valuable impact – any claims that a single or particular new technology is a panacea are foolish.
- Appropriate new technology has the potential to be very valuable for the poorest people in low-income countries. It is important to incorporate possible beneficiaries in decision-making at all stages of the development process.

5 See Annex A of the Project's Final Report for a list of experts and stakeholders that were closely involved.

Box 1.3 High-level conclusions

A major conclusion of this Report is the critical importance of interconnected policy-making. Other studies have stated that policy in all areas of the food system should consider the implications for volatility, sustainability, climate change and hunger. Here it is argued that policy in other sectors outside the food system also needs to be developed in much closer conjunction with that for food. These areas include energy, water supply, land use, the sea, ecosystem services and biodiversity. Achieving much closer coordination with all of these wider areas is a major challenge for policy-makers.

There are three reasons why broad coordination is needed. First, these other areas will crucially affect the food system and therefore food security. Secondly, food is such a critical necessity for human existence, with broad implications for poverty, physical and mental development, wellbeing, economic migration and conflict, that if supply is threatened, it will come to dominate policy agendas and prevent progress in other areas. And, thirdly, as the food system grows, it will place increasing demands on areas such as energy, water supply and land – which in turn are closely linked with economic development and global sustainability. Progress in such areas would be made much more difficult or impossible if food security were to be threatened.

However, there is a tension between the Report's identification of five key challenges to the food system and its stress on the importance of considering policy development in the round. The following highlight a number of key themes and conclusions that both summarise the findings and cut across the different challenges, with an emphasis on what needs to be done immediately.

1. Substantial changes will be required throughout the different elements of the food system and beyond if food security is to be provided for a predicted nine billion people. Action has to occur on all of the following four fronts simultaneously:

- More food must be produced sustainably through the spread and implementation of existing knowledge, technology and best practice, and by investment in new science and innovation and the social infrastructure that enables food producers to benefit from all of these.
- Demand for the most resource-intensive types of food must be contained.
- Waste in all areas of the food system must be minimised.
- The political and economic governance of the food system must be improved to increase food system productivity and sustainability.

The solution is not *just* to produce more food, or change diets, or eliminate waste. The potential threats are so great that they cannot be met by making changes piecemeal to parts of the food system. It is essential that policy-makers address all areas at the same time.

2. Addressing climate change and achieving sustainability in the global food system need to be recognised as dual imperatives. Nothing less is required than a redesign of the whole food system to bring sustainability to the fore.

The food system makes extensive use of non-renewable resources and consumes many renewable resources at rates far exceeding replenishment without investing in their eventual replacement. It releases greenhouse gases, nitrates and other contaminants into the environment. Directly, and indirectly through land conversion, it contributes to the destruction of biodiversity. Unless the footprint of the food system on the environment is reduced, the capacity of the earth to produce food for humankind will be compromised with grave implications for future food security. Consideration of sustainability must be introduced to all sectors of the food system, from production to consumption, and in education, governance and research.

3. It is necessary to revitalise moves to end hunger. Greater priority should be given to rural development and agriculture as a driver of broad-based income growth, and more incentives provided to the agricultural sector to address issues such as malnutrition and gender inequalities. It is also important to reduce subsidies and trade barriers that disadvantage low-income countries. Leadership in hunger reduction must be fostered in both high-, middle- and low-income countries.

Though the proportion of the world's population suffering from hunger has declined over the last 50 years, there are worrying signs that progress is stalling and it is very unlikely that the Millennium Development Goals for hunger in 2015 will be achieved. Ending hunger requires a well-functioning global food system that is sensitive to the needs of low-income countries, although it also requires concerted actions that come from within low-income countries.

4. Policy options should not be closed off. Throughout, the Project's Final Report has argued the importance of, within reason, excluding as few as possible different policy options on *a priori* grounds. Instead, it is important to develop a strong evidence base upon which to make informed decisions.

Food is so integral to human wellbeing that discussions of policy options frequently involve issues of ethics, values and politics. For example, there are very different views on the acceptability of certain new technologies, or on how best to help people out of hunger in low-income countries. Box 1.2 both illustrates the need to keep policy options open and gathers together the Report's conclusions about the application of new technologies, such as the genetic modification of living organisms and the use of cloned livestock and nanotechnology. Achieving a strong evidence base in controversial areas is not enough to obtain public acceptance and approval – genuine public engagement and discussion needs to play a critical role.

5. This Report rejects food self-sufficiency as a viable option for nations to contribute to global food security, but stresses the importance of crafting food system governance to maximise the benefits of globalisation and to ensure that they are distributed fairly. For example, it is important to avoid the introduction of export bans at time of food stress, something that almost certainly exacerbated the 2007 – 2008 food price spike.

The food system is globalised and interconnected. This has both advantages and disadvantages. For example, economic disruptions in one geographical region can quickly be transmitted to others, but supply shocks in one region can be compensated for by producers elsewhere. A globalised food system also improves the global efficiency of food production by allowing bread-basket regions to export food to less favoured regions.

2 Important drivers of change affecting the food system

This is a unique time in history – decisions made now and over the next few decades will disproportionately influence the future:

- For the first time, there is now a high likelihood that growth in the global population will cease, with the number of people levelling in the range of eight to ten billion towards the middle of the century or in the two decades that follow.
- Human activities have now become a dominant driver of the Earth system: decisions made now to mitigate their detrimental effects will have a very great influence on the environment experienced by future generations, as well as the diversity of plant and animal species with which they will share the planet.
- There is now a developing global consensus, embodied in the Millennium Development Goals, that there is a duty on everyone to try to end poverty and hunger, whether in low-income countries or among the poor in more wealthy nations.

Threats from interacting drivers of change will converge in the food system over the next 40 years. Careful assessment of the implications of these drivers is essential if major pressures are to be anticipated, and future risks managed. Six particularly important drivers are outlined here. This Project

has considered the combined effect of such drivers on the food system to explore interactions, feedbacks and non-linear effects.

I. Global population increases. Policy-makers should assume that today's population of about seven billion is most likely to rise to around eight billion by 2030 and probably to over nine billion by 2050. Most of these increases will occur in low- and middle-income countries; for example, Africa's population is projected to double from one billion to approximately two billion by 2050. However, population projections are uncertain and will need to be kept under review. Factors affecting population size include GDP growth, educational attainment, access to contraception and gender equality; possibly the single most important factor is the extent of female education. Population growth will also combine with other transformational changes, particularly in low- and middle-income countries as rising numbers of people move from rural areas to cities that will need to be serviced with food, water and energy.

II. Changes in the size and nature of per capita demand. Dietary changes are very significant for the future food system because, per calorie, some food items (such as grain-fed meat) require considerably more resources to produce than others. However, predicting patterns of dietary change is complex because of the way pervasive cultural, social and religious influences interact with economic drivers.

- *Meat:* different studies have predicted increases in per capita consumption (kg/capita/annum) from 32 kg today to 52 kg by the middle of the century. In high-income countries, consumption is nearing a plateau. Whether consumption of meat in major economies such as Brazil and China will stabilise at levels similar to countries such as the UK, or whether they will rise further to reach levels more similar to the USA is highly uncertain. However, major increases in the consumption of meat, particularly grain-fed meat, would have serious implications for competition for land, water and other inputs, and will also affect the sustainability of food production.
- *Fish:* demand is expected to increase substantially, at least in line with other protein foods, and particularly in parts of east and south Asia. The majority of this extra demand will need to be met by further expansion of aquaculture, which will have significant consequences for the management of aquatic habitats and for the supply of feed resources.

Major uncertainties around future per capita consumption include:

- the degree to which consumption will rise in Africa
- the degree to which diets will converge on those typical of high-income countries today
- whether regional differences in diet (particularly in India) persist into the future
- the extent to which increased GDP is correlated with reduced population growth and increased per capita demand – the precise nature of how these different trade-offs develop will have a major effect on gross demand.

III. Future governance of the food system at both national and international levels. Many aspects of governance have a significant impact on the workings of the food system:

- The globalisation of markets has been a major factor shaping the food system over recent decades and the extent to which this continues will have a substantial effect on food security.
- The emergence and continued growth of new food superpowers, notably Brazil, China and India. Russia is already significant in global export markets, and likely to become even more so, with a large supply of underutilised agricultural land.
- The trend for consolidation in the private sector, with the emergence of a limited number of very large transnational companies in agribusiness, in the fisheries sector, and in the food processing, distribution and retail sectors. There is some evidence that this trend may be reversing, with the entry into international markets of new companies from emerging economies.
- Production subsidies, trade restrictions and other market interventions already have a major effect on the global food system. How they develop in the future will be crucial.
- The extent to which governments act collectively or individually to face future challenges, particularly in shared resources, trade and volatility in agricultural markets. The inadequate governance of international fisheries, despite severe resource and market pressures, illustrates in microcosm many of the political and institutional obstacles to effective collective action.

- The adequacy of the current international institutional architecture to respond to future threats to the global food system, and the political will to allow them to function effectively, is unclear.
- The control of increasing areas of land for food production (such as in Africa) will be influenced by both past and future land-purchase and leasing agreements – involving both sovereign wealth funds and business.

IV. **Climate change.** This will interact with the global food system in two important ways:

- Growing demand for food must be met against a backdrop of rising global temperatures and changing patterns of precipitation. These changing climatic conditions will affect crop growth and livestock performance, the availability of water, fisheries and aquaculture yields and the functioning of ecosystem services in all regions. Extreme weather events will very likely become both more severe and more frequent, thereby increasing volatility in production and prices. Crop production will also be indirectly affected by changes in sea level and river flows, although new land at high latitudes may become suitable for cultivation and some degree of increased carbon dioxide fertilisation is likely to take place (due to elevated atmospheric carbon dioxide concentrations). The extent to which adaptation occurs (for example through the development of crops and production methods adapted to new conditions) will critically influence how climate change affects the food system.
- Policies for climate change mitigation will also have a very significant effect on the food system – the challenge of feeding a larger global population must be met while delivering a steep reduction in greenhouse gas emissions (see Section 6 below).

V. **Competition for key resources.** Several critical resources on which food production relies will come under more pressure in the future. Conversely, growth in the food system will itself exacerbate these pressures:

- *Land for food production:* Overall, relatively little new land has been brought into agriculture in recent decades. Although global crop yields grew by 115% between 1967 and 2007, the area of land in agriculture increased by only 8% and the total currently stands at approximately 4,600 million hectares. While substantial additional land could in principle be suitable for food production, in practice land will come under growing pressure for other uses. For example, land will be lost to urbanisation, desertification, salinisation and sea level rise, although some options may arise for salt-tolerant crops or aquaculture. Also, while it has been estimated that the quality of around 16% of total land area including cropland, rangeland and forests is improving, the International Soil Reference and Information Centre has estimated (2009) that of the 11.5 billion hectares of vegetated land on earth, about 24% has undergone human-induced soil degradation, in particular through erosion. In addition, with an expanding population, there will be more pressure for land to be used for other purposes. And while some forms of biofuels can play an important role in the mitigation of climate change, they may lead to a reduction in land available for agriculture.

  There are strong environmental grounds for limiting any significant expansion of agricultural land in the future (although restoration of derelict, degraded or degrading land will be important). In particular, further conversion of rainforest to agricultural land should be avoided as it will increase greenhouse gas emissions very significantly and accelerate the loss of biodiversity.
- *Global energy demand:* This is projected to increase by 45% between 2006 and 2030 and could double between now and 2050. Energy prices are projected to rise and become more volatile, although precise projections are very difficult to make. Several parts of the food system are particularly vulnerable to higher energy costs – for example, the production of nitrogen fertilisers is highly energy intensive: the roughly fivefold increase in fertiliser price between 2005 and 2008 was strongly influenced by the soaring oil price during this period. The financial viability of fishing (particularly capture fisheries) is also strongly affected by fuel price.
- *Global water demand:* Agriculture already currently consumes 70% of total global 'blue water' withdrawals from rivers and aquifers available to humankind. Demand for water for agriculture could rise by over 30% by 2030, while total global water demand could rise by 35–60% between 2000 and 2025, and could double by 2050 owing to pressures from industry, domestic use and the need to maintain environmental flows. In some arid regions of the world, several major non-renewable fossil aquifers are increasingly being depleted and cannot be replenished, for example in the Punjab, Egypt, Libya and Australia. Estimates suggest that exported foods account for between 16% and 26% of the

total water used for food production worldwide, suggesting significant potential for more efficient global use of water via trade, although there is the risk of wealthy countries exploiting water reserves in low-income countries.

VI. **Changes in values and ethical stances of consumers.** These will have a major influence on politicians and policy makers, as well as on patterns of consumption in individuals. In turn, food security and the governance of the food system will be affected. Examples include issues of national interest and food sovereignty, the acceptability of modern technology (for example genetic modification, nanotechnology, cloning of livestock, synthetic biology), the importance accorded to particular regulated and highly specified production methods such as organic and related management systems, the value placed on animal welfare, the relative importance of environmental sustainability and biodiversity protection, and issues of equity and fair trade.

3 Challenge A: Balancing future demand and supply sustainably

Concerted action across several policy domains is essential to address the challenge of balancing supply and demand sustainably over the next 40 years. This section sets out five classes of action, drawing out their potential contribution, and where efforts should best be focused. They relate to the better use of existing knowledge, capitalising on new science and technology, reducing waste, and improving governance and influencing demand.

It is important to stress that action involving difficult decisions is important in all areas. Concentrating on one or a subset of the five classes will not be sufficient and progress in one reduces pressures on the others.

3.1 Improving productivity sustainably using existing knowledge

It has been estimated that the application of existing knowledge and technology could increase average yields two- to threefold in many parts of Africa, and twofold in the Russian Federation. Similarly, global productivity in aquaculture could, with limited changes to inputs, be raised by around 40%. However, in determining where and how much to invest in producing more food, policy-makers will need to consider a range of criteria rather than increases in production alone. These criteria will need to acknowledge the existence of both positive and negative externalities associated with different forms of food production, and the particular needs of poor rural communities whose livelihoods often depend on food production.

Making decisions about different ways of producing more food is difficult because the consequences of different actions may be hard to quantify economically and environmentally. Operational definitions of sustainability are also complicated by issues of geographical scale and levels of uncertainty, as well as by their long-term or inter-generational implications. Equally, it is clear that there are no simple, blueprint solutions that have universal application. Rather, design of these policies involves social and political choices, in a contested space within which different interest groups advance particular arguments that they hope will influence outcomes in their favour.

A wide range of evidence considered by the Project provides support for four classes of intervention aimed at raising agricultural productivity. These relate mostly to middle- and low-income countries because it is here that policy interventions are likely to have the greatest influence in increasing yields sustainably.

- **The revitalisation of extension services to increase the skills and knowledge base of food producers (often women) is critical to achieving sustainable increases in productivity in both low-income and high-income countries.** Recent experience with models for extension that make use of new forms of social infrastructure should be applied to increase producers' knowledge about best practice, and expand the social capital within and between institutions and communities in the food supply chain. The role of women needs particular consideration in view of their often significant role as food producers in lower income countries.
- **Improving the functioning of markets and providing market access, particularly in low-income countries.** In many low-income countries food markets function poorly or only very locally. Business

and financial reform designed to facilitate entrepreneurship in the food production sector can increase food production, household revenue, livelihood diversification and the strength of rural economies. Another possibility includes spreading best practice relating to access to capital – such access enables producers to invest in new and better farming or fishing methods, diversify into new activities such as aquaculture or specialist crops, and access markets.

- **Strengthening rights to land and natural resources, such as water, fisheries and forests should be a high priority.** Uncertainty in such rights is a major disincentive to investment in food production in many low-income countries. They should be strengthened at the levels of individual local producers and communities and should build upon customary rights. Developments in China and Ethiopia provide examples of the effectiveness of such measures.
- **Physical infrastructure must be improved in middle- and low-income countries to facilitate access to markets and investment in rural economies.** Such infrastructure includes roads, ports, irrigation projects, storage facilities and information and communication technology (ICT) systems. The importance of these developments is demonstrated in Africa where, for certain landlocked countries, transport costs can be as high as 77% of the value of their exports. The establishment of development corridors linked to major ports can be a very effective way of stimulating local economies.

3.2 New science and technology to raise the limits of sustainable production and address new threats

The application of existing knowledge and technology has very substantial potential to increase crop yields. Investment in research and development is critical to:

- **producing more food efficiently and sustainably**
- **securing ecosystem services**
- **keeping pace with evolving threats such as the emergence of new and more virulent pests and diseases**
- **addressing new challenges, such as the development of new varieties of crops that are resistant to increased drought, flooding and salinity arising from climate change**
- **meeting the particular needs of the world's poorest communities.**

Looking across the entirety of the evidence reviewed by the Project, the following strategic conclusions on research and development can be drawn:

- There is a strong case for reversal of the low priority accorded to research on agriculture, fisheries and the food system in most countries. Countries such as China have demonstrated the effectiveness of agricultural research in raising productivity.
- Recent scientific and technological advances offer significant new opportunities to address major environmental challenges such as climate change, water scarcity and soil degradation.
- Research on climate change adaptation and mitigation in the food system should be a priority. Agriculture and food production will need to adapt to a changing world with a higher likelihood of extreme weather events.
- Investment in food production research needs to focus on raising yields in conjunction with improving sustainability and maintaining ecosystem services. This shift must recognise that special measures will often be needed to incentivise research that produces public goods.
- A pluralistic research portfolio is essential: the magnitude of the challenges are so large that no single research avenue will address all the new knowledge required.
- New ways are required to incentivise research and development that meets the needs of low-income countries and where at least initial returns on investment will be low. Where incentives do not currently exist for investment in research that provides public goods, new models of delivery are needed to mobilise the considerable strengths of private-sector research and scientific entrepreneurship.
- The contribution of funders to research from the public, private and third sector needs better coordination.

- Investment in research and development is not enough in itself. Communication is critical – not just to spread new knowledge to policy-makers and potential users, but also to the public, specifically to engender trust in new science and its application.

This Foresight Project has commissioned a series of reviews exploring the new science required to meet the challenges of producing more food more sustainably. Important priorities are summarised in the Project Synthesis Report C6. The Final Project Report also concurs with the conclusions of the Royal Society's recent report, *Reaping the Benefits,* which explores in more detail research challenges in crop production. The following suggest general priorities:

- **Development of new varieties or breeds of crops, livestock and aquatic organisms**, capitalising on recent advances in the biosciences.
- **The preservation of multiple varieties, land races, rare breeds and closely related wild relatives of domesticated species.** This is very important in maintaining a genetic bank of variation that can be used in the selection of novel traits.
- **Advances in nutrition and related sciences.** These offer substantial prospects for improving the efficiency and sustainability of animal production (both livestock and aquaculture).
- **Scientific and technological advances in soil science and related fields.** Relatively neglected in recent years, these offer the prospect for a better understanding of constraints to crop production and better management of soils to preserve their ecosystem functions, improve and stabilise output, reduce pollutant run-off and cut greenhouse gas emissions.
- **Targeted research in modern crop and animal science, agro-ecology, agricultural engineering and aquaculture management.** Research across a broad range of subjects, including areas that have received less investment in recent years, is critical to improving yields and sustainability at the same time.

This Project has also considered other more revolutionary advances, such as the development of perennial grain crops, the introduction of nitrogen fixation into non-legume crops, and re-engineering the photosynthetic pathways of different plants. These are important areas for study, although they are unlikely to contribute significantly to raising agricultural productivity until at least the latter end of the 40-year period considered by this Report. In parallel with the development of the science, it will be critical to consider how such advances would be commercially sustainable and hence could be deployed on a large scale.

3.3 Reducing waste

Although global estimates of waste are reliant so far on a weak evidence base, there is little doubt that the scale is substantial. It has been estimated that as much as 30% of all food grown worldwide may be lost or wasted before and after it reaches the consumer. Some estimates have placed it as high as 50%. Addressing waste across the entire food chain will be critical in any strategy to feed around eight billion people sustainably and equitably by 2030, and nine billion by 2050.

Making the food chain more efficient through waste reduction measures will reduce pressure on resources required for food production, lower greenhouse gas emissions and contribute to other policy agendas, such as cutting the need for further space set aside for landfill, which in turn would reduce greenhouse gas emissions.

Food waste is defined here as edible material intended for human consumption that is discarded, lost, degraded or consumed by pests as food travels from harvest to consumer or, as some put it, 'from field to fork'. This definition includes food that is fit for human consumption but intentionally used as animal feed, and spans the entire food supply chain. Whilst such a broad definition is appropriate, it creates problems in gathering accurate estimates of the *total* global food waste. This is because it is difficult to obtain accurate estimates of all the different kinds of waste. This Report focuses primarily on food waste that is either not used at all or not used productively or sustainably or where the resulting benefits are small compared with the value of the original food product.

Halving the total amount of food waste by 2050 is considered to be a realistic target, in view of the evidence reviewed by this Project. If the current global estimate of 30% waste is assumed, then halving

the total could reduce the food required by 2050 by an amount approximately equal to 25% of today's production[6].

Making waste reduction in the global food system a strategic target would be more easily achieved if there was high-level international political support and an international body willing to act as champion. This is because many diverse organisations would need to come together to tackle the highly variable levels of waste that occurs in the food supply chain in different parts of the world.

Rising food prices should themselves act as an incentive for waste reduction. However, there are a number of areas where the market alone will not achieve what is possible, and where other interventions will be required. The following are considered particularly promising.

Reducing post-harvest waste, chiefly in low-income countries:

- **Deployment of existing knowledge and technology in storage and transport infrastructure.** There are many examples of relatively simple and often traditional technologies that can substantially reduce post-harvest waste. One example concerns a Food and Agriculture Organization (FAO) project that provided simple sealed storage drums for grain farmers in Afghanistan and elsewhere.
- **Investment in new, appropriate technology to reduce post-harvest waste.** An example would be the use of modern scientific advances to produce crops that are less susceptible to pests and spoilage, or better fish-smoking kilns that reduce losses and demand less fuel.
- **Infrastructure, financial and market reforms to reduce waste.** The use of ICT (mobile phones in particular) could help improve market information and allow producers to make better decisions about timely supply to markets, avoiding or at least reducing seasonal gluts.

Reducing waste by consumers, and the food service sector, chiefly in high-income countries:

- **Campaigns to highlight the extent of waste and the financial benefits of reducing it.** Specific programmes aimed at consumers, companies in the food supply chain, and those providing meals in restaurants, firms, hospitals, schools and other institutions.
- **The development and use of cheap, mass-produced sensor technology that can detect spoilage in certain perishable foods.** This would allow more sophisticated food management than reliance on estimated 'best before' dates in retail food labelling and have the potential to ensure food quality as well as reduce waste.
- **Productive recycling of surplus food deemed as non-premium quality.** This could be achieved through redistribution of good-quality surplus food to consumers via schemes such as 'Fareshare' in the UK[7] or the use of food no longer fit for human consumption as animal feed or a source of energy through processes such as anaerobic digestion.
- **Spreading best practice.** For example, a project in the Netherlands involving modest funding shows how waste in the supply chain from food processing through to the home can be significantly reduced by a combination of education and simple technology.

3.4 Improving governance of the food system

3.4.1 General conclusions on governance

These are:

- **Food security is best served by fair and fully functioning markets and not by policies to promote self-sufficiency.** However, placing trust in the international system does not mean relinquishing a country's sovereignty, rights and responsibilities to provide food for its population.
- **Greater powers need to be given to international institutions to prevent trade restrictions at times of crisis.** Interventions should include economic incentives and penalties designed to stop the erection of trade barriers that exacerbate price rises. In the absence of new institutional structures it is likely

6 The actual saving will depend upon a number of uncertain factors, not least the size of demand in 2050. However, the figure of 25% is considered to give an approximate estimate of the magnitude of savings that may be achieved.

7 FareShare is an independent UK charity that provides quality food – surplus 'fit for purpose' product from the food and drink industry – to organisations working with disadvantaged people in the community.

that the G20 will play a key role in the short term. Even with this coordinated response, humanitarian reserves and mobilisation capacity may need to be strengthened or introduced in vulnerable regions.

- **In high-income countries, food production subsidies and related interventions act as a disincentive to efficient global food production, raise consumer prices in protected countries, and are ultimately harmful to global food security. The current trend to reduce them [for example in the last decade's reform of the European Union's (EU's) Common Agricultural Policy (CAP)] should be accelerated to encourage the self-sustaining improvements in productivity which are necessary to meet future increase in demand sustainably.** In addition to direct interventions, careful international monitoring and sanctions against the use of sanitary, phytosanitary (SPS) and other standards as deliberate or unintentional non-tariff barriers to trade should continue, with further support for poorer producers to meet the growing and confusing array of these requirements.
- **Where there are strong reasons to support rural communities and the provision of environmental public goods via agriculture, nations should do this in way that does not distort food prices.**
- **Future reform of international institutions such as the World Trade Organization cannot ignore the issues of sustainability and climate change. But there is the risk that allowing sustainability to be reflected in trade rules may lead to environmental protectionism.** Whether or not trade rules eventually do change, reaching agreement between low-, middle- and high-income countries on baseline standards for sustainability in food production and processing that can be implemented at national scale will be an important first step.
- **An essential first step towards a more equitable global trading system for poor agricultural producers is the realisation of a *genuinely* pro-development Doha Development Agenda agreement via the negotiations of the World Trade Organization (WTO).** The principles of special and differential treatment, which allow 'developing countries' and the 'least developed countries' (WTO terminology) to protect vulnerable sectors where they are essential for rural livelihoods, or more generally to liberalise at a slower and less steep pace, are essential.

3.4.2 Governance of capture fisheries

The governance of capture fisheries in inland, coastal or open waters faces particular problems. Fishery resources are commonly held as public goods, at national level or by international treaty, but harvesters have insufficient incentives to resist overexploitation. Regulation is complex, and monitoring, control and surveillance (MCS) is difficult and expensive to implement, and few authorities have the means or sanctions to control over-fishing. Possible improvements include:

- **More effective options built on approaches that link traditional community-shared management of common property with economic arguments of responsible ownership and efficient production.** Using longer term and sometimes tradable allocation of resource rights to individuals or community groups, incentives can be created for reducing effort and building resource value, landing and recording all catches, transparently acquiring and sharing data on resources, improving returns to harvesters, reducing management costs and increasing resource rents. Approaches to adaptive management based on efficient ecosystem-based concepts also need to be adopted, and temporarily or permanently protected areas may be required. As impacts of climate change are likely to become a frequent feature in fisheries, leading, for example, to changes in the spatial and temporal location of fish stocks, these approaches will become even more critical in maintaining resilience.
- **Responsible fishing can also be incentivised by pressures from consumers and retailers, international initiatives for controlling illegal fishing, restricting landing locations and campaigns to sanction non-compliant fleets.**

More broadly, governance approaches in fisheries are strongly connected with those for the food system, in issues such as marketing, government investment, development of new technology and the critical need to improve sustainability. Also, many people gain their livelihoods from a combination of crop production, animal husbandry and in seasonal fishing. However, although the nutritional, social and economic value of the sector is widely recognised, poor levels of support and commitment at national and multilateral levels have compounded the problems of governance and weakened its future potential.

3.4.3 Corporate governance in the global food system

Over the last two to three decades a relatively small number of companies have come to dominate in the global food supply chain. This trend is apparent all along the supply chain, from agri-business (including seeds, crop protection) through to commodity wholesalers, manufacturers and retailers. Concerns have been raised regarding the exercise of this concentration of corporate power, for example in retail markets and purchase contracts with suppliers (particularly smaller farmers); wider public access to agricultural intellectual property and the transparency of governance in the food system.

However, there does not seem to be an argument for intervention to influence the number of companies in each area or how they operate – provided that the current numbers of major companies in each area and region of the food system were not to contract to a level where competition was threatened, and provided that all organisations adhere to high international standards of corporate governance. Governance of the food system should ensure that a global diversity of actors is reflected in healthy competition at local levels.

Continuing open and transparent dialogue, and increased collaboration between governments, the private sector and civil society, with commitments to robust standards of action and performance to achieve this, will be essential to achieving future sustainability in the global food supply chain.

At the workshop Foresight held on developments in the global food supply chain, it was clear that there is very considerable scope for the food industry to play a significant role in facilitating greater sustainability. **Extending best practice in the food supply chain has the potential to make radical improvements in sustainability across the food system. To encourage this shift, food industry leaders have called for a 'level playing field' in standardising best practice in sustainability. These behavioural shifts will entail government support for the development of new metrics of sustainability, strong direction setting and a consensus for action amongst diverse actors.**

3.5 Influencing demand

The balance between supply and demand can also be influenced by measures aimed at influencing demand – changing people's diets. This approach has potential because different foods vary considerably in the resources required for their production[8].

A number of different levers have been identified in the literature. They include:

- economic interventions, including taxing non-preferred food types
- 'choice editing', regulatory or voluntary actions, including purchasing guidelines by retailers and the food service sector to restrict choices by consumers or selectively enhance access to better foods
- campaigns to change individual behaviour involving public education, advertising, targeted programmes in schools and workplaces, and the provision of better labelling to enable the public to make more informed decisions.

Evidence from the health sector shows that changing diets is difficult but not impossible. It requires concerted and committed actions, possibly over long timescales.

However, constraints on modifying consumption can include resistance from consumers, and also from business and producers whose interests may be adversely affected by changing diets. Also, public good campaigns can sometimes be undermined by commercial interests; for example the five-a-day message promoting consumption of fruit and vegetables in the UK has been used to promote foodstuffs that do not belong to these categories and which do not offer the same nutritional benefits. However, dietary change can have multiple benefits, and hence there are some synergies across different areas of policy, such as health and sustainability, which could help achieve action.

If policy-makers decide to seek to influence patterns of consumption, there are a number of guiding principles that should be considered:

- Better decisions are made by an informed consumer.

8 For example, see Box 3.1 for a discussion on policies relating to the production and consumption of meat.

- Simple, consistent and trusted information on food is important.
- Government fiscal and regulatory intervention ideally requires societal consensus.

Box 3.1 Policies on the production and consumption of meat

It has been argued that a reduction in the amount of meat consumed in high- and middle-income countries would have multiple benefits: a reduced demand for grain, leading to lower greenhouse gas emissions, and a positive effect on health. Although this is a complex issue, there are three unequivocally beneficial options for policy:

- There is little dispute about the importance of a balanced diet and the role of a moderate intake of livestock products; communicating this to the consumer should be a priority for public health (recognising the power of vested interests in promulgating contrary messages).
- There should be investment in, and incentives for, production systems that maximise efficiency of inputs such as water and energy and minimise the trade-off between the production of animal feed and crops for human consumption.
- Reducing greenhouse gas emissions (and other negative externalities) from livestock production is an important global good; regulatory frameworks and incentives, and public-funded investment in research and development, aimed at reducing emissions and other environmental harm, is a priority.

However, policy-makers should recognise that more proactive measures affecting the demand and production of meat may be required should current trends in global consumption continue to rise. A discussion of the triggers and options for further actions are provided in the Project's Final Report.

4 Challenge B: Addressing the threat of future volatility in the food system

High levels of volatility in global food markets are an issue because of the adverse effects they have on consumers and producers, because of the disruption they cause to the global food system, and, when particularly severe, because of the general economic and political instability that can occur. These effects will be most severe for low-income countries and the poor, and spikes in food price can be a major cause of increased hunger.

4.1 Volatility in the past and in the future

The pattern of fluctuations in the price of five major food commodities (wheat, rice, sugar, beef and palm) over the last 50 years shows that food prices can be strongly affected by shocks from outside the food system, such as the oil crises of the early 1970s. It also shows that the last 20 years have been a period of relatively low volatility compared with the previous three decades – in particular, the spike in food prices of 2007 – 08, while receiving considerable political and media attention, was relatively small compared with the fluctuations in the 1970s (see Box 4.1 for a discussion of the possible causes).

Box 4.1 The causes of the 2007–08 spike

The most likely contributing factors were a steady increase in global demand, in particular due to economic growth in middle-income countries; an increase in energy prices and regulatory changes encouraging the conversion of agricultural land to the production of biofuels; a series of poor wheat harvests in 2006 and 2007 in agriculturally important regions such as Australia; and a general rundown in commodity stocks. The height of the spike was undoubtedly exacerbated by the introduction or tightening of export restrictions by governments in some important producer countries. It has also been argued that commodity speculation was an important causal factor, but the empirical evidence for this is contested and does not allow the relative importance of the various factors in causing or exacerbating the price spikes to be distinguished.

The number of factors affecting volatility and the levels of uncertainty associated with each make it very difficult to predict whether the magnitude of fluctuations in food prices will fall or rise in the coming decades. Although predicting future volatility is complex, there are several arguments

suggesting that volatility may well increase in the future. Also, at least some food price spikes are inevitable.

A wide range of drivers is likely to affect volatility in the future: non-economic factors such as armed conflict and breakdown of regional or national governance; general economic factors such as globalisation and international trade, and shocks in other commodities particularly in the price of oil; the level of food stocks held by private and public sector agents; how the markets are regulated; continuing improvements in crop protection and biotechnology; subsidies or incentives to biofuels; and for particular commodities the size of the relevant market. The cultural importance of certain foods can also be influential, as this can lead to government interventions to reduce price volatility.

4.2 Policy implications relating to future volatility

While the amount of volatility remains uncertain, price spikes in the future are inevitable.

The key issues for policy-makers are:

- **What levels of volatility are considered 'acceptable', and should governments intervene to attempt to control volatility within defined bounds?**
- **How can the negative consequences of volatility be mitigated, and which interventions would be most effective?**
- **Is it better to develop mechanisms to protect producers or consumers from the effects of volatility and, if so, how?**
- **To what extent should collective action and planning at the international level (for example the G20) occur to protect the poorest from the worst effects of volatility?**

Determining acceptable levels of volatility in food prices is a political judgement that needs to consider the negative effects of volatility, but also the costs of intervention.

Negative implications of volatility include:

- periods of high food prices that particularly have impact on low-income countries, and the poor everywhere
- risks of political and social instability
- distortions of investment decisions by making returns harder to gauge and incurring costs in hedging risk.
- potential to exacerbate problems of macroeconomic and fiscal management.

But the costs to interventions to reduce volatility include:

- high costs: they are expensive and require resources that could be used elsewhere
- risk of distorting markets or of interventions being hijacked for political reasons
- failure to be effective or making problems worse through unintended consequences.

Protection of the most vulnerable groups from the worst effects of food price volatility should be a priority, especially those in low-income countries where market and insurance institutions are weak. This can be done indirectly through intervention to try to influence market prices, but is likely to be more effective through the provision of safety nets for poor consumers or producers that are designed to stabilise real incomes.

It is essential that mechanisms are put in place to give governments the confidence in the global trade system to resist what will often be intense political pressures to impose export restrictions at times of high food prices.

Improving the functioning of commodity markets can reduce the element of volatility that does not reflect underlying market fundamentals.

Well-functioning markets require access to accurate information – information on international production and the size of commodity stocks is generally poor and in some cases deliberately withheld. The incorporation of commodities in more complex markets and over-the-counter traded derivatives, and the effect of automatic computer trades need to be explored further. Also, the effects of these issues, if any, on excess volatility should be explored to determine if action is needed by policy-makers.

There have been calls for a global system of virtual or actual international grain reserves to help dampen price fluctuations on global markets. The Project did not find the arguments in favour of this strategy to be sufficiently strong to suggest that it be given priority.

In most circumstances the costs and policy risks of using international food reserves, virtual or real, to dampen volatility (as opposed to protecting the poor directly) will tend to outweigh the benefits. Past experience with international agreements, such as those for coffee and sugar following the 1970s price spikes, were not successful – they broke down when divergent interests of the participants emerged as markets recovered. There is a case, however, for higher public stock holding at the national or regional level, as noted below.

Governments and regional systems of support (such as the EU) have a clear role in improving education and awareness of the options available to improve risk management. Special measures for the most vulnerable countries include:

- Targeted food reserves for vulnerable (typically low-income) countries should be considered. There is a strong case for establishing an emergency food reserve and financing facility for the World Food Programme to help low-income countries facing sudden increases in food import bills when price spikes occur.
- The poorest food producers need specific assistance to obtain insurance against risk and volatility.
- Safety nets will be required at times of unusually high food prices.

5 Challenge C: Ending hunger[9]

5.1 Hunger today

Ending hunger is one of the greatest challenges to be considered by this Project. Today, there are an estimated 925 million people who suffer from hunger and perhaps an additional billion who, while having access to sufficient macronutrients, suffer from the 'hidden hunger' of not having enough vitamins and minerals.

This challenge is already recognised in the target of Millennium Development Goal 1. This aims to halve the number of undernourished people from the 1990 level of 16% to 8% in 2015. The current figure is 13.5%. Although China met its target in the early 2000s, many countries in Africa and south Asia are unlikely to succeed by 2015; although there has been a slight fall (from 1,020 million to 925 million over the past 12 months), progress has been slow.

There are substantial difficulties in defining and measuring hunger, undernutrition and food security. This issue contributes to a serious shortfall in the evidence and data available to inform policies. For example, household surveys have demonstrated that, in some countries, FAO data may underestimate the number of people suffering from hunger by as much as a factor of three.

Hunger intersects with food insecurity and undernutrition in complex ways. It is important for policy-makers to take a broad view of the nature and causes of hunger and its many impacts, including the severe and long-lasting nature of the effects that hunger and undernutrition can cause, particularly in children.

Hunger results in increased morbidity and mortality, through diseases caused by nutrient deficiency, and a greater susceptibility to disease more generally. It leads to distress behaviour that undermines development, including the sale of assets, the withdrawal of children from school (particularly girls) and into the labour force, the prompting of outmigration and, at worst, permanent destitution, prostitution and child trafficking. It also contributes to the onset of armed conflict. The food price rises of 2007–08 and their impacts, particularly on the poorest households, highlighted the inability of the current global food system to protect the most vulnerable from volatility in food prices.

9 The emphasis here is on ending chronic hunger.

There is a widespread consensus on the causes of hunger: for people to be free of hunger, there has to be physical, economic and social access to food. However, interventions will require the deliberate generation of a more robust and consistent consensus on tackling hunger. Strong levels of political courage and leadership will be required to carry this through.

Many of the factors that enable poor people to access money and other resources to consume, purchase or grow good-quality food lie from outside the food system. However, there is still much more that national and international actors can do to tackle hunger through the food system itself. These are considered below.

5.2 Making agriculture work harder to reduce hunger

In the countries where hunger is most chronic (south Asia and sub-Saharan Africa) agriculture can make a major contribution to its eradication. For this to occur, agricultural development must be designed and incentivised with hunger reduction as a primary goal. Food production, whether from terrestrial or aquatic sources, has a powerful potential triple role in ending hunger:

- Production is essential for physical access to food. Technologies, institutions, infrastructure and information that support increased, sustainable productivity and which are equitable (i.e. are desirable, available and practical for the poorest farmers to adopt) can increase the supply of a diverse and locally desirable food at affordable prices.
- These technologies, institutions, infrastructure and information sources can improve economic access for all by raising farm income, generating employment on and off farm, and reducing food prices.
- Production can address issues of social access by deliberately empowering women and other socially excluded groups.

In the poorest countries, agriculture provides not only food for households, but also a very important means of broadly based income generation. Recent empirical evidence suggests that, compared with growth from other sources, growth in agriculture generates welfare gains that are much stronger for the poorest parts of the population. Cross-country econometric analysis reported in the 2008 World Development Report shows that a 1% gain in gross domestic product (GDP) originating in agriculture generates a 6% increase in overall expenditure of the poorest 10% of the population, while the equivalent figure for GDP growth originating in non-agricultural sectors is zero growth.

There are grounds for optimism that agriculture can become a more powerful force for the reduction of hunger and poverty in the decades ahead – but agriculture needs to be repositioned within governments as a profession dedicated to multiple ends, of which hunger and poverty reduction are central.

For many governments, the purpose of agriculture is seen primarily as food production. In reality, agriculture requires flexibility to adapt to multiple agro-ecological niches; social analysis to understand issues of equity and exclusion; environmental skills to, among other things, work within the climate change mitigation and adaptation agendas; and political resourcefulness to forge new alliances that enable the sector to leverage additional funds and influence. This means a repositioning of agriculture as a profession dedicated to multiple ends, of which hunger and poverty reduction are central. Food production is the means, not the end. Such a repositioning would mean changing the formal and informal training of professionals in agricultural development, the ways in which Ministries of Agriculture are located, organised and staffed, and how the media perceives agriculture. The following are particularly important:

- Innovation in how to involve producers in improving yields sustainably is as important as innovation in research – there is still a need for far greater participation of producers in defining and monitoring success.
- With much technology development taking place at greater distances from the farmer's plot, stronger mechanisms are needed to ensure that representatives of poor farmers and groups experiencing chronic hunger are included in local and national fora.
- Smallholder farming has been long neglected. It is not a single solution, but an important component of both hunger and poverty reduction.

- Women in low-income countries play a critical role in agriculture, and agriculture plays a critical role in women's livelihoods. Purposively empowering women and focusing on their unique challenges will bring much wider gains in terms of poverty and productivity.

5.3 Measures in the broader food system

Hunger cannot be ended by agriculture alone. Other policies and investments to increase food access, income, reduce differences in gender power and improve nutrition status are vital. Interventions discussed elsewhere in this Executive Summary in the areas of trade, research and development, training and extension have a critical contribution in addressing hunger as well as increasing production of, and access to, food.

- **There has been considerable recent innovation in different forms of social protection to improve access to food.** Cash transfers – with or without conditions –are quickly becoming the main type of programme for social protection to help vulnerable households be less exposed, less sensitive and more adaptive to a range of shocks.
- **However, it is important not to view social protection policies uncritically.** Social protection can compete with agriculture for political support and may only be affordable for the poorest 10% of the population.
- **In addition to placing gender power relations at the heart of the agricultural research and development system, there is a wide range of complementary measures that can be undertaken to promote the agency of women in ways that will accelerate hunger reduction.** They include the eradication of gender-based discrimination (such as land ownership and user rights) and steps to actively promote women's status (such as quotas for representation in agricultural decision-making bodies).
- **Undernutrition needs to be tackled by direct and by indirect interventions.** 'Direct nutrition' interventions focus exclusively on improving nutrition status – for these the main issue has been the challenge of scaling up. 'Indirect' interventions refer to programmes or policies that do not have improvements in nutrition as a core aim, but have the potential to be beneficial – particularly as some draw upon large budgets. Programmes relating to agriculture, social protection and women's status fall within this category. For these, empowering women will help accelerate gains in addressing hunger and undernutrition. But so too will embedding direct nutrition components within larger resource flows – examples of promising innovations include biofortification of staple food crops with micronutrients, and the health conditionalities embedded in cash transfers.

5.4 Efforts to end hunger

A stronger constituency for hunger reduction needs to be built. The international community must challenge itself over the apparent ease with which hunger is ignored and ask why hunger is so easy to neglect. Brazil's experience of the past 10 years shows that if the political will is present, poverty and hunger can be substantially reduced.

Reducing the number of people suffering from hunger rarely receives political priority, since the poorest section of society exercises little leverage, nationally or globally. Arguably agriculture receives even less attention than hunger reduction. In the African context, it is often seen as old-fashioned, and the preoccupation of previous generations[10].

In the donor countries, investment in agricultural development has declined in recent decades because of changing donor fashions.

This is partly because of a shift in focus to social development and governance, and partly because those involved in agriculture did not invest sufficiently in impact analysis to defend it. In the last few years, however, greater attention has been given to agricultural development. For example, the World Development Report in 2008 focused on agriculture, and the aid given to agriculture by the

10 But see Box 5.1 for a discussion of the dynamism in parts of the African food system.

Development Assistance Committee (DAC) of the Organization for Economic Cooperation and Development (OECD) and multilateral agencies has increased.

However, despite this recent surge, the prolonged dip in investment means that agricultural training, infrastructure and research have suffered a 20-year period of underinvestment. There is now a need for a bold and global consensus for tackling hunger and ensuring investment in pro-poor, anti-hunger agricultural growth.

An infrastructure to strengthen commitment to hunger reduction needs to be developed to:

1. Monitor more appropriate outcomes. The FAO and the World Bank should be tasked with working together to develop a new set of hunger outcomes.

2. Monitor outcomes better and raise awareness of hunger. Governments need data on hunger within the year to adjust and respond. New mobile phone and global positioning system (GPS) technologies have the potential to revolutionise the mapping of hunger.

3. Monitor commitments and inputs, levels and perceptions – concerning government action and spending on hunger reduction. Constructing an index for measuring governmental commitment to hunger reduction could provide useful means of comparing the performance of different governments.

4. Strengthen the culture of monitoring, impact and learning in agriculture. Mixed-method approaches to agricultural measurement and evaluation are available. They must be used to understand what works, why, how and when. Agricultural organisations need to be incentivised to use these methods and to learn from them.

5. Enable greater strategic prioritisation and sequencing of actions to address hunger and undernutrition. There is a need to take much better account of the complementarities and interactions between different factors in addressing hunger, rather than focusing on their independent effects. The aim would be to develop and apply a 'growth diagnostics' approach (as currently being used to help policy stimulate economic growth), so that a broad range of factors contribute in concert.

6. Develop a culture that supports the emergence of leaders to champion hunger reduction. Very little is known about how to create leadership for hunger reduction, including the issue of whether such leadership will emerge independently or whether leaders might be encouraged by programmes on leadership for hunger reduction at the community and national levels. The lack of conclusive evidence suggests the need for experimentation and innovation across the field.

7. Mobilise mechanisms for accountability in hunger reduction. At a local level there are many mechanisms for social accountability that have proven to be effective in strengthening service delivery and improving the agency of the poorest. At a global level, the United Nations (UN) is leading a worldwide effort to build enforceable international law recognising the 'right to food'. While this work is welcome in terms of affirming values, it remains to be seen whether it leverages resources to accelerate hunger reduction.

Box 5.1 Agriculture in Africa – the myth and the reality

Agriculture accounts for 65% of full-time employment in Africa, 25–30% of GDP, and over half of export earnings. Perceptions about African agriculture are mixed. It has been called stagnant by some, and assumed to have failed smallholders – per capita production indicates that the amount of food grown on the continent per person has only just recovered today to the 1960 level.

However, when account is taken of the substantial growth in demand from population increases, it can be argued that African agriculture has been dynamic and adaptive over decades. Indeed, net production data show that there has been substantial growth in production across all regions of Africa, with output more than trebling over 50 years (with the greatest growth in north and west Africa), and growing faster than world output. A review commissioned by this Project of 40 African case studies demonstrates where sustainable increases in agricultural yield have been achieved – and the considerable potential that could be realised if these examples can be scaled up and applied elsewhere[11].

Nevertheless, the challenge still remains substantial for African agriculture: continued population growth, rapidly changing patterns of consumption and the impacts of climate change and environmental degradation are driving limited resources of food, energy, water and materials towards critical thresholds.

6 Challenge D: Meeting the challenges of a low emissions world

Greenhouse gas (GHG) emissions from the global food system constitute a substantial fraction of all emissions and need to be a focus of efforts to mitigate climate change. Equally, it will be critically important for policies on climate change mitigation to take full account of their potential impact of the global food system, in view of its vital role in human survival and wellbeing and its influence on wider issues of sustainability.

Developing policies in this area is particularly difficult because in addition to carbon dioxide (CO_2), the food system emits substantial volumes of the more powerful greenhouse gases methane (CH_4) and nitrous oxide (N_2O), which complicates monitoring and regulation. Also, the contribution that the food system makes to greenhouse gas emissions is difficult to measure and depends critically on where the boundaries of assessment are drawn. For example, in recent years the consequences of greenhouse gas emissions from land use change associated with agriculture have been of the same order as the sum of all other agricultural factors.

6.1 The food system and greenhouse gases – past and future

Agriculture itself is estimated to contribute 12–14% of greenhouse gas emissions, including those associated with fertiliser production; the figure rises to 30% or more when costs beyond the farm gate and especially land conversion are added. Moreover, agriculture contributes a disproportionate amount of greenhouse gases with high impact on warming: approximately 47% and 58% of total CH_4 and N_2O emissions respectively. Low- and middle-income countries are currently responsible for about three-quarters of agricultural greenhouse gas emissions with their proportionate share increasing. A study in 2006 estimated that 31% of the EU's greenhouse gas emissions were associated with the food system. The single most important contribution of agriculture to greenhouse gas emissions is through the production and application of nitrogen fertilisers, and the second most significant is from livestock production through enteric fermentation and manure.

These highly aggregated figures contain much variation among food types and across regions. For example, within livestock, ruminants produce significant amounts of methane when compared with monogastrics, while crop production and distribution systems that involve growing under heated glass, air-freighting or refrigerated distribution are particularly energy-intensive. N_2O from soils is the main source of greenhouse gas emissions from industrialised nations as well as in Africa and most of Asia, while CH_4 emissions from livestock dominate from Central and South America, Eastern Europe, central Asia

11 These are reported in a Project paper – see chart of Project outputs in Annex E.

and the Pacific. Wetland rice production and biomass burning are important sources of GHG emissions in south and east Asia and in Africa and South America respectively.

Looking to the future, the EU has enacted legislation to reduce emissions by 20% by 2020 (taking 1990 as the base), while the UK has set the legally binding target of reducing emissions by 34% by 2020 and at least 80% by 2050 (Scotland's targets are 42% and 80% respectively, with the same baseline). These ambitious goals cannot be achieved without the food system playing an important part. At the global level, substantial increases in GHG emissions from agriculture are highly likely in the decades ahead.

Global increases will be especially associated with increased production of artificial fertiliser to serve both an expanded food-production system, and to redress the currently low levels of use in certain parts of the world, notably sub-Saharan Africa. Because agriculture is currently not included in many national greenhouse gas reduction initiatives, the proportional contribution of emissions from this sector is likely to rise.

6.2 The food system in a low-carbon world – policy implications –

There is a clear case for substantially integrating and improving considerations of agriculture and food production in negotiations on global emissions reductions, although the special features of this sector must be taken into account. These include the possible effects on efforts to reduce hunger, and ethical issues concerning which geographical and economic groups should bear the costs of mitigation. Consideration also needs to be given to whether other sectors should set more ambitious emissions reduction targets – so that food production is not constrained, and economic development in low-income countries is not impeded.

Changes in agricultural practices that affect the net flux of greenhouse gases between the land, aquatic margins and the atmosphere could, depending on their direction, have significant positive or negative effects on global warming. There is nearly as much carbon in the organic compounds contained in the top 30 cm of soil as there is in the entire atmosphere and a vast amount of carbon is tied up in land used for food production.

It is desirable to develop smart policies to achieve multiple goals in the food system: There are four main ways in which impetus can be given to emissions reduction in the food system:

- Creation of market incentives to encourage emissions reductions. These might include grants, subsidies, levies, carbon taxes or carbon cap and trade schemes.
- Introduction of mandatory emissions standards or limits by direct regulation.
- Adoption of low-emission strategies through market pressures driven by consumer choice. This requires active and informed consumers, and sources of accurate and trusted information such as labelling for emissions or product certification.
- Voluntary (non-profit driven) measures taken by industry as part of corporate social responsibility.

In designing, encouraging and facilitating such initiatives, it is essential to consider not only their effects on greenhouse gas emissions but how they affect the amount of food produced, the quantity of inputs required, and all the other externalities of the food system from ecosystem services to animal welfare.

The following points should be noted:

- *Reducing emissions can occur without loss of production or productivity.* In some cases, emissions reduction can occur without loss of production or productivity or even with a gain in efficiency. For example, incentives that encourage the more efficient use of water and fertilisers (including recycling) may both reduce emissions and increase value per resource unit, and also have other benefits such as reducing nitrogen leaching and run-off, and pressure on increasingly scarce resources such as energy and water, to the benefit of sectors beyond the food system.
- *Developments in science or technology can influence and increase the efficiency of interventions to reduce greenhouse gas emissions.* For example, precision agriculture with reduced volume of fertiliser

application, breeding for improved nitrogen use by plants, and breeding for reduced greenhouse gas emissions in beef and dairy cattle and via genetic improvements in their fodder.

- *Where emissions reduction affects yield, interventions should be chosen to achieve the greatest greenhouse gas reductions at the least cost.* However, it will be critical to understand how an intervention affects yields and productivity, and whether it will have an impact on the poorest people least able to bear the cost of mitigation. In particular, it will be important to give careful consideration to the consequence of interventions for smallholders and for women, as well as for societies such as many pastoral communities whose culture is intimately connected with agriculture and food production.
- *The need to recognise the importance of land conversion in policies to reduce greenhouse gas emissions.* The single largest way the global food system contributes to greenhouse gas emissions is through land conversion, particularly from forest into farmland. One of the strongest arguments for the Project's conclusion that the global food supply must be increased through sustainable intensification without significant new land being brought into cultivation is the emissions of greenhouse gases that would otherwise result. Emissions policy for agriculture must be developed within the broader context of emissions from all land use types.
- *The importance of the link between mitigation policies, biofuels and the food system.* Though some biofuel systems have net positive effects for greenhouse gas emissions, many first-generation biofuels do not contribute to greenhouse gas reduction but reduce the area available to grow food. The history of the introduction of biofuels illustrates the dangers of not considering all the consequences of a climate change policy, and the way they can be exploited by those with vested interests.
- *Policies to mitigate climate change can incentivise the delivery of multiple public goods associated with the food system.* A theme running through this Report is the importance of internalising within the global food system the negative consequences for the environment of different forms of production. This approach incentivises best practice but also provides the means by which food producers can be rewarded for supplying multiple goods without direct public funding.

Many examples of the application of existing knowledge and technology to increase sustainable food production will also have positive effects on reducing greenhouse gas emissions. The creation of new knowledge to increase current yield ceilings in the most sustainable way will also have the potential to make a contribution. However, measures that are greenhouse gas emission-neutral, but which increase productivity, reduce demand or increase the efficiency of the food system are also beneficial for climate change mitigation because they reduce the pressure on the food system to expand, and therefore help to limit greenhouse gas increases that might otherwise occur.

For measures to reduce emissions, an audit of their consequences for greenhouse gas emissions should be carried out. The results should become part of decision-making processes in allocating funds for interventions and for research.

Particularly promising options for reducing emissions include reducing waste; more efficient use of nitrogen in crop and livestock production; implementing management changes to the cultivation of wetland rice to reduce the amount of anaerobic decomposition (a major source of methane); encouraging agroforestry; reducing CH_4 and N_2O emissions from livestock production; and increasing the efficiency of land use to harvest solar radiation for food and energy through second-generation biofuels and the integration of biomass production. In the future, energy crops based on algae or macroalgae (seaweed) may be cultivated in integrated systems linked to terrestrial or aquatic food production. Increased carbon sequestration through integrated soil and vegetation management is also promising: were the organic carbon pools in the world's soils to be increased by 10% in the 21st century, it would be the equivalent of reducing atmospheric CO_2 by 100 parts per million.

6.3 Enabling greenhouse gas reduction in the food system

Developing better and more comprehensive metrics of greenhouse gas emissions in the global food system should be a priority. Government-backed schemes setting sector-wide sustainability standards would obtain strong support from industry and be a very positive contribution to increasing sustainability.

In measuring how greenhouse gas emissions are affected by different strategies, it is critical to include not only the direct but also the indirect consequences, such as effects on land use conversion and those mediated by global trade. There is also a balance to be struck between comprehensiveness and simplicity that will vary across applications.

Senior representatives of the UK food retail sector gave the clear message that they would welcome government-accredited national schemes that set standards for sustainability. They argued that the key to its success would be in setting a level playing field in this intensively competitive sector, and that it would be important for the definitions of standards to be in place for a sufficient time to encourage investment in sustainability.

7 Challenge E: Maintaining biodiversity and ecosystem services while feeding the world

Until recently, policies in conservation and in food security were largely developed in isolation. However, increasingly and rightly, they are being pursued together, driven by a growing realisation of their interdependence.

There are both economic and non-economic arguments for why ecosystem services and biodiversity should be integral parts of decision-making in the global food system. It is only in the last few decades that the importance of the services provided by different managed and unmanaged ecosystems to food production has been realised, and efforts started to quantify their economic significance. Different national and international 'ecosystem assessments' seek to understand how various drivers of change will affect the provision of ecosystem services in the future.

A key argument of this Report is that the global food supply will need to increase without the use of substantially more land and with diminishing impact on the environment: sustainable intensification is a necessity. Pursuit of this agenda requires a much better understanding of how different policy options, both within and outside the food system, affect biodiversity and ecosystem services.

Box 7.1 What the Project means by sustainability

The principle of sustainability implies the use of resources at rates that do not exceed the capacity of the earth to replace them. Thus water is consumed in water basins at rates that can be replenished by inflows and rainfall, greenhouse gas emissions are balanced by carbon fixation and storage, soil degradation and biodiversity loss are halted, and pollutants do not accumulate in the environment. Capture fisheries and other renewable resources are not depleted beyond their capacity to recover. Sustainability also extends to financial and human capital; food production and economic growth must create sufficient wealth to maintain a viable and healthy workforce, and skills must be transmitted to future generations of producers. Sustainability also entails resilience, such that the food system, including its human and organisational components, is robust to transitory shocks and stresses. In the short to medium term non-renewable inputs will continue to be used, but to achieve sustainability the profits from their use should be invested in the development of renewable resources.

The political reality is that sustainability[12] cannot be pursued in the absence of food security. Nevertheless, it is important for policy-makers to appreciate a range of trade-offs affecting decisions involving the food supply and ecosystem services. Important trade-offs include yield versus ecosystem services; trade-offs between different ecosystem services; land sparing versus wildlife-friendly agriculture; and the relationship between biodiversity and the needs of the poor.

Some of the most threatened and diverse habitats on earth exist in very low-income countries, and interventions to make farming more wildlife friendly, fishing less damaging, or to set land aside as reserves may affect the livelihoods of the very poorest people. Whatever strategies are adopted, the human impacts need to be understood and quantified as there are strong ethical arguments against imposing the costs of protecting biodiversity on those least able to pay them.

12 See Box 7.1 for a discussion of what the Project means by sustainability.

The fact that food production requires ecosystem services provided by both farmed and non-farmed land means that policy in these two areas needs to be developed and properly connected at global, national and landscape scales. Therefore:

- **At global and international levels:** recognise that food security and environmental protection are interdependent; develop mechanisms to reward countries that produce supranational environmental goods – international policy needs to ensure that countries obtain benefits from providing global goods, especially when costs are borne by low-income countries; avoid policies that have negative environmental impacts in other countries; coordinate the protection of biodiversity across administrative or national borders – much significant biodiversity can only be protected with coordinated regional or international action.
- **At national and landscape levels:** make land sparing work; develop new infrastructure sensitively; consider biodiversity in planning at the landscape scale; implement realistic minimum environmental flows; consider setting aside marine and freshwater protected areas; and recognise the importance of 'wild foods' in low-income countries. (See Box 7.2 for a discussion of the particular need to preserve tropical rain forests.)

Box 7.2 The imperative to preserve tropical rain forests

Much of the land that could be brought into agriculture is currently covered by tropical rainforest. Pressure from expanding agriculture has been a major factor leading to recent tropical deforestation, especially in South America (where conversion to soybean and cattle ranching is the greatest pressure) and south-east Asia (owing to oil palm conversion). Such deforestation has a number of very adverse effects:

- The conversion of tropical forests to agriculture releases large one-off amounts of greenhouse gases. It also reduces the land's subsequent ability to take up greenhouse gases.
- Tropical deforestation may have direct and damaging effects on local climate.
- Much of the associated biodiversity can only exist in rainforest, and is lost immediately once the land is converted to other uses.
- Tropical rainforests are home to many indigenous groups.

The Report concludes that there will hardly ever be a case to convert forests, especially tropical rainforests, to food production.

The importance of tropical forests to climate change is the focus of the UN Collaborative initiative on Reducing Emissions from Deforestation and Forest Degradation (REDD) and REDD+, which also includes the role of conservation, sustainable management of forests and enhancement of forest carbon stocks. An increased focus on aligning REDD+ with agriculture and food security in low-income countries will be essential for its success.

Terrestrial and aquatic ecosystems used in food production need to be managed to achieve multiple goals. Where high levels of productivity are important then sustainable intensification is the key concept. But as explored in a recent Foresight report, land will also need to be managed for multiple functions, for example food production, supporting rural economies, flood management and protection of biodiversity. Aquatic zones, particularly in inland and coastal areas, require similar approaches. The challenges and opportunities of multifunctional uses, integrating land and water systems are critical for policy formulation.

Some ecosystems used primarily for food production have particularly high biodiversity value. Examples include many agro-ecosystems in the Mediterranean basin that have high levels of biodiversity adapted to agricultural practices which have persisted for several thousand years; grassland ecosystems such as the steppes where cattle, sheep and other livestock have replaced natural grazers, some of which are now extinct; wetlands used for rice growing, and coral reef marine ecosystems subject to capture fisheries. For these special agro-ecosystems there will be a strong policy imperative to protect biodiversity even at the cost of reduced yields. But even when such considerations do not apply, it may be possible to improve the provision of ecosystem services or protect biodiversity with relatively modest costs to yields.

- **Evidence-based, wildlife-friendly farming.** Such schemes can potentially be of great benefit to wildlife, but there needs to be a more analytical and evidence-based approach to what works best. For example, in investing to support biodiversity a full range of management options (including setting land aside in reserves) should be considered, and in comparing alternatives, the appropriate spatial and temporal scales should be employed.
- **Biodiversity-sensitive fisheries.** The development of ecosystem approaches for fisheries (EAF) management has potential benefits for both biodiversity and production, and although comprehensive approaches require considerable resources, elements of EAF can be adopted in many fisheries. In the absence of fully developed EAFs, the immediate prospects for protecting or building biodiversity are based on strategic measures such as controlling illegal fishing, reducing by-catch by improving fishing gear, as well as more specific actions such as creating protected zones, defining and protecting endangered species, controlling stock movements, banning destructive fishing methods and restricting predator culls. For aquaculture, measures to avoid the use or release of non-native species, contamination of wild-species gene pools, and the culling of endangered bird, reptile or mammal predator species are important to protect biodiversity.

But it must also be recognised that much biodiversity can only be protected in relatively natural habitats. It is therefore critical to produce enough food from cultivated land to allow land to be spared for wildlife, and for the ecosystem services these habitats provide.

7.1 Strategic policy implications

The arguments presented here and in the Project's Final Report illustrate the benefits of making environmental issues integral to policy making in the food system. Some strategic implications for policy makers concern:

Major knowledge gaps that urgently require further research. They include the ecological basis of many ecosystem services and their resilience to perturbation; the economic assessment and valuation of ecosystem services and biodiversity; the development of a more analytical evidence base to judge amongst different management alternatives.

National and supranational governance. Many of the most critical decisions in this area require decisions at the national level (for example land use policy) or the international level (governance of factors affecting global goods). Environmental issues are being given much higher priority than in the past at all levels, but this must be continued and strengthened.

Negative environmental externalities. There needs to be much greater realisation that market failures exist in the food system that, if not corrected, will lead to irreversible environmental damage and long-term threats to the viability of the food system. Moves to internalise the costs of these negative environmental externalities are critical to provide incentives for their reduction.

Aligning environmental and market incentives. Progress on achieving desirable environmental goals will be most easily achieved when they are congruent with market incentives.

Environmental protection and stewardship. Payments for environmental stewardship are a means of both supporting rural incomes and protecting the environment without distorting agricultural markets. Such schemes should be designed so that they support the long-term maintenance of on-farm biodiversity and are robust to changes in economic and food system conditions. Stewardship schemes are less frequent in low-income countries including those with centres of biodiversity, and should be encouraged.

8 Priorities for action

A key conclusion of this Foresight Project is that no single approach can meet all of the complex challenges that have been outlined above – decisive action is needed across a wide front. This is perhaps unsurprising, given the diversity and scale of the challenges, and the need for the global food system to deliver much more than just food, and food security in the future. The attention of policy makers will therefore shift to the question of prioritisation – where to focus efforts, and how best to deploy scarce resources.

The following 12 cross-cutting actions (Box 8.1 – these are not in any order of importance) are priorities for policy-makers suggested by the wider analysis of the Project.

Box 8.1 Key priorities for action for policy makers

1. Spread best practice.
2. Invest in new knowledge.
3. Make sustainable food production central in development.
4. Work on the assumption that there is little new land for agriculture.
5. Ensure long-term sustainability of fish stocks.
6. Promote sustainable intensification.
7. Include the environment in food system economics.
8. Reduce waste – both in high- and low-income countries.
9. Improve the evidence base upon which decisions are made and develop metrics to assess progress.
10. Anticipate major issues with water availability for food production.
11. Work to change consumption patterns.
12. Empower citizens.

1. Spread best practice

There are major advances to be made using existing knowledge and technologies to raise yields, increase input efficiency and improve sustainability. But this will require significant investment of both financial and political capital to ensure that food producers have the right incentives and are equipped with the necessary skills to meet current and future challenges. This Report has highlighted the following priorities to achieve these ends: improvements in extension and advisory services in high-, middle- and low-income countries; and the strengthening of rights to land and natural resources in low-income countries. Adopting proven models of extension and knowledge exchange to build human and social capital is critical to addressing all aspects of food production from sustainable agronomy to business skills.

2. Invest in new knowledge

There is a consensus among the results of food system models that one of the most critical drivers of future food supply is the rate of growth of yields due to new science and technology. New knowledge is also required for the food system to become more sustainable, to mitigate and adapt to climate change, and to address the needs of the world's poorest. These challenges will require solutions at the limits of human ingenuity and at the forefront of scientific understanding. No one technology or intervention is a panacea, but there are real sustainable gains to be made by combining biotechnological, agronomic and agro-ecological approaches. Because of the significant time lags in reaping the benefits of research, investment in new knowledge needs to be made now to solve problems in the coming decades. Investment needs to occur not only in the important field of biotechnological research but across all the areas of the natural and social sciences involved in the food system.

3. Make sustainable food production central in development

The 'Cinderella status' of primary food production in international development financing has for too long ignored the crucial role that it plays in rural and urban livelihoods. There is evidence from a series of recent initiatives that this neglect is now changing. Such investment is not only about food production but also the web of people, communities and physical infrastructure that surrounds it. Investment in the sector offers a pro-poor model of economic growth with much wider positive impacts on low- and middle-income economies and a means of producing a broader range of public goods. Development trajectories should be chosen to help food producers in low-income countries adapt to the effects of climate change to which they are likely to be disproportionately exposed. Development of sustainable production systems that avoid the mistakes made by countries which moved out of the low-income class in earlier times is required. Investment in infrastructure and capacity is needed at a scale which will be realised only by innovative new partnerships between governments, multilateral bodies and the private sector.

4. Work on the assumption that there is little new land for agriculture

Relatively little new land on a global scale has been brought into food production in the last 40 years. Although modest amounts may in future be converted to agriculture, the Report concludes that major expansion is unwise. In particular, it is now understood that one of the major ways that food production contributes to greenhouse gas emissions is through land conversion, particularly of forests. Only in exceptional circumstances can conversion of forests (especially tropical rainforests), natural grasslands and wetlands to agricultural land be justified. This Report also recognises that while some biodiversity can be maintained on land used for food production, a very significant fraction, especially in the tropics, requires relatively undisturbed non-agricultural habitats. In contrast to land conversion, the restoration of degraded agricultural land can be an important means of increasing the food supply and a good use of international development monies.

5. Ensure long-term sustainability of fish stocks

Very few of the world's wild fish stocks are not currently exploited, with many over-exploited and subject to poor fisheries management. This is exacerbated by illegal fishing which thrives where controls are weak, and by the continued provision of capacity-enhancing subsidies. There is an urgent need to reform fisheries governance at national and international levels to ensure the long-term sustainability of this natural resource and enable it to meet the challenges identified in this Report. The status quo is not an option, as many fish stocks will be more open to overexploitation to meet increasing demand, be less resilient to climate change and at greater risk of collapse. More effective management needs to be put in place, building on examples of best practice around the world and based on long-term allocation of clearer entitlements to fish to incentivise more sustainable use of the resource. At the same time, aquaculture, which will have a major role to play in meeting the supply and resource challenges ahead, will need to produce more with increased sustainability.

6. Promote sustainable intensification

It follows that if (i) there is relatively little new land for agriculture, (ii) more food needs to be produced and (iii) achieving sustainability is critical, then sustainable intensification is a priority. Sustainable intensification means simultaneously raising yields, increasing the efficiency with which inputs are used and reducing the negative environmental effects of food production. It requires economic and social changes to recognise the multiple outputs required of land managers, farmers and other food producers, and a redirection of research to address a more complex set of goals than just increasing yield.

7. Include the environment in food system economics

The food system relies on a variety of services that are provided without cost by the environment – what are now called ecosystem services. The food system may negatively affect the environment and hence harm the same ecosystem services it relies upon, or affect those that benefit other sectors. Understanding the economics of ecosystem services is a very active area of current research and incorporating the true costs (or benefits) of different productions systems on ecosystem services is a powerful way to incentivise sustainability. It also helps identify situations where moves to increased sustainability impact upon the poorest people who will require help and support.

8. Reduce waste – particularly in high- and low-income countries

Food is wasted at all stages of the food chain: in high-income countries waste tends to be concentrated at the consumer end and in low-income countries more towards the producer's. Reducing food waste is an obvious priority and this Report supports earlier analyses in according it very high priority. It is also an area where individual citizens and businesses, particularly in high-income countries, can make a clear contribution.

9. Improve the evidence base upon which decisions are made and develop metrics to assess progress

This Report makes specific recommendations for the creation of a global, spatially explicit, open-source data base for the analysis of agriculture, the food system, and the environment, and the setting up of an International Food System Modelling Forum to enable a more systematic comparison of different models, to share results and to integrate their work better to meet the needs of policy-makers.

10. Anticipate major issues with water availability for food production

While this Report has highlighted a series of issues concerning competition for the inputs for food production, it is growing pressure on water supplies that is likely to be experienced first. The dangers come from higher demand for water from other sectors, the exhaustion of aquifers, and changes in precipitation patterns, higher sea levels and altered river flows caused by climate change. Incentives to encourage greater efficiency of water use and the development of integrated water management plans need to be given high priority.

11. Work to change consumption patterns

The informed consumer can effect change in the food system by choosing to purchase items that promote sustainability, equitability or other desirable goals. Clear labelling and information is essential for this to happen. Governments are likely to need to consider the full range of options to change consumptions patterns including raising citizen awareness, approaches based on behavioural psychology, voluntary agreements with the private sector, and regulatory and fiscal measures. Building a societal consensus for action will be key to modifying demand.

12. Empower citizens

Investment is needed in the tools to help citizens hold all other actors (and themselves) to account for their efforts to improve the global food system. Examples include the better provision and publication of information on the commitments of different groups, the extent to which they have acted on their commitments, and through information on a food system 'dashboard' a measure of their effectiveness. Modern ITC needs to be mobilised to provide, for example, real-time hunger surveillance and to allow farmers and consumers to give feedback on what is working and not working in hunger reduction efforts.

These priorities, together with the many other more detailed actions that are set out in this Executive Summary, will need to be pursued by a wide range of actors in the global food system, often acting in concert. These include UN and other international organisations, governments, the private sector, non-governmental organisations and the research community. Indeed, individual consumers could also play an important role, as outlined above. A broad range of actions that these various actors should consider are described in more detail in the concluding chapter of the Final Project Report.

9 Why action is needed now

There is urgency in taking what may be very difficult policy decisions today relating to the diverse challenges facing the global food system, and also to address the present levels of hunger – 925 million people suffer from hunger and perhaps a further billion lack sufficient micronutrients. It is imperative that the need for rapid action is realised by all concerned. This task is difficult because, not withstanding recent volatility in food prices, the food system is working for the majority of people. Also, those suffering or at risk from hunger generally have the least influence on decision-making in the food system.

Besides the unacceptability of the present levels of hunger, some of the main arguments for immediate action are:

- The lack of sustainability in the global food system is already causing significant environmental harm, for example through nitrogen pollution, food production's contribution to greenhouse gas emissions, and the drying up of rivers and lakes. Many marine ecosystems are damaged by unsustainable fishing.
- There is increased competition for, and scarcity of, inputs into food production. Of these, as discussed above, water is the most pressing with significant effects on regional productivity likely to occur by 2030. Competition for land has also emerged as a significant factor in many countries.
- Some effects of climate change are now inevitable and the food system must prepare for them and adapt.
- The food system is a significant producer of greenhouse gases and must contribute to global mitigation efforts; immediate action on climate avoids the necessity of more radical measures in the future.
- There is the risk of negative irreversible events if action is not taken; this includes the loss of biodiversity, the collapse of fisheries and the loss of some ecosystem services (for example the destruction of soils).
- There is substantial evidence for increasing global demand for food (which probably contributed to the recent food price spike).
- Food security in 2030 and out to 2050 will require new knowledge and technology, and the basic and applied research underlying this needs to be funded now; there is evidence of a slowdown in productivity gains today correlated with a reduction in research and development (R&D) investment in many countries over the last two decades.
- The absence of food security will also make it much harder or impossible to pursue a broad range of other policy goals. It may also contribute to civil unrest or to failed states; it may stimulate economic migration or fuel international tensions.
- Actions taken in the near future can address problems that, if allowed to develop, will require much more difficult and expensive measures later on.

10 Conclusion

Despite inevitable uncertainties, the analysis of the food system presented in this Report makes clear that the global food system between now and 2050 will face enormous challenges, as great as any that it has confronted in the past. The Report carries a stark warning for both current and future decision-makers on the consequences of inaction – food production and the food system must assume a much higher priority in political agendas across the world. To address the unprecedented challenges that lie ahead the food system needs to change more radically in the coming decades than ever before, including during the Industrial and Green Revolutions.

Although the challenges are enormous there are real grounds for optimism. It is now possible to anticipate a time when global population numbers cease to rise; the natural and social sciences continue to provide new knowledge and understanding; and there is growing consensus that global poverty is unacceptable and has to be ended. However, very difficult decisions lie ahead and bold actions by politicians, business leaders, researchers and other key decision makers will be required, as well as engagement and support by individual citizens everywhere, to achieve the sustainable and equitable food system that the world so desperately needs.

1 Introduction

Chapter 1 introduces the Project and presents its aims and objectives.

The critical importance of the global food system and the need to take a broad perspective is discussed. The technical approach to the work and the structure of the Report is set out.

1 Introduction

Project aim: to explore the pressures on the global food system between now and 2050 and identify the decisions policy makers need to take, today and in the years ahead, to ensure that a global population rising to nine billion or more can be fed sustainably[13] and equitably.

The global food system over the next 40 years will experience an unprecedented confluence of pressures. On the demand side, global population size will increase from nearly seven billion today to eight billion by 2030, and to probably over nine billion by 2050. Many people are likely to be wealthier, creating demand for a more varied, high-quality diet requiring additional resources to produce. On the production side, competition for land, water and energy will intensify, while the effects of climate change will become increasingly apparent. The need to reduce greenhouse gas emissions and adapt to a changing climate will become imperative. Over this period globalisation will continue, exposing the food system to novel economic and political pressures. Any one of these factors would present substantial challenges to food security, but together they constitute a major threat that requires a strategic reappraisal of how the world is fed. Addressing the implications in a pragmatic way that promotes resilience to shocks and future uncertainties is vital if major stresses to the food system are to be anticipated and managed.

Although there has been marked volatility in food prices in the last two years, the food system continues to provide plentiful and affordable food for the majority of the world's population. Yet it is failing in two major ways:

- 925 million people experience hunger[14]: they lack access to sufficient of the major macronutrients (carbohydrates, fats and protein). Perhaps another billion suffer from 'hidden hunger': where important micronutrients (such as vitamins and minerals[15]) are missing from their diet, with consequent risks of physical and mental impairment. In contrast, a billion people are substantially over-consuming, spawning a new public health epidemic involving chronic conditions such as type-2 diabetes and cardiovascular disease[16]. Much of the responsibility for three billion people having suboptimal diets lies within the global food system.
- Many systems of food production are unsustainable, putting at great risk future food production. There are widespread problems with soil loss due to erosion, loss of soil fertility, salination and other forms of degradation; rates of water extraction for irrigation are exceeding rates of replenishment in many places; over-fishing is a widespread concern; and there is heavy reliance on fossil fuel-derived energy for synthesis of nitrogen fertilisers and pesticides. In addition, emissions to air and water from food production systems are frequently in excess of the levels considered environmentally benign. Livestock and nitrogenous fertiliser are major sources of emissions of the greenhouse gases methane and nitrous oxide, while losses of nitrates and phosphates from soil cause loss of water quality.

Despite these long-standing failings, and likely confluence of future pressures, the food system has until recently received relatively little attention from policy-makers. The spikes in food prices in 2008 were a stark warning of the vulnerability of the global food supply, and a jolt to the complacency that had set in after the gains in production in many parts of the world over the previous four decades. Governments around the world responded by taking a closer look at the causation of the food prices spikes and the UN has responded by establishing a High-Level Task Force on the Global Food Security Crisis, whilst the international community, led by the G8, committed an additional $22 billion over three years from July 2009 towards sustainable agricultural development[17]. While these developments are welcome, it is clear that much more needs to be done. Short-term measures to address these issues will not achieve the pace and scale of the reforms that are likely to be required.

A crucial issue is the growing linkage of the food system to a broad range of global policy issues. Climate change mitigation and adaptation, energy security and supply, water scarcity, land use change and the

13 Sustainability implies the use of resources at rates that do not exceed the capacity of the Earth to replace them. A more detailed description of the use of the term in the Report is given in Box 3.5

14 FAO (2010a)

15 UN Standing Committee on Nutrition (2004); World Bank (2006a)

16 Foresight (2007); WHO/FAO (2003); Haslam and James (2005)

17 'Joint Statement on Global Food Security ('L'Aquila Food Security Initiative')' July 2009 endorsed by G8 and G20.

valuing of ecosystem services[18] are all closely tied to production and the global food supply chain. The food system already uses 70% of the extracted fresh water globally, and 34.3%[19] of the land area[20], and is a major producer of greenhouse gas emissions. Consequently, it has a very dominant influence on terrestrial and aquatic ecosystems and major effects on biodiversity. The future expansion of the food system will steadily increase its impact on these areas and *vice versa*. Without much closer linkages and integration, there is a risk that policies in all such areas will become increasingly inefficient or ineffective, and frustrated by competing aims.

The food system is thus moving into a new era of uncertainty and pressure. To prepare policy-makers accordingly, comprehensive and strategic analysis is required which looks both across adjacent policy areas and ahead to the future challenges and possible solutions. This Report aims to make a contribution to that goal. It builds on the *Food Matters* Report published by the UK Cabinet Office in the wake of the food price spikes of 2008, which called for a major new Foresight Project to examine future global food systems. This Report marshals the complex and vast evidence base across the food system to examine the challenges ahead and identify possible options for policy.

1.1 The need for a broad perspective

The Project takes a broad perspective of the global *food system* from production to the plate. The system is not a single designed entity, but rather a partially self-organised collection of interacting parts. Much food is produced on the farm, but capture fisheries and aquaculture are also important, both in terms of nutrition (about a billion people rely on fish as their main source of animal proteins[21]) and in providing livelihoods, especially for the poor. Many vulnerable communities obtain a significant amount of food from the wild ('wild foods'[22]), which increases resilience to food shocks. Most of the economic value of food, particularly in high-income countries, is added beyond the farm gate in food processing and in retail, which together constitute a significant fraction of world economic activity.

The consumer is not a passive recipient of food but exerts choices and preferences that influence the food system, while companies in the food supply chain have great political and societal influence and can shape consumer preferences. And while in the past the food systems of different countries were only weakly connected, today they are linked at all levels, from trade in raw materials through to processed products. Therefore, the ramifications of possible future developments in the global food system need to be carefully considered.

The Project also takes a broad view of *food* that goes far beyond issues of nutrition, economics and food security. Food is essential for survival and for mental and physical development – nutritional deficiencies during pregnancy and in early growth (especially the first two years) can have lifelong effects[23]. For the very poor, obtaining a minimum amount of calories becomes a dominant survival activity. Issues of culture, status, and religion also strongly affect both food production and demand and hence shape the basic economics of the food system[24]. Also, food production, cooking and sharing are major social and recreational activities for many in middle- and high-income countries.

There is a strong emphasis in this Report on the need for action as the consequences of inaction or deferring some decisions will be severe. In addition to the risk of higher prices, volatility in the food system could increase, for example, if the threat of extreme climatic events is not addressed. Potential negative feedbacks such as the effect of environmental degradation on food production could also develop further. Inaction also increases the risks of major events occurring – for example, the collapse of the food system in a country or region – with global economic and political implications. Finally, if actions

18 For a definition of ecosystem services see Chapter 8.

19 This figure is drawn from FAOSTAT (2008); Evans (1998); and DR7B (Annex E refers).

20 There is continuing controversy over how much land is currently used for food production and what potential cultivable land is available for exploitation. This figure includes crop and pasture land currently used for food production. See Project Report C2 (Annex E refers).

21 WHO/FAO (2003)

22 Wild foods are defined here as non-domesticated crops and species; see Project Report DR21 (Annex E refers) which provides a list of all the commissioned reviews and papers.

23 Foresight (2008)

24 For example, food production and consumption can define an individual's primary identity (a 'farmer'; a 'vegetarian') and can be encoded in religious norms. Consumption of certain foods, or of large quantities of food, is a signal of status in some cultures.

are deferred they may be more difficult to implement at a later date and be more disruptive. There is a risk of irreversibilities, such as tipping points in the climate system or high extinction rates for key components of the terrestrial and aquatic biodiversity on which food production systems depend.

1.2 Five key challenges

The Project has explored the challenges facing the food system in the five broad categories shown below. In each case, the size and nature of the challenge is assessed alongside the options for addressing the multiple issues raised by each. Where possible, advice on priorities or particularly promising approaches is provided, while recognising that choices may need to be made on the basis of an evidence base that is inevitably incomplete.

A: Balancing future demand and supply sustainably (Chapter 4)

B: Addressing the threat of future volatility in the food system (Chapter 5)

C: Ending hunger (Chapter 6)

D: Meeting the challenges of a low emissions world (Chapter 7)

E: Maintaining biodiversity and ecosystem services while feeding the world (Chapter 8)

The analysis of health impacts associated with food in this Project has focused on over- and undernutrition, and the associated drivers, impacts and policy issues. There are also significant health effects associated with foodborne disease, which affects millions of people worldwide. While these issues are not discussed in detail in this Report, a healthy diet[25] and good standards of animal health and food safety are essential components of a sustainable and secure food system (see Box 1.1).

For all five challenges the Project has:

- **Adopted an international perspective**. While led by the UK's Government Office for Science, the Project has drawn upon the advice and assistance of experts and stakeholders from across the world. Multidisciplinary expertise and diverse organisational experience were required because of the unique role food plays in human wellbeing and culture, the size and complexity of the food system, its impact on the environment, and the many linkages between the food system and other policy areas.
- **Based its analysis on the best available scientific and other evidence.** Besides drawing upon the existing international literature, a broad range of studies was commissioned from leading experts. These included more than 20 reviews of key drivers of change; 40 reviews of the state of the art in different areas of the natural and social sciences; seven reviews of specific issues with an explicitly regional focus; and other commissioned work, for example, on modelling[26].
- **Adopted no *a priori* position on the utility or acceptability of any possible approaches for addressing future challenges.** The approach taken here has been to consider a broad range of options and not to exclude *a priori* particular technologies or approaches. The evidence base is considered critical in judging the safety and efficacy of different approaches, and also in estimating the opportunity costs of excluding certain options. Different groups with particular special interests hold firm value-based views on certain options that have a rightful place in the political arena, but not in the collection and analysis of evidence.
- **Regarded some factors that influence the food system as exogenous to the issues considered by the Project.** In particular, the Project does not explore possible policy options for influencing population growth rates. Similarly, although the role of the food system in contributing to the mitigation of climate change is analysed, general climate change policy is not discussed, although this will clearly have an impact on food production.

25 For discussion of the requirements of a healthy diet, see Project Report WP1 (Annex E refers).

26 See Annex E for a full list. All are available through *www.bis.gov.uk/foresight*

The analysis was also based on a number of assumptions. Chief among these was that there would not be radical changes in the structure of the global economy over the next four decades.

Box 1.1 Important facets of the food system: food safety; foodborne disease and zoonoses

The analysis of health impacts associated with food in this Project has focused on over- and undernutrition, and the associated drivers, impacts and policy issues. There are also significant health effects associated with foodborne disease. According to the World Health Organization (WHO), up to 30% of the population in high-income countries may suffer from foodborne diseases each year, while the picture in low-income countries is less clear but likely to be worse[27].

Food safety is a key facet of the global food system, with impacts on health and the economy; it is the focus of consumer and industry concerns, and food policy, regulation and governance. Food safety is an essential component of a sustainable and secure food system, and responses to the challenges identified in this Report must take account of the need for effective management of food safety and the reduction of the burdens of foodborne disease.

About 75% of all diseases emerging during the last two decades have been zoonoses (diseases that can be transmitted from animals to humans)[28]. A Foresight study on infectious diseases identified zoonoses as one of eight important future disease risks[29] and concluded that the risk of zoonotic infection could increase in the future. Wild animals and plants are crucial to many agricultural communities[30] and the Food and Agriculture Organization (FAO) estimates that about one billion people use wild foods in their diet[31]. Bushmeat and fish provide 20% of protein in at least 60 low-income countries[32]. Trade in bushmeat is driven mostly by population growth, globalisation, the development of infrastructure, and rural poverty[33]. The wildlife trade may provide a source of zoonoses, while trade and markets can create the pathway for disease transfer and evolution[34]. Although it is difficult to quantify, the illegal trade in wildlife is estimated to be worth more than US$8 billion[35]. Recent research suggests that about 270 tonnes of potentially contaminated illegal bushmeat may be passing unchecked through a single European airport each year[36].

1.3 The structure of this Report

A starting point for the work was the detailed consideration of more than 20 key drivers of change that will affect the food system. Chapter 2 outlines several which are considered to be particularly important. Chapter 3 then considers how these and the other drivers could interact to affect the food system in the future; new and existing modelling work and also future scenarios are used to frame that discussion.

Chapters 4–8 cover each of the five challenges set out above. Priorities for improving the evidence to support the choices that need to be made are presented in Chapter 9. Finally, the conclusions and proposals for action are outlined in Chapter 10. These are provided in more detail at the end of Chapters 4–8 and in the Executive Summary.

The 10 chapters and subsections of this Report are based on 13 more detailed Reports, which have synthesised and interpreted the evidence reviewed by the Project. These 'Synthesis Reports' are published together with this Report to provide a more detailed discussion[37]. In turn, these Synthesis

27 The World Health Organization is coordinating a major initiative to estimate better the global burden of foodborne disease. See http://www.who.int/mediacentre/factsheets/fs237/en
28 Zommers and McDonald (2006)
29 Foresight (2006)
30 DR21 (Annex E refers)
31 Aberoumand (2009)
32 Bennet and Robinson (2000)
33 Zommers and McDonald (2006)
34 Zommers and McDonalrd (2006)
35 Nooren and Claridge (2001)
36 Chaber et al. (2010)
37 These 'Synthesis Reports' are designated C1–C13. A full list can be found in Annex E and all are freely available by download or on CD through www.bis.gov.uk/foresight

Reports draw upon over 100 technical Reports commissioned by the Project on advice from the Lead Expert Group, and which form a major part of the evidence base[38].

Box 1.2 Building on our understanding of the global food system

Over the past five years a number of reports have been published which have focused on the global food system, reflecting its increasing importance to domestic and international policy. This Project has drawn on several of these reports in its analysis and a complete list is provided in Annex C.

These reports have placed different emphasis on a range of options to improve and ensure a sustainable global food system. The IAASTD (2008) report emphasised the gains to be made from better use and dissemination of existing agricultural knowledge, science and technology, and other innovations in practice and knowledge transfer[39], while a major report by the Royal Society (2009)[40] considered pushing the bounds of new technologies and practices. The report from the Royal Society was an important attempt to bridge the divide in much of the literature between applying approaches that stress biotechnological solutions, and further intensification of production; and utilising agro-ecological solutions to achieve *sustainable intensification.* Sustainable intensification is a new concept that has become firmly embedded within this Report (see Box 3.5).

The UK's All Party Parliamentary Group on Agriculture And Food For Development (2010) published a report highlighting the crucial role that food production plays in rural livelihoods in low-income countries; it criticised the lack of attention and underfunding this area has received of late from donors[41]. Another recent report on the same topic has considered the ways in which support should be provided by European donors[42]. To this end, recent reports, including the comprehensive *World Development Report* (2008), have supported the view that agriculture can contribute towards meeting the Millennium Development Goals, and provide a basis for growth in agriculture-based countries[43].

The ways in which agriculture will be affected by future climate change and the role the food system must play in mitigating the impacts of climate change have also been the focus of a number of recent reports, including the recent IFPRI (2010) report *Food security, farming, and climate change to 2050*, which was co-sponsored by this Project. This report assesses the risks of climate change to food security and provides recommendations for their mitigation.

There is a general consensus amongst these reports that 'business as usual' is no longer a viable option. This Project attempts to build on these and other studies by taking a very broad view of the global food system – recognising it as a complex collection of interacting parts. It is impossible for a broadly-scoped Project such as this to consider the range of issues and disciplines in the same detail as the more focused work of individual researchers and organisations. Rather, its insights should be seen as complementary, aiming to provide a fresh look and a challenge to existing thinking, as well as offering signposts to the most critical issues and promising approaches. It aims to present a framework for thinking about the future, and for more detailed analysis and policy development by others. This has been achieved by:

38 See Annex E for a list. The detailed technical reports commissioned by the Project are also freely available by download or on CD through the above website. All project publications listed as 'Driver Reviews'; 'State of Science Reviews' and 'Regional Studies' have been peer-reviewed by the Project's lead expert group. All 'Driver Reviews' and 'State of Science Reviews' have been submitted to at least one external peer reviewer (and in the majority of cases, two or more external peer reviewers). The case studies of Sustainable Intensification in African Agriculture have also been peer-reviewed, unless listed as Working Papers. This Final Report and the Synthesis Reports have also been submitted to peer review during the synthesis process. Particular thanks are due to the external peer reviewers listed in Annex A; and to several other peer reviewers who have also contributed their time on various aspects of the Report.

39 IAASTD (2009)

40 The Royal Society (2009)

41 All Party Parliamentary Group (2010)

42 Global Author Team (2010)

43 World Bank (2008)

- Providing an international outlook: considering the concerns and experiences of many different types of stakeholder, from African smallholder to multinational retailer.
- Involving participants from a very wide range of disciplines: natural and social scientists, experts in risk management, economics and modelling.
- Looking across both aquatic and terrestrial based food production in an attempt to integrate future challenges and approaches.
- Taking a long-term, strategic look forward to the next 20 years to 2030, and the next 40 to 2050. The Project has used futures techniques to consider the many inherent uncertainties that lie ahead, and to identify choices that are resilient to a range of outcomes.

1.4 How the food system must adapt to climate change and future resource pressures

The adaptation and resilience of the global food system to future pressures – particularly from climate change, resource scarcity, and population growth, are key themes throughout this Report. There is no one section on 'adaptation', as the following analysis is intended to give policy makers and others a sense of:

- The way in which agriculture and fisheries will be affected by climate change and related impacts on different ecosystems.
- The ways in which the global food supply chain as a whole – from farmers and fishers to consumers – will need to become more resilient to future shocks caused by climate change, and, importantly, the combination of climate change in other significant developments impacting on the food system over the next 40 years.

Adaptation can be divided into autonomous and planned measures[44], the former describing the way, for example, a farmer might begin to plant earlier or harvest their crops later in response to local changes in circumstances; the latter indicating more formal strategies or policy decisions to improve the capacity of food production systems to adapt. Adaptation over the long term will certainly require planned measures – and article 4.1b of the United Nations Convention on Climate Change mandates all parties to design and implement national or regional measures.

This Report and the wide evidence base commissioned can be seen as a substantive package of analysis of the need for adaptation and of strategic measures to develop the global food system's resilience to future change. These include:

- Chapter 2 and Project Reports C2, DR2 and DR5 deal with the impact of climate change on agriculture, in anticipation of the way that agriculture will have to adapt and become more resilient to a changing climate and significant (and related) resource pressures.
- Chapter 3 and Project Report C4 consider further the likely impacts of climate change, drawing heavily on IFPRI's IMPACT model, which integrates climate, crop, water and economic modelling techniques. Such models will become key policy tools in helping policy-makers to consider the resilience of food production and agricultural markets to future changes in climate.
- Chapter 4, Project Report C6 and a number of the evidence reviews commissioned by the Project consider the new science necessary to adapt food production to a changing climate, alongside new techniques and practices, for example, within fertiliser management or irrigation (e.g. SR7; SR31; SR35[45]).
- Chapters 4 and 5 consider how governance, particularly the governance of global markets, will need to reflect a more volatile world, with markets responsive and functioning effectively in response to climatic and other shocks.
- Project Report C9 and the 38 case studies commissioned on sustainable intensification in African agriculture provide examples of how agriculture and aquaculture may increase yields sustainably, make

44 FAO (2007a) – Adaptation to climate change FAO paper
45 Annex E refers

better use of inputs, and build social capital among producers. These will be key strategies in building resilience and adaptability in African agricultural systems.

- Chapter 7 and Project Report C12 consider how agriculture and food production must change to meet the challenges of a low-emissions world. This recognises the breadth of measures that must be taken to address the need both to adapt to and mitigate climate change and other resource pressures.

Overall, the Project's stress on sustainable intensification and making sustainability operational in food production (see Box 3.5) should be seen as a major strategy for adaptation for the food system in the decades ahead.

2 Key drivers of change affecting the food system

Chapter 2 presents the context for the Project, outlining drivers of change that will affect the global food system in the next 40 years. It explains the need to consider interactions between these drivers and also their inherent future uncertainties.

It argues that this is a unique time in history. Decisions made over the next decade will disproportionately influence the future. Conversely, a failure to act will be an opportunity that is lost irreversibly, leading to social, economic and environmental harm.

2 Key drivers of change affecting the food system

This is a unique time in history – humanity is facing a future that is very different from the past. Decisions made now and over the next few decades will disproportionately influence the future.

- For the first time, there is now a high likelihood that growth in the global population will cease, with the number of people levelling in the range 8–10 billion towards the middle of the century or in the two decades that follow. It may even decline beyond that.
- Human activities have now become a dominant driver of the Earth system; decisions made now to mitigate their detrimental effects will have a very great influence on the environment experienced by future generations, as well as the diversity of plant and animal species with which they will share the planet.
- There is a developing global consensus, embodied in the Millennium Development Goals, that there is a duty on everyone to try to end poverty and hunger, whether in low-income countries or among the poor in more wealthy nations[46].

Threats from interacting drivers of change will converge on the food system over the next 40 years. Together, they will create diverse challenges that require a strategic reappraisal of how the world is fed. Careful assessment of the implications of these drivers is essential if major pressures on the food system are to be anticipated, and future risks managed. The Project commissioned more than 20 reviews of drivers of change, as well as undertaking workshops[47]. The aim was to assess how different drivers might affect the food system, and the uncertainties associated with them[48]. Six were highlighted:

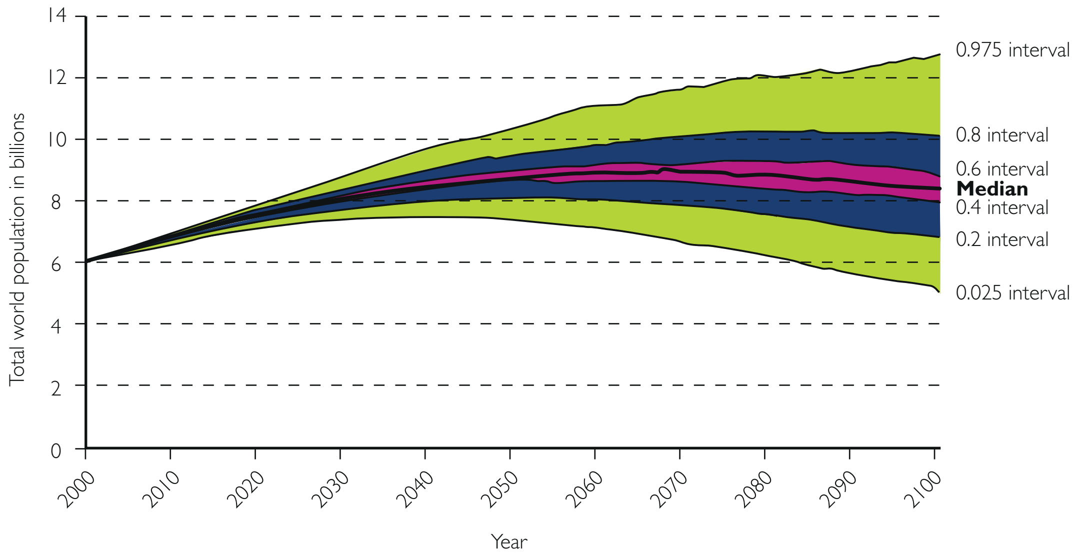
1. Global population increases[49]. Based on United Nations Population Division projections, policy-makers should assume that today's population of about seven billion is most likely to rise to around eight billion by 2030 and to probably over nine billion by 2050[50]. Most of these increases will occur in low-income countries – for example, Africa's population is projected to double from one billion to about two billion by 2050[51]. However, population projections are uncertain and will need to be kept under review. Probabilistic population projections by the International Institute for Applied System's Analysis offers an 80% confidence range for mid-century population numbers of between 7.8–10.0 billion (see Figure 2.1) which spans a very broad range of implications for food system policy.

Population growth rates are determined by a series of correlated drivers including GDP growth, educational attainment, access to contraception and gender equality. More detailed analysis reveals that possibly the single most important factor is the extent of female education. For example, the Demographic and Health Survey for Ethiopia shows that women without any formal education have on average six children, whereas those with secondary education have only two[52]. Future demand for food will thus be influenced by complex economic and social drivers acting through population growth.

Population increase will combine with other transformational changes, particularly in low-income countries as rising numbers of people move from rural areas to cities that will need to be serviced with food, water and energy. Half the world's population now live in urban environments, a figure projected to rise to 60% by 2030[53]. It is estimated that there will be 26 cities with more than 10 million inhabitants in 2025, up from 19 today. Five of these new 'megacities' will be in Asia[54].

46 For a report of the Foresight workshop on Ethics and the food system. See Project Report W6 (Annex E refers).
47 These driver workshops included: Factors affecting aquatic derived food. See Project Report W1 (Annex E refers); and Developments in the food chain (this event involved *inter alia*, representatives from major international businesses), see Project Report W2 (Annex E refers).
48 These 'driver reviews' are termed DR1–DR22 in this Report. See Annex E for a list. All are available through *www.bis.gov.uk/foresight*
49 DR1 (Annex E refers)
50 UN medium variant, UNPD (2008)
51 DR1 (Annex E refers) and UNPD (2006)
52 See http://www.measuredhs.com
53 UNPD (2007)
54 UN-HABITAT (2008)

Figure 2.1: Total world population in billions: probabilistic projections until 2100 (green 95% interval; blue 60%; pink 20%).



Source: Modified from Figure 1 of DR1 (Annex E refers) and Lutz and Scherbov (2008)

2. Changes in the size and nature of per capita demand[55]. Future levels of GDP growth are difficult to estimate but have important direct and indirect effects on the food system. However, the precise relationship between income and demand is one of the most complex in the food system and a relationship that makes projecting future demand very difficult. This is because the relationship between income and demand is non-linear, and follows an 'Engel curve'. According to Engel's Law, with a given set of tastes and preferences, as income rises, consumers increase their expenditures for food products (in percentage terms) less than their increases in income. In other words, household expenditures on food in the aggregate decline as incomes rise; and the income elasticity of demand for food in the aggregate is less than one and declines towards zero with income growth. This effect is clearly demonstrated in Figure 2.2, which illustrates Engel curves for world food consumption. Increasing wealth is also associated with a decline in the proportion of starch staple foods in the diet, with a greater proportion of calories obtained from fats, protein and sugar (Bennett's Law).

The workings of these two processes can be seen in recent trends in calorie consumption and diets. Over the last 40 years calorie intake in the global population rose by about 15%, reaching a plateau in high-income countries during the last 10 years, while in rapidly-developing economies there has been an increase. This increase has substantially reduced the prevalence of undernutrition, but masks declines in some countries from what was already a very low *per capita* level of food consumption. This is especially the case in sub-Saharan Africa, where there has been a gain of only 3% over the region during the period 1969–2005, and marked declines in the last two years. In contrast, consumption levels in East Asia have increased by 41% during the same period[56].

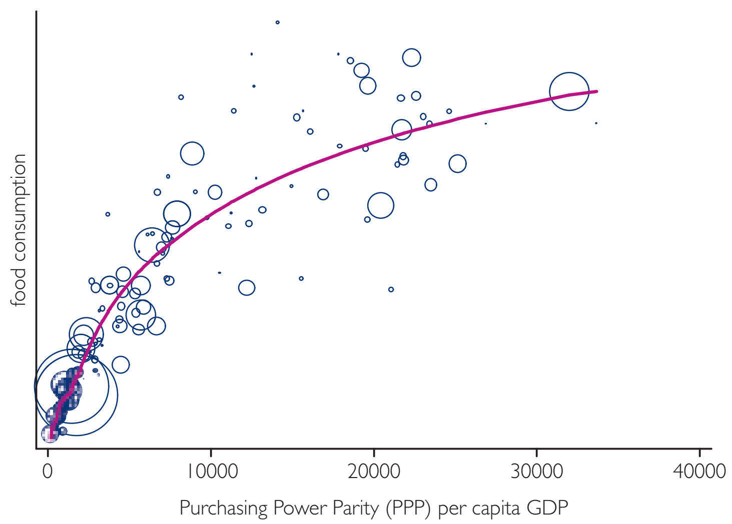
Dietary changes are very significant for the future food system because, per calorie, some food items require considerably more resources (such as land, water, energy) to produce than others. However, predicting patterns of dietary change is complex because of the way pervasive cultural, social and religious influences interact with economic drivers. A particular issue is the growth in demand for meat, where studies have predicted increases in *per capita* meat consumption (kg/person/year) from 37kg at present to around 52kg in 2050 (from 26–44 kg in the low-income countries)[57].

55 DR3 (Annex E refers) reviews what could happen to consumption patterns across the world. Regional Review R4 (Annex E refers) considers consumption patterns in India.

56 See Project Report C1 (Annex E refers)

57 Bruinsma (2009); issues of future demand are explored more fully in Chapter 3.

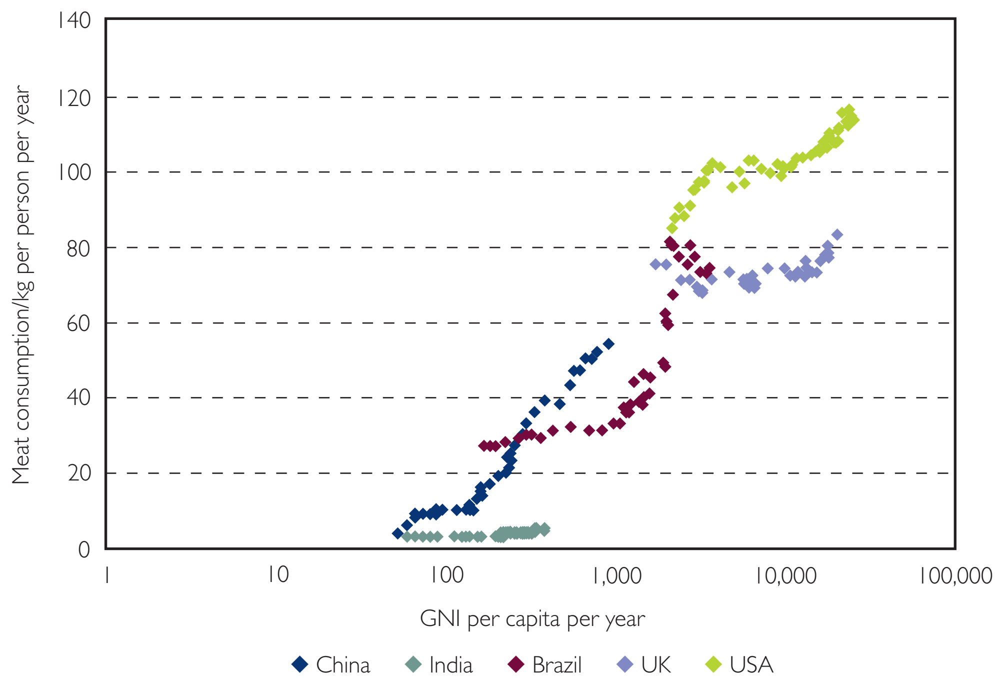
Figure 2.2: World food Engel curve: estimation of semi-logarithmic Engel curve for most countries in the world using the data of the International Comparison Program of the World Bank. Circles represent countries, and their size is proportional to the population of each country. On the graph the large circle of the United States to the end of the curve, and of India and China on the left and beginning of the curve, are clearly visible. The world income elasticity of food consumption estimated by these curves is 0.48.



Source: DR19. Calculated using data from the International Comparison Program.

Figure 2.3 shows how consumption of meat has changed over the past four decades as national income has risen. This trend suggests that significant increases could occur in some countries as incomes rise further in the future. The increases in consumption of meat in China and Brazil are particularly striking. More generally, there has been a dramatic rise in East and Southeast Asia (particularly in China) while in South Asia, which has experienced similar economic growth but which for cultural and religious reasons has more vegetarian or fish-based diets (around 40% of the population in India are vegetarians), the increase has been minimal[58]. In the countries of the old Soviet Bloc, consumption of meat dropped markedly as their economies contracted after 1989. In high-income countries, consumption is nearing a plateau. Whether consumption of meat in major economies such as Brazil and China will stabilise at levels similar to countries such as the UK, or whether they will rise further to reach levels more similar to the USA, is highly uncertain.

Figure 2.3: Changing consumption of meat in relation to gross national income in China, India, Brazil, UK and USA (1961–2007)



Source: FAOSTAT; World Bank

58 See Project Report C1 (Annex E refers)

A significant amount of meat is obtained from 'grain-fed' (primarily wheat, barley, maize and soya) livestock (particularly poultry and pigs), and diets high in this type of food have a large resource footprint. The highest proportion of grain-fed meat is found in US diets, where the *per capita* requirement of grain is four times that of a vegetarian diet. However, there is great variation in the impact of different meat production systems, and the largest growth (particularly in Asia) is predicted in pigs and poultry, where resource efficiency can be relatively high. There are also exceptions to the generalisation that only the relatively wealthy have high meat-based diets. Many poor pastoral communities have diets based on livestock but sell high-value livestock products to buy lower-cost staple foods, and addressing their needs is critical to the reduction of hunger. Overall, the global cattle population has been predicted to increase by around 70%, from 1.5 billion in 2000 to about 2.6 billion by 2050, and the global goat and sheep population by nearly 60%, from 1.7 billion to about 2.7 billion over the same period[59]. While acknowledging that these predictions are inherently uncertain, increases in the consumption of meat at this scale will have major implications for resource competition and sustainability[60].

Demand for fish will increase substantially, at least in line with other protein foods, and particularly in parts of East and South Asia in which there are strong preferences for fish[61]. There is some potential for yields from capture fisheries to increase if management is improved, but the majority of this extra demand will need to be met by aquaculture. The supply of fish and seafood from global aquaculture already accounts for more than 50% of the world's fish food supply. Asia, particularly China, strongly dominates production and output growth, but notable expansion has also occurred in Africa, Latin America and the Caribbean, the Near East, and parts of Europe (see Figure 2.4). Further expansion will have significant consequences for the management of aquatic habitats and for the supply of fertilising and feed resources.

Table 2.1: Key aspects of national growth rates

Highest growth rate, 2004–06			Large producers with high growth rates 2006–07			
	2006, '000 tonnes	%/yr		2007, '000 tonnes	%/yr	% of global change
Uganda	32.4	141.8	Vietnam	2156.5	30.1	16.7
Guatemala	16.3	82.2	Iran, Islamic Rep of	158.8	22.4	1.0
Mozambique	1.2	62.2	Korea, Rep of	606.1	18.0	3.1
Malawi	1.5	43.1	Norway	830.2	16.6	3.9
Togo	3.0	40.7	Philippines	709.7	13.9	2.9
Nigeria	84.6	38.7	Large producers with falling production 2006-07			
Cambodia	34.2	28.6	Spain	281.2	-4.0	-0.4
Pakistan	121.8	26.1	Canada	168.8	-1.3	-0.1
Singapore	8.6	25.9	Thailand	1390.3	-1.2	-0.6
Mexico	158.6	23.3	France	337.6	-0.2	-0.0

Developed from FAO(2008; 2009) – aquaculture excluding aquatic plants

The pace and scale of urbanisation will also affect global food consumption, changing the relationship between income and diet. Economies of scale allow even relatively poor people in cities access to processed foods, while the adoption of urban lifestyles and exposure to advertising can lead to increased consumption of foods high in fats and sugars. However, concentrations of people in cities can also provide governments with the opportunity to promote initiatives in food and diet while enabling the population to organise and lobby on food issues, as well as increasing the probability of riots and other forms of protests at times of food crises.

59 See Project Report C1 (Annex E refers)
60 DR5B (Annex E refers)
61 FAO (2010)

Major uncertainties around future *per capita* consumption therefore include:

- The degree to which consumption will rise in Africa.
- The degree to which diets will converge on those typical of high-income countries today.
- Whether regional differences in diet (particularly in India) persist into the future.
- The extent to which increased GDP is correlated with reduced population growth and increased *per capita* demand – the precise nature of how these different trade-offs evolve will have a major effect on gross demand.

3. Future governance of the global food system at both national and international levels[62]. There are several important aspects of the governance of the global food system to consider:

- The globalisation of markets has been a major factor shaping the global food system over recent decades and the extent to which this continues will have a substantial effect on food security. It has been driven by the fall of barriers between national economies, and technological advances reducing transaction costs and simplifying trade logistics across large geographical distances. Economic growth and further technological advances are likely to lead to greater globalisation. In high-income countries, globalisation has led consumers to expect cheap, safe and very varied food available all year round. It has also built economic dependence on these markets among poorer countries. Also, diversity of supply has increased the resilience and price stability of the food system.
- New food superpowers have emerged. In 2008, Brazil became the third largest world exporter of agricultural products after the United States and the European Union, exporting US$55.6 billion of goods[63]. Still wary of the famines of the 20th century, China and India have built huge capacity and invested in large public stockholdings and distribution systems with agricultural policies that remain inward-facing. Despite this, China is a substantial food exporter (US$29 billion in 2008) but remains a net importer (imports in 2008 totalled US$57 billion). Although India is a recipient of rising agricultural imports (particularly of edible oils), it is actually a net agricultural exporter. Russia is already significant in global export markets, and likely to become more so with a large supply of underutilised agricultural land. Recent growth in agricultural productivity in Brazil and China has been built, in particular, on a significant and expanding domestic research base.
- There has been a trend for consolidation in the private sector with the emergence of a limited number of very large transnational companies in agribusiness, in the fisheries sector, and in the food processing, distribution and retail sectors. There is some evidence that this trend may be slowing with the entry into international markets of new companies from emerging economies.
- Production subsidies, trade restrictions and other market interventions already have a major effect on the global food system, and how they develop in the future will be crucial. In recent decades there has been a decline in the level of some of the most distorting subsidies and a reduction in import tariffs, although substantial market distortions still exist. Important issues include: the degree to which international trade agreements constrain subsidies of the food production sector in high-income countries and/or limit their application to environmental and rural development issues; the extent to which low-income countries receive 'special and differential treatment' in such agreements to protect vulnerable sectors and allow for agriculture-led economic growth; and the role that a growing range of public and private standards (for example, food safety, phytosanitary or veterinary health restrictions, and wider private standards promoting social and environmental sustainability) may act to facilitate or block the entry of poorer producers in global markets.
- The extent to which governments act collectively or individually to face future challenges, particularly in shared resources, trade and volatility in agricultural markets. The political sensitivity of food puts great pressures on governments to act in the national interest. But putting this first can have negative impacts on the wider system as seen in 2007–08, when pressures which resulted from food price spikes were amplified by temporary trade restrictions[64]. The inadequate governance of international fisheries under severe resource and market pressures illustrates in microcosm many of the political and institutional challenges to collective action.

62 See Project Report C3 and WP8 (Annex E refers)
63 USDA (2009a)
64 This has been demonstrated by modelling commissioned by the Project. See Project Report WP6 (Annex E refers).

- The adequacy of the current international institutional architecture to respond to future threats and the political will to allow it to function effectively are unclear. Many current institutions are concerned with only one aspect of the system (productivity, sustainability, equity, trade and hunger); the degree to which these silos break down will be a major determinant of whether and how the multiple challenges facing the food system can be addressed coherently. Issues of governance are a recurrent theme throughout this Report, and are discussed in particular in Chapter 4.
- The control of increasing areas of land for food production (such as in Africa) will be influenced by both past and future land-purchase and leasing agreements – involving both sovereign wealth funds and business[65].

4. Climate change[66]. This will interact with the food system in two important ways:

- Growing demand for food must be met against a backdrop of rising global temperatures, and changing patterns of precipitation. These changing climatic conditions will affect crop growth and livestock performance, the availability of water, fisheries and aquaculture yields, and the functioning of ecosystem services in all regions[67]. Extreme weather events will very likely become both more severe and more frequent, thereby increasing volatility in production and prices. Fisheries habitats will be affected by changes in hydrology, sea level and oceanic processes. Crop production will also be indirectly affected by changes in sea level and river flows, although new land at high latitudes may become suitable for cultivation, and some degree of increased CO_2 'fertilisation' is likely to take place (due to elevated atmospheric CO_2 concentrations). The extent to which adaptation occurs in the food system (for example, through the development of crops and production methods adapted to new conditions) will critically influence how climate change affects the global food system.
- Policies for climate change mitigation will also have a very significant effect on the food system[68]. Global greenhouse gas (GHG) emissions must be reduced by at least 50–60% by 2050 compared to current levels to avoid major climate change[69]. The challenge of feeding a larger global population must therefore be met while delivering a steep reduction in GHG emissions. Agriculture is a major contributor to climate change, responsible for around 10–12% of emissions. Emissions also occur beyond the farm gate, and indirectly through the effect of deforestation to increase the land available for agriculture[70]. Mitigation policies could have profound effects on where food is produced, the use of fertilisers, whether land is brought into agriculture, and how land is managed. Several potential policy options for agricultural mitigation are discussed in Chapter 7.

5. Competition for key resources[71]. Several critical resources on which food production relies will come under increasing pressure in the future. Conversely, growth in the food system will itself exacerbate these pressures:

- **Land for food production[72]:** overall, relatively little new land has been brought into agriculture in recent decades. Although global crop yields grew by 115% between 1967 and 2007, the area of land in agriculture went up by only 8% and the total currently stands at approximately 4600 million ha. Of this, around 1400–1600 million ha of land is cultivated for crops[73]. Overall, the global agricultural area in use per person to produce food for a growing global population has declined (from 1.30 to 0.72 ha per person in the period 1967–2007[74]). However, there are marked regional contrasts: increased production in Asia since 1960 has been achieved almost exclusively without an increase in the area farmed, whereas in Africa cereal yields have remained static but more land has been brought into agriculture[75]. Globally, expansion of agricultural land has been mostly at the expense of forests, savannah and natural grasslands[76] (see Figure 2.5 which covers changes between1990 and 2007). ISRIC (2009) estimated that of the 11.5 billion ha of vegetated land on earth, about 24% had undergone human-induced soil degradation, with

65 Cotula et al. (2009)
66 DR2 (Annex E refers) reviews the possible effect of climate change on agricultural production.
67 IPCC (2007)
68 See Chapter 7
69 IPCC (2007)
70 IPCC (2007)
71 See Project Report C2 (Annex E refers) for further discussion of external pressures on the food system.
72 DR7B (Annex E refers)
73 FAOSTAT (2008); Project Report DR7B (Annex E refers)
74 FAOSTAT (2010)
75 See Project report C1 (Annex E refers)
76 DR7B (Annex E refers)

erosion as the main process of degradation. Although cropland occupies only 12% of land area, almost 20% of the degraded land was once cropped. FAO estimates that 30% of forests and 10% of grasslands are undergoing degradation[77]. However, around 16% of total land area, including cropland, rangeland and forests, is improving[78], with some significant land reclamation projects, for instance, in northern China[79].

- **Issues involving capture fisheries and aquaculture:** marine and freshwater areas may be required for biodiversity reserves or sport fishing. Pressure on coastal and riparian margins is particularly intense, with land required for conservation, urban and industrial development, tourism and providing ecosystem services, such as protection from storms and erosion.

Figure 2.4: (a) Absolute Mha change in forest/wood and agricultural areas from 1990 to 2007, globally and in different world regions

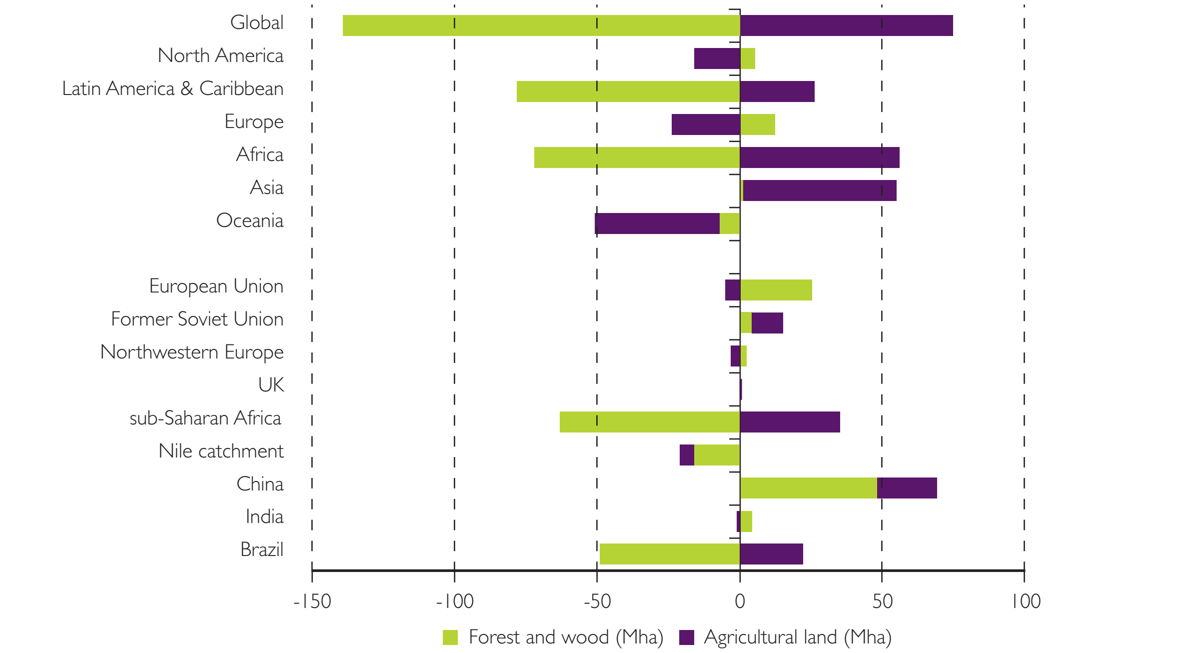
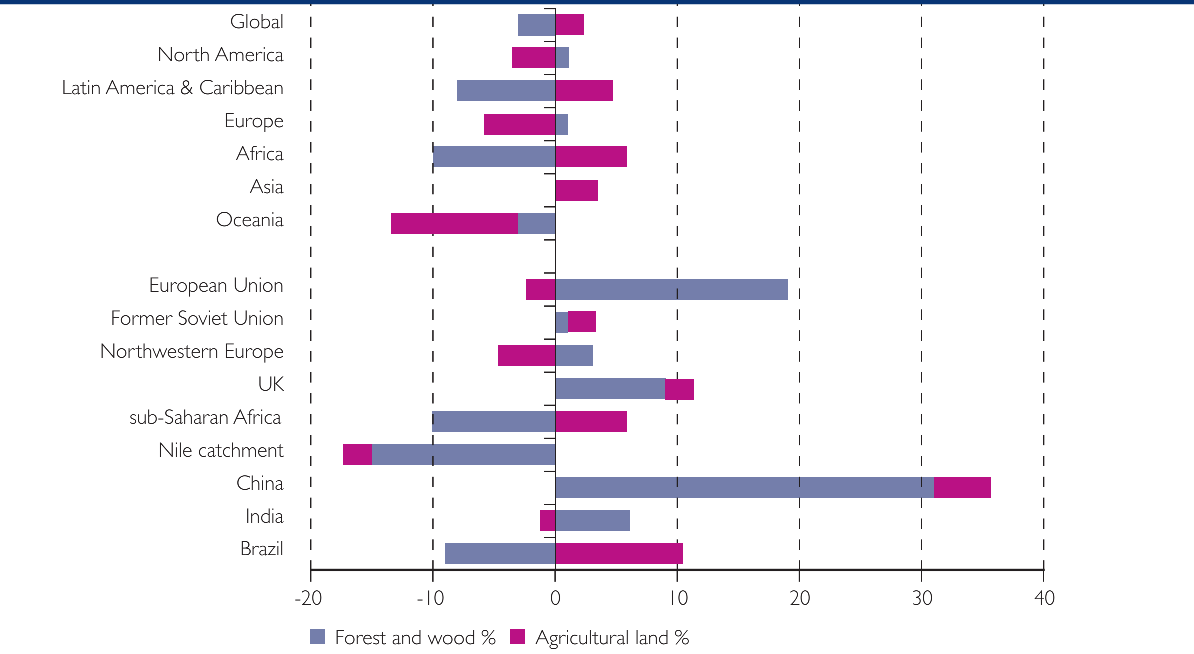


Figure 2.4: (b) percentage change (of total agricultural and forest/wood area) in forest/wood and agricultural areas from 1990 to 2007, globally and in different world regions



Source: DR7B. Data sourced from FAOSTAT (2010)

77 FAO Newsroom (2008)
78 DR7B (Annex E refers)
79 FAO Newsroom (2008)

Estimates suggest that of the 13,400 million ha of land on earth, 3,000 million is suitable for crop production, but only approximately half (1400–1600 million ha) is cultivated. The FAO estimates that, ignoring impacts on biodiversity and the carbon cycle, some 2,400 million ha is at least moderately suitable for wheat, rice and maize cultivation[80]. Other studies have variously suggested between 50–1,600 million ha of land to be suitable for agricultural expansion[81]. The fact that estimates range so widely reflects the major uncertainties involved. Indeed, estimates even of current land usage vary widely[82]. However, while substantial additional land could, in principle, be suitable for food production, in practice, land will come under growing pressure for other uses[83].

Chapter 8 describes how there are strong environmental reasons to limit any significant expansion of agricultural land in the future (although restoration of derelict, degraded or degrading land will be important[84]). In particular, it concludes that further conversion of rainforest to agricultural land should specifically be avoided as it will increase greenhouse gas emissions and accelerate the loss of biodiversity. Land will also be lost to urbanisation (recent rates have been 16 million ha per annum, often in highly productive areas[85]). Agricultural land is also lost to erosion, desertification, salinisation and sea level rise, although some options may arise for salt-tolerant crops or aquaculture. In addition, with a rising population, there will be more pressure for land to provide ecosystem and other services (see Box 8.1, Chapter 8). And while some forms of biofuels can play an important role in the mitigation of climate change, they may lead to a reduction in land available for agriculture[86]. In addition, some biofuel production systems have: (i) poor overall carbon efficiency; (ii) negative environmental consequences, particularly increased demand for tropical plant oils leading to deforestation; and (iii) public subsidies that can have distorting and sometimes perverse effects[87].

- **Global energy demand**[88]**:** this is projected to increase by 45% between 2006 and 2030[89] and could double between now and 2050 (Figure 2.5a). Energy prices are projected to rise and become more volatile, though precise projections are very difficult to make. Several parts of the food system are particularly vulnerable to higher energy costs. For example, production of nitrogen fertilisers is highly energy-intensive: the roughly five fold increase in fertiliser price between 2005 and 2008 was strongly influenced by the soaring oil price during this period[90]. The financial viability of fishing (particularly capture fisheries) is also strongly affected by fuel price.

80 FAO/IIASA (2000)

81 CE Delft (2008); EEA (2007); IWMI (2007)

82 FAOSTAT (2008); IWMI (2007)

83 However, it is recognised that a single parcel of land can simultaneously deliver many outputs – so called 'multifunctional land use'. For example, a farm can also contribute to preserving biodiversity, flood risk management and the provision of ecosystem services. For a more detailed discussion, see Foresight (2010).

84 It was reported above that 24% of land has undergone human-induced soil degradation (Bai et al. 2008).

85 Holmgren (2006); DR13 (Annex E refers)

86 Mitchell (2008)

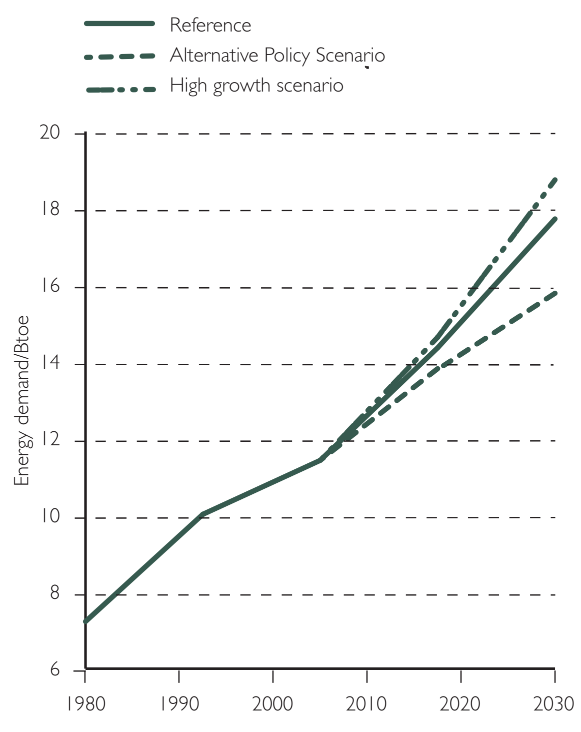
87 House of Commons Environmental Audit Committee (2008)

88 DR4 (Annex E refers) reviews future energy and its use in agriculture.

89 Based on IEA's reference scenario; Chatres (2008); Shen et al. (2008)

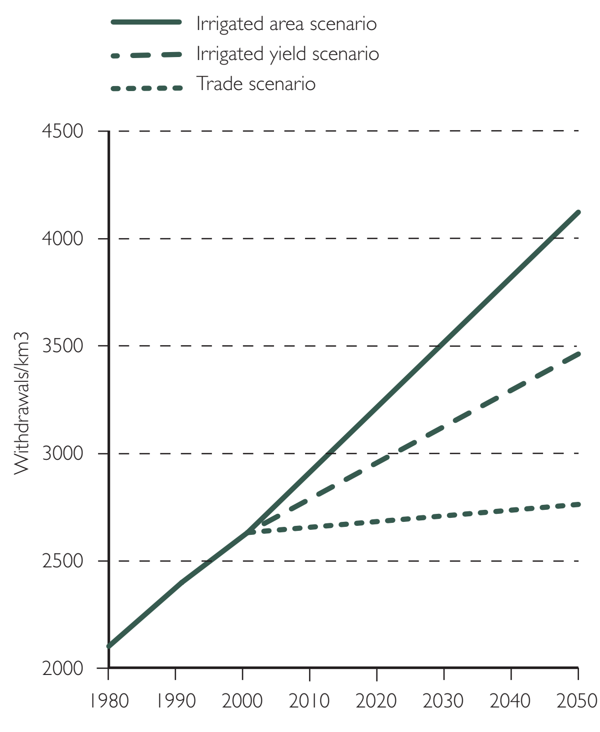
90 Piesse and Thirtle (2009)

Figure 2.5: (a) Global primary energy demand in billion tonnes oil equivalent (1980-2030)



Source: IEA (2008)

Figure 2.5: (b) Global withdrawals for water for agriculture (1980-2050)



Source: IWMI (2007)

- **Global water demand**[91]**:** agriculture already currently consumes 70% of the total global 'blue water' withdrawals from rivers and aquifers available to humankind[92]. Demand for water for agriculture could rise by over 30% between 2000 – 2030 and could double by 2050, depending on which future scenario is adopted (Figure 2.5b)[93], but will be affected by pressures from industry, domestic use, and the need to maintain environmental flows[94]. There are also important interactions with freshwater fisheries that are greatly threatened by water extraction and water quality degradation, and with coastal fisheries and aquaculture affected by increasingly nutrient-rich terrestrial run-off. In some arid regions of the world, several major non-renewable fossil aquifers are increasingly being depleted and cannot be replenished – for example, in the Punjab, Egypt, Libya and Australia[95].

Future development in currently low-income countries will see increasing competition from other sectors, heightening the risk of over-extraction of groundwater[96]. Poorly managed irrigation schemes have already led to widespread problems with salinity and waterlogging, affecting, for example, 25% of the irrigated land in Pakistan[97]. In some developed countries too, lack of water regularly limits crop production, Australia being a prime recent example. There is also an increasing appreciation of the need for environmental flows to maintain aquatic biodiversity and ecosystem services, and a growing recognition that many estimates of minimum required environmental flows need to be revised upwards[98].

Estimates suggest that exported foods account for around 16–26% of the total water used for food production worldwide, suggesting significant potential for more efficient global use of water via trade[99],

91 Driver Review DR12 (Annex E refers)
92 The Royal Academy of Engineering (2010)
93 IWMI (2007). Scenarios constructed using the IWMI Watersim model
94 Environmental flows refers to minimum designated flow in a waterway required for the maintenance of aquatic ecosystem services. It can also be viewed as a demand for floodplain maintenance, fish migration, cycling of organic matter, maintenance of water quality, or other ecological services, Smakhtin (2008).
95 Seckler et al. (1999); see Project Report C2 (Annex E refers)
96 IWMI (2007)
97 Hazell and Wood (2008); World Bank (2006a)
98 Driver Review DR12 (Annex E refers)
99 Hoekstra and Chapagain (2007); Zimmer and Renault (2003)

if exporters are able to achieve higher water productivity than importers. In most cases, the major exporters (USA, Canada and the European Union) have highly productive rain-fed agriculture, while most importers rely on irrigation or low output rain-fed systems. Traded virtual water may also be helpful in raising farm incomes and in increasing the potential for exports. However, potential disadvantages to virtual water trade include a higher risk of environmental impact in exporting regions, and possible impacts on the food security of poor people in exporting countries where water is not managed to meet both local and export needs[100].

6. Changes in values and ethical stances of consumers. These will have a major influence on policy-makers, as well as on patterns of consumption in individuals. In turn, food security and the governance of the food system will be affected. Examples include:

- Issues of national interest and 'food sovereignty'.
- The acceptability of modern technology, in particular (for example, genetic modification, nanotechnology, cloning of livestock, synthetic biology).
- The importance accorded to particular regulated and highly specified production methods such as 'organic', 'biodynamic', 'conservation grade' or 'sustainably managed'.
- The value placed on animal welfare.
- The relative importance of environmental sustainability and biodiversity protection.
- Issues of equity and fair trade.

Ethical stances can change rapidly, as illustrated by public wariness of genetically modified (GM) technology in Europe over the last two decades, and by the recent large increases in expenditure on Fairtrade certified products (€3.4 billion in 2009, a 15% increase on the previous year).

100 SIWI, IFPRI, IUCN and IWMI (2005)

Box 2.1 Regional study: The Mekong river basin – a microcosm of conflicting drivers and demands, and the need for integrated analysis[101]

Bridging Cambodia, the People's Republic of China, Lao People's Democratic Republic, Myanmar, Thailand and Vietnam, the Mekong is one of the world's major transboundary freshwater ecosystems and one of the richest areas of biodiversity in the world. It supports a rapidly expanding population – the Lower Mekong is set to grow from 60 million people today to 100 million by 2050. Aquatic resources have been a social and economic mainstay; some 40 million people are involved in capture fishing, in 2008 harvesting 2.6 million tonnes of fish worth US$2–3 billion. The fast-growing aquaculture sector was additionally worth about US$1.4 billion. The region's economy is rapidly growing and diversifying, but despite recent economic success, it still holds some of the world's poorest and most vulnerable people.

Many interacting drivers will affect the Mekong in the near future and over the next four decades. Regional economic integration through the Greater Mekong Subregion (GMS) programme and the ASEAN-China Free Trade Area (ACFTA) has ambitious aims, embracing agriculture, energy, environment, human resources, investment, telecommunications, tourism, trade and transport. Combined with regional economic growth, its catalysing investment of US$15 billion for the 10 years to 2020 will make it a key driving force, though potential impacts of climate change, within and outside the system, will also be critical (including, for example, salinity intrusion in the Lower Mekong Basin). Other major pressures include: land clearance, urban and industrial development, agricultural intensification and related water abstraction, diversion and waste discharges. With prospects of greatly reduced downstream water flows, there are rising concerns for how the aquatic ecosystem will support these demands, and how the growing population will maintain and improve access to food, while sharing in an expanding export-led economy.

Current analyses show that some elements and implications of change are becoming clear at national and sectoral levels. Regional policy must aim towards improvements in ecosystem maintenance, economic market integration and integrated assessment of fisheries and agriculture development in order to meet sustainably the present and future needs of the population. Decisive policy action is needed to arrive at a compromise between short-term growth and sustainable exploitation of aquatic resources in the long term. Multiple sector scenario building and shared policy development will be essential in ensuring a sustainable future for the Mekong.

Reviews of these and other drivers led the Project to focus on how to meet the five challenges discussed in chapters 4–8. Policy makers and analysts need to bear three things in mind when designing future policy to meet these challenges:

- **There is a need to consider and plan for the *combined* effect of drivers of change.** Treating each separately can be simplistic, as many interact with one another to produce feedbacks and non-linear effects (a classic example being the relationship between income and consumption modelled by Engel curves and explained above).
- **Policies need to be robust to the many uncertainties that are possible in the future.** For example, fine-tuning the right level of investment in the right R&D is required to ensure productivity growth at a rate necessary to meet future demand, when climate, productivity and demand are themselves subject to the multiple uncertainties discussed above.
- **Policies and plans will need to be regularly updated, informed by monitoring of critical variables and their uncertainty (see also Chapter 9).** This is crucial as under- or overestimates will have disproportionate consequences. For example, as discussed above, the current range of population projections for 2050 is 7.8–10.0 billion. Higher population figures are likely to be an outcome of low-income countries experiencing low GDP growth, resulting in much higher levels of poverty and hunger. Policy-makers need to monitor and adjust to improved estimates of future population growth as they become available.

101 Project Review R6 (Annex E refers)

To help address these points, the Project has used different modelling approaches to explore how multiple drivers interact with the economics of the food system, the results of which are described in the next chapter. Here 'scenarios' have been used to help policy-makers understand the implications of plausible futures for food security outcomes[102]. The model simulations on which the scenarios and sensitivity analyses are based are not predictions and are subject to their own uncertainties. As a result this analysis is not valid in absolute quantitative terms, but it is nevertheless a useful way to compare outcomes under different futures.

Box 2.2 Drivers of change that are difficult to imagine

A major challenge for policy-makers will be to cope with the unexpected. While such events are by definition unpredictable, the Project explored a range of drivers that are unusual or difficult to imagine. It also considered events that might lead to qualitative changes in the operation of the food system[103]. The results are not exhaustive but are useful in challenging the policy development process.

A sample of the drivers and events includes:

- A new transnational consumer movement comes into existence, facilitated by social networking on a global scale.
- The emergence of middle-income countries falters and their development trajectories go into reverse.
- Major change in the governance of global intellectual property allows low-income countries much faster access to innovations from high-income countries and emerging economies.
- Removal of energy as a constraint (for example, through the eventual commercialisation of nuclear fusion).
- Major volcanic eruptions not just spreading dust locally, but diminishing solar energy to cultivated land, for several years[104].
- Failure of one or more nuclear power stations, contaminating and rendering useless a significant agricultural region.
- Loss of honeybees as pollinators (for example, through the exacerbation of current colony collapse disorder).
- Major breakthroughs in crop genetic improvement technologies such as the ability to produce F_1 hybrid wheat, cold-tolerant high-yielding protein crops.
- Targeted gene mutations or apomictic seed production (seed produced without the need for pollination and fertilisation).
- Some countries organising to form an 'OPEC' equivalent for specific food commodities.

102 These are described further in Chapter 3.

103 See Project Workshop Report W3 (Annex E refers)

104 This part of the Project was completed before the eruption of Mount Eyjafjallajökull in Iceland.


WASHINGTON
WASHINGTON

3 Future demand, production and prices

Having introduced important drivers affecting the global food system in Chapter 2, this chapter considers how they could combine to affect food demand, production and prices over the next 40 years out to 2050.

The emphasis here is on the future, but past and present trends are also considered, where they provide insights and lessons.

3 Future demand, production and prices

The previous chapter described particularly important drivers that are likely to affect the food system in the decades ahead, through to 2050. This chapter now explores the combined effects of these and other drivers on food supply, demand and efficiency. Predicting possible outcomes is very difficult because of: (i) the many uncertainties in the system; (ii) the complex and non-linear way in which the drivers influence supply and demand; (iii) the role of economic processes in modulating the effects of different drivers through price and other mechanisms; (iv) the multiple responses of the food system (for example, price, hunger, environmental externalities); and (v) the certainty that not all relevant drivers are known.

To provide insights into the consequences of the main drivers for the food system through to 2050 the Project commissioned new food system modelling as well as a review of existing studies. Although modelling is an imperfect tool whose assumptions and simplifications need to be clearly understood, it is nevertheless a valuable means for exploring complex quantitative processes. It also allows the interactions between production, demand and prices to be explored because, at the level of the entire food system, they need to be considered together. This chapter summarises the modelling component of the Project and describes its main conclusions. It also explores the main uncertainties and attempts to identify the trigger points that will require new actions from policy-makers between now and 2030, and beyond.

The results from the Project's modelling work and its review of other studies105 suggests that there is a strong likelihood that food prices will rise significantly over the next 40 years. As discussed below, while there is debate amongst analysts about the drivers underlying the price-rise scenarios, there is broad agreement that the long-term trend over the past century of low food prices is at an end. This has major implications for achieving food security in the future. If the increasing global population is to be fed sustainably and equitably in the decades ahead, it will be necessary to improve the efficiency of production, to provide broader access to food, and to modify demand[106]. More generally, this chapter shows that price rises will themselves interact with other drivers to create five major challenges for policy-makers over the next 40 years – assessing how to address these will be the focus of subsequent chapters.

3.1 Modelling the food system

3.1.1 Modelling commissioned by this Project

The Project commissioned two types of modelling:

- Work using a model of the global food system (the IMPACT model) to explore the effect of different scenarios (which embodied assumptions about different drivers, including climate change) on global food prices and the number of undernourished people.
- Work using a model of the global economic system (the GLOBE model) to explore how changes in trade policy and other exogenous processes affect the food system, with an emphasis on the role of international trade.

The two different approaches are described in Boxes 3.1 and 3.2[107].

105 See section 3.1.2 below and Project Reports C4 and DR10A (Annex E refers)

106 See Chapter 4

107 These are discussed more fully, together with the modelling results, in Project Reports C4, WP2 and WP6 (Annex E refers).

Box 3.1 The IMPACT model

The IMPACT model was developed at the International Food Policy Research Institute (IFPRI) and is an advanced version of a family of agriculture-focused, multi-market, partial equilibrium (PE) models[108]. It represents the agricultural sector in great detail at the cost of more simplified modelling of its relationship with other parts of economy. The model simulates growth in crop production, determined by crop and input prices, externally determined rates of growth in productivity and area expansion, investment in irrigation, and availability of water. Demand is a function of prices, income, and population growth, and contains four categories of demand in crop commodity – food, feed, biofuels, and 'other uses'. The 2009 version of the model includes a hydrology model and links to the Decision Support System for Agrotechnology Transfer (DSSAT) crop-simulation software, with yield effects of climate change at 0.5-degree intervals aggregated up to the food-production-unit level. Economy-wide competition for factors of production such as land, labour or capital is not simulated. The model solves simultaneously for all prices that clear the balance of supply and demand in all markets for agricultural commodities.

The domain of applicability of partial equilibrium models like IMPACT is limited to analysis of the production, consumption and trade of agricultural commodities, subject to policies or scenarios that will have little feedback effects on the allocation of factors of production throughout the economy. Processed food products represent an increasing share of world trade, but their production is based in the non-agricultural part of the economy and they are not considered in these PE models. Nor are aquatic products included. However, the strength of the PE models is that they can provide a detailed simulation of supply, demand and trade in primary commodities, from which wider implications can be explored.

Box 3.2 The GLOBE model

The GLOBE model is in the tradition of multi-country, trade-focused, Computable General Equilibrium (CGE) models developed to analyse the impact of global trade negotiations and regional trade agreements[109]. This version of GLOBE is based at the Institute of Development Studies (IDS) at the University of Sussex, UK. The model consists of a set of individual country or region models that provide complete coverage of the global economy and are linked through international trade in a multi-region model system. The GLOBE model solves the *within* country models and *between* country trade relationships simultaneously. The country models simulate the operation of factor and commodity markets, solving for wages, land rent, profits, and commodity prices that achieve supply-demand balance in all markets. Each country engages in international trade, supplying exports and demanding imports. The model determines world prices that achieve supply-demand balance in all global commodity markets, simulating the operation of world markets.

Multi-country CGE models such as GLOBE represent the full economy, including the agricultural sector. Their strength is that they include the value chain from crops, processing and distribution, through to demand for food by households. They also incorporate links between agricultural and non-agricultural sectors, and the links between production, factor payments, and household income. Current CGE models, however, include little or no modelling of biophysical processes, and only a simplified representation of the complexities of the agricultural sector. Multi-country CGE models are well suited for analysis of policies or scenarios that will change the volume and structure of production, demand, and international trade, and the allocation of factors of production throughout the economy.

For the IMPACT model, three main scenarios were defined: 'Optimistic', 'Baseline', and 'Pessimistic', referring to the assumptions they made about population (the UN 2008 low, medium and high projections respectively) and income growth[110]. Population growth tends to be inversely related to economic growth and the three scenarios assumed relatively high, medium or low GDP growth respectively. Each of the three scenarios was explored assuming no climate change and also using four

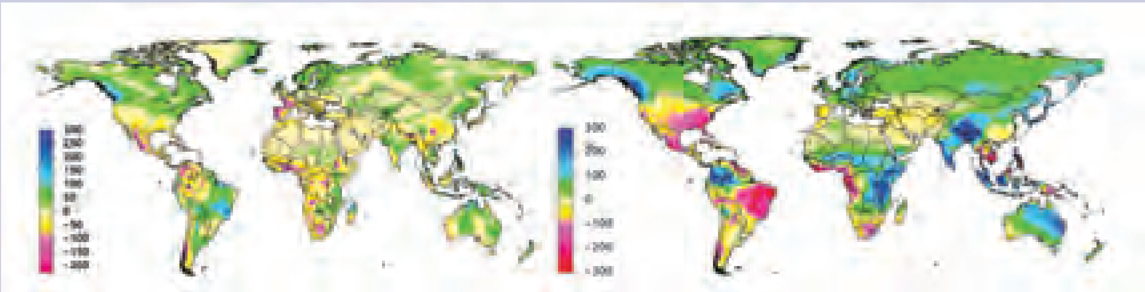
108 Nelson at al. (2010)
109 McDonald et al. (2007)
110 Nelson et al. (2010)

different possible future climate scenarios (see Box 3.3). In each case, grain prices provide a convenient indicator of future food prices.

Box 3.3 Simulating the impact of climate change on agriculture[111]

The simulated impact of climate change on agriculture has differed depending on the climate model used[112]. Four different ways of simulating climate change were chosen here. Two climate models have been used: the Center for Climate System Research (University of Tokyo), National Institute for Environmental Studies, and Frontier Research Centre for Global Change, Japan, MIROC model (MIR), and the Commonwealth Scientific and Industrial Research Organization, Australia CSIRO model (CSI). Both models are used to simulate future temperature and precipitation outcomes based on the A1B and B1 emissions scenarios of the IPCC Fourth Assessment Report[113]. All these scenarios have higher temperatures in 2050, leading to higher evaporation and increased precipitation as water vapour returns to earth in the form of rain. The CSI A1B and B1 scenarios represent a 'drier' future and the MIR A1B and B1 scenarios represent a 'wetter' future. Global averages conceal substantial regional variability as well as potential changes in seasonal patterns of precipitation (Figure 3.1).

Figure 3.1: Change in average annual precipitation, 2000–2050, A1B (mm). Drier CSI results on left, wetter MIR results on right.



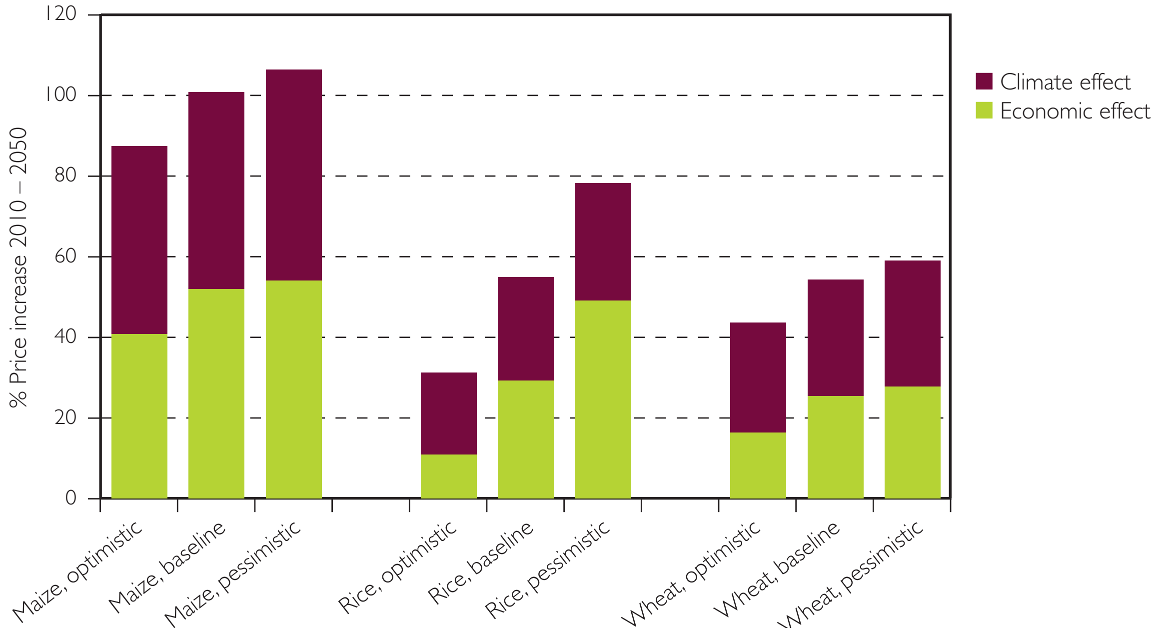
Source: IFPRI calculations based on downscaled climate data

It should be stressed that models of this type inevitably incorporate many assumptions and simplifications and should be treated as a guide to the way the food system may evolve in the future under different assumptions rather than providing precise quantitative predictions. Despite these limitations, clear conclusions can be drawn from this work. Three key results are as follows:

i. Under all three future scenarios, the IMPACT model shows significant rises in grain prices by 2050 (Figure 3.2), assuming that growth in productivity does not exceed rates experienced in recent decades – demand due to growth in population and income is not matched by increased supply. Maize shows the greatest rise in prices, but it is the world price of rice that is most sensitive to different scenarios of economic development. Price rises are less for scenarios that embody low rates of population growth. Climate change leads to even greater increases in grain prices, largely because it reduces yields. The effects of climate change, however, vary widely across countries and regions, and at the country if not the regional level there are winners as well as losers.

111 Nelson et al. (2010)
112 Parry et al. (2004); Fischer et al. (2005)
113 Nakicenovic et al. (2000)

Figure 3.2: Real food price changes for the main scenarios, 2010–2050 (%).



Source: Nelson et al. (2010)

ii. The implications of different scenarios for food prices are particularly sensitive to assumptions about agricultural productivity growth, since there are severe limitations on the potential growth of land devoted to agriculture.

iii. Results from scenario analysis in both the IMPACT and GLOBE models show clearly that a well-functioning global trade system acts to dampen negative impacts from regional demand and supply-side perturbations to the global food system. If countries react to supply or demand shocks with a protectionist response, limiting trade, the impacts on other countries are potentially serious, as economic theory would suggest. For example, if an exporting country suffers from a supply shock such as a drought and restricts exports in response, it can achieve temporary protection from increases in world prices, at the cost of exacerbating impacts on other countries through larger price increases and shortages in world markets.

3.1.2 Results from other models of the food system

In 2006, the FAO produced a baseline projection of the food system to 2050 that has been widely cited[114]. Updated in 2009, this projection estimated that to meet global demand, food production would have to increase by 70% in the period 2000–2050, which represents an annual growth rate in supply of about 1.1%[115]. While the long-term assumptions underlying this particular projection have been challenged[116], there is wide agreement that feeding the global population in 2050 will require the continued achievement of historical agricultural growth rates. Given limitations in land available for crops in the future, such growth must be largely based on increases in yields (output per hectare)[117]. Models of long-term agricultural growth indicate that such growth rates are achievable, but differ widely in specifying how they are to be achieved, how demand changes over time, and the impacts on prices.

Although demand for food increased sharply throughout the 20th century, and many commentators predicted severe food shortages, growth in productivity has kept pace with demand and food prices have fallen. For the last three decades, prices have been fairly constant at an all-time low in real terms (with the recent food price spikes being unusual) (Figure 3.3). However, since the mid-1980s, yield growth has fallen in both high-income and low-income countries[118].

114 Alexandratos (2006)
115 OECD (2010); Bruinsma (2009)
116 See Project Report C1 (Annex E refers)
117 Defra (2009); Soil Association (2010); Environment, Food and Rural Affairs Committee (2009)
118 DR8 (Annex E refers)

There have been several studies using long-term models to explore future scenarios of agricultural growth, demand, and prices, and some of these are discussed below. Many of these studies have explored the sensitivity of results to different assumptions about major drivers. A number of models present scenarios where prices of major crops rise significantly over long periods, and also explore plausible assumptions about growth in productivity that essentially eliminate price rises. However, there is broad agreement across these models that prices will not fall significantly in the future – the trend over the last century of low or falling food prices is likely to be at an end.

Scenarios explored in the IMPACT model indicate that rising prices in the future would be required to match demand with increases in supply. As discussed in Project Report C4 ('Food system scenarios and modelling'), the results from the IMPACT model are certainly sensitive to assumptions about yield growth, population growth and income.

Box 3.4 Is agricultural productivity growth improving or deteriorating?

From 1961–2008, growth rates of yields (output per hectare) for grains in developed countries were on average 1.5% per annum and 2.1% in developing countries. Since 1985, there has been a reduction in these average growth rates[119]. Projections of food prices are very sensitive to assumptions about growth in supply, and hence to changes in yields.

Growth in agricultural output can result from growth in either area planted or yields, or both. Yield growth can arise from intensification of inputs (more inputs used with the same amount of land) or from productivity growth (changes that yield more output for the same level of inputs). Total factor productivity (TFP) growth is a measure of increases in output per unit of all inputs, including land, and is used as a summary measure of increases in output that are not due to increases in inputs. While intensification (e.g. greater use of machinery, labour, or chemicals with the same amount of land) is an important source of growth in agriculture in low-income countries, productivity growth is generally more important. Identifying the nature and sources of productivity growth is crucial for policy, informing what mix of policies should be emphasised to develop improved machinery, seeds, chemicals, farm management practices, and improvements in land and irrigation.

Research suggests that global TFP growth has improved in recent decades and accounts for an increasing share of the growth in agricultural output[120]. In fact, there has been a slowdown in the growth of inputs for production, with variation across different regions.

Growth in TFP is important to the concept of sustainable intensification[121] because it will ease constraints on land, labour and other resources: 1% growth in TFP means 1% fewer resources are needed to produce the same amount of output. Research and development is key to increasing productivity, but there may be long lead times before benefits are fully realised. In summary, productivity growth has offset the deceleration of input growth to keep global agriculture growing at an average of 2% per annum since the 1960s[122]. There has, however, been a slowdown in recent years in public research and development expenditure on agriculture, particularly on productivity-enhancing research[123].

There are both optimistic and pessimistic views on the future of agricultural productivity[124]. In its base scenario, the IMPACT modelling framework assumes that growth rates of yields increase slightly over the next 10–15 years and then decline gradually to 2050. These assumed trends incorporate assumptions about intensification and productivity growth, assuming 'business as usual' levels of resources applied to research and development.

Two studies using dynamic global CGE models (similar in structure to the GLOBE model), found that grain prices are highly sensitive to assumptions about growth in productivity (measured by total factor

119 DR8 (Annex E refers)
120 Fuglie (2008); Fuglie (2010)
121 Sustainable intensification produces more food from the same amount of land in a renewable way; see The Royal Society (2009).
122 Fuglie (2010)
123 DR8 (Annex E refers)
124 DR8 (Annex E refers)

productivity rather than crop yields)[125]. One of these studies specified a scenario in which prices of maize, rice, and wheat rose by 127%, 110%, and 68% respectively to 2050, but when they assumed increases in total factor productivity of 1% per year, there were only minimal price rises[126]. The second study found that growth in global total factor productivity of 2.1% per year led to a slight decrease in prices in 2030, but does not report the change in yields[127]. Growth rates of yields in the IMPACT model for maize, wheat and rice range from 0.2–1.9% per year.

Two other modelling exercises have investigated the impact of climate change on food security using IPCC emissions scenarios[128]. Food prices vary depending on the crop and climate model used, but are projected to be higher than current levels. For example, in one exercise, without the impact from climate change, grain prices rise between 30–80% from 1990 to 2050[129]. Results including the impact of climate change are reported with and without CO_2 fertilisation on the basis that true effects will fall somewhere in between. When positive effects of CO_2 fertilisation are included, the impact of climate change raises prices roughly by a further 7–20%. Without these effects, the impact of climate change raises prices by a further 50–100%. The IMPACT model used in this Project makes a cautious assumption about any positive effects from CO_2 fertilisation[130].

Previous modelling exercises tend to agree that climate change appears likely to widen the existing gaps in cereal yields across countries, especially between high-income and low-income countries[131]. With the IMPACT model the results are similar, apart from the case of maize where climate change has a more negative effect on yields in high-income countries. Disruptions to supply due to the impacts of climate change tend to lead to higher prices in the future – a result also shown by the IMPACT model. Climate change is expected to increase prices, but population and economic growth are also likely to have a strong impact on food security[132]. Other models tend to show that increased international trade can ameliorate the regional impacts of supply shocks; these findings are consistent with results from both the IMPACT and the GLOBE models[133].

Agricultural performance and food prices are also sensitive to competition for land, energy and water. Recent analysis has suggested that many models could be projecting higher food price rises by underestimating the responsiveness of the long-term supply of land for food production as prices increase[134]. However, assuming that there is much untapped potential for new land supply risks seriously misjudging the externalities of bringing new land into production – particularly where this land is forest with high value for both biodiversity and carbon sequestration. Land use is also sensitive to competing economic forces and policy choices. For example, the impact of biofuel production, which has the potential to compete with food crops, will depend on future uncertainties such as energy prices, tax/subsidy policies and technological change. Current modelling finds that increased biofuel production results in food price rises, but also that increases are reduced if second-generation technology (i.e. using cellulose stocks, rather than carbohydrate-based crops) is available or if international trade encourages production in more suitable regions[135].

Systematic comparison of different models of the food system is required to improve understanding of variation in methods and results. More generally, the availability, coverage, quality and accessibility of spatially explicit datasets for global production and trade, land use and hydrology, which provide the basis for model calibration and validation, require improvement[136]. Extensions are also required to cover foods of aquatic origin.

125 Ivanic and Martin (2010); van der Mensbrugghe et al. (2009). The two measures of productivity will give the same results for growth if there are no changes in factor prices. See Box 3.4 for a discussion of productivity measures.

126 Ivanic and Martin (2010)

127 van der Mensbrugghe et al. (2009)

128 Parry et al. (2004); Fischer et al. (2005)

129 Parry et al. (2004)

130 For the purposes of CO2 fertilisation, IMPACT assumes an atmospheric concentration of 369 ppm so that the uncertain biophysical effects in the field are not overestimated.

131 Parry et al. (2004); Fischer et al. (2005)

132 Easterling et al. (2007)

133 DR10A (Annex E refers)

134 Hertel (2010)

135 Fischer (2009); Msangi and Rosegrant (2009); Bouet et al. (2010)

136 DR10A (Annex E refers)

3.2 The possibility of rising food prices – a critical concern for policy-makers

A fundamental issue for policy-makers concerns what is a 'desirable' level for food prices, and what is an 'acceptable' degree of price volatility. In turn, this raises questions about 'desirable and acceptable for whom': whether policymakers should seek to influence prices, and how the poor can best be provided with food security when volatility or high prices occur.

The results of the body of modelling work that specify a variety of drivers and scenarios described above indicate that, with high probability, the long-run trend of low prices for major crops is over and that there is a significant likelihood that prices of major crops will rise, perhaps dramatically, over the next 40 years. This conclusion has important implications for policy-makers. It has been argued that food prices are currently too low and that there may be advantages to some rise in prices[137]. Limited increases could benefit food producers; create greater pressure to curb waste; and would stimulate growth in agricultural-based economies – the last of which could be a significant factor in reducing poverty more generally[138].

However, price rises would also give rise to disadvantages. Food security for the poor would be compromised, as discussed below. The stimulus to food production could undermine efforts to increase sustainability of the food system, leading to dangerous feedbacks through environmental deterioration, imperilling future production. It could also reduce incentives to adapt agriculture to deliver wider public goods such as ecosystem services and the protection of biodiversity.

3.3 Results from the IMPACT model on future price rises and hunger

If price rises are too great there is a genuine risk of substantial political and social consequences, including conflict and civil unrest. This would compromise efforts to address hunger and have a devastating effect on the world's poorest people, both those in low-income countries and the least privileged people in high- and middle-income countries. These developments would have broad implications for physical and mental development, which in turn could result in negative feedbacks on economic growth and poverty.

Predicting levels of hunger in the future is very difficult as its causes are multifactorial, including many determinants that lie outside the food system[139]. However, economic models that include measures of income, prices and production can be used to estimate daily available energy intake, and hence the risk of hunger and undernutrition. But it is critical to stress that the results of such exercises must be interpreted very cautiously and not treated as exact quantitative predictions.

The results of new economic modelling using the IMPACT model concerning possible future world food prices have been described above[140]. Food prices were predicted to rise under an 'optimistic' (low population, high income growth) scenario, but much more so under a 'pessimistic' scenario (high population, low income growth). The impact of climate change also increased food price rises. This section describes how the IMPACT model was used to explore how the three different scenarios influence hunger and undernourishment.

Food system modelling in this Project using the IMPACT model suggests that within the range of possible scenarios describing the food system over the next 40 years, hunger may either markedly decrease or increase (Figure 3.3). Policy decisions that influence the modelled scenarios of population and income growth and climate change will thus have a very significant effect on hunger.

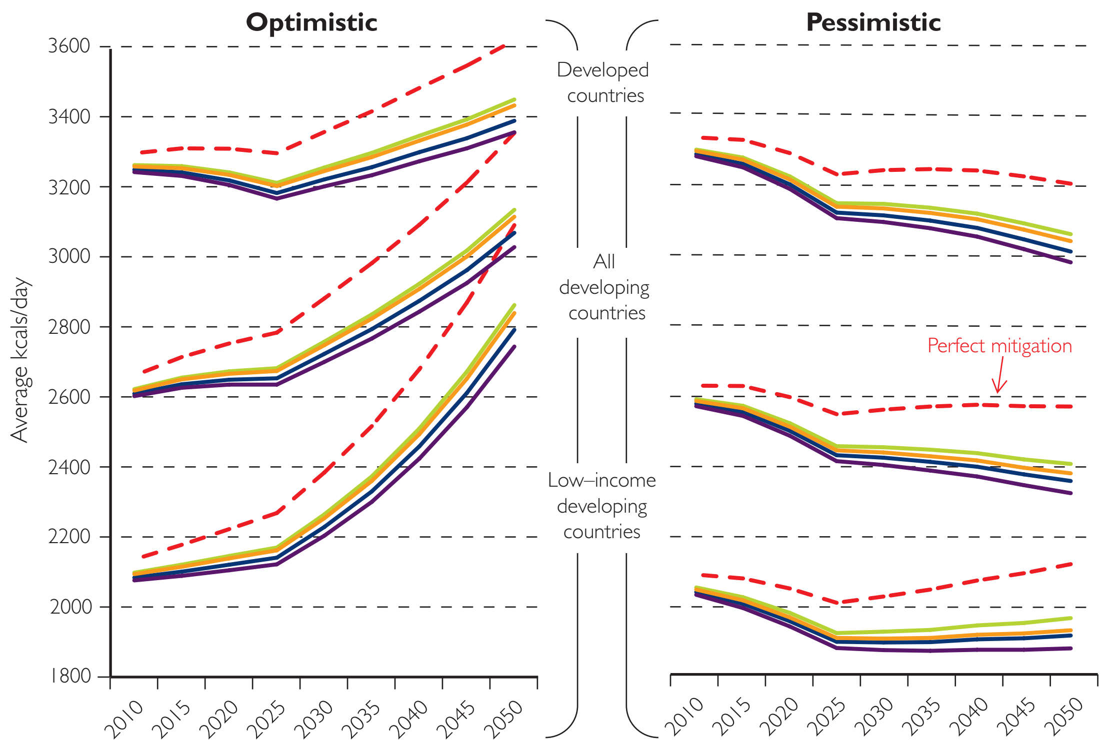
137 International Fund for Agricultural Development (2010)

138 See Chapter 6

139 See Chapter 6 and Project Report C11 (Annex E refers)

140 See also A8 (Annex E refers)

Figure 3.3: Impact of economic development and climate change on average daily kilocalorie availability[141]. For each group of countries the dashed line represents a future with no impact from climate change. The cluster of lines below the top line is the outcomes with four combinations of different climate scenarios used in the IMPACT modelling (See Box 3.3).



Source: Project report C4; IFPRI

Assuming relatively low increases in population growth but high income growth (the 'optimistic' scenario), calorie consumption converges for people living in developed and developing countries. Although food prices rise, the higher income of people in developing countries in this scenario means they are more likely to be able to afford food. Also, the slower rate of population growth (itself correlated with income growth) prevents demand growing too rapidly. Economic development in this case induces a positive accelerator effect on average kilocalories outcomes. The effect is particularly strong in developing countries where the income elasticity of demand[142] for food is higher. The reverse occurs in the 'pessimistic' scenario and the average daily kilocalorie level declines.

Future price rises will have significant impacts on hunger, although this will be moderated by wider economic growth.

In the 'optimistic' scenario, the effects of climate change result in a lower increase in energy availability in low-income countries, while in the 'pessimistic' scenario, outcomes are even worse. **Climate change makes it harder to address hunger, as it reduces productivity, especially in low-income countries.**

Food prices are by no means the only factor hindering progress in achieving a sustainable food system and ending hunger – at a time of historically low food prices, there are still many hungry people across the world and the food system is operating under increasing stress. Containing food prices within reasonable bounds is essential to address both issues.

Given the strength of likely future pressures on food prices, and the risks of inaction, policy-makers are strongly advised to consider how to keep prices within reasonable bounds for poor people and prevent disruptive volatility.

141 Recommended dietary energy requirements vary according to age, gender and lifestyle. For an average adult between the ages of 30 and 60 the requirement for a male is 2,750 kilocalories per day and for a woman 2,350 kilocalories per day, FAO/WHO/UNU (2001).

142 Income elasticity of demand for food measures the responsiveness of the demand for food to changes in income. A negative elasticity indicates that demand for food falls as income increases whereas a positive elasticity indicates that demand rises.

It will be seen in later chapters that the scale of the threats are such that no single class of intervention – increasing supply, moderating demand, improving the efficiency of the food system – is alone likely to be sufficient. Policy-makers will need to pursue a portfolio of measures involving all aspects of the food system.

3.4 Five key challenges for the next 40 years

In exploring the consequences for policy-makers of the different drivers affecting the food system the Project found it useful to define five separate challenges, which are described below. These challenges interact with one another within the entire food system, and possible interventions to address them should be viewed in this wider context.

Challenge A: Balancing future demand and supply sustainably

Ensuring that the food system continues to supply affordable food for the growing global population so that all can be fed adequately, healthily and safely is the fundamental challenge to policy-makers. Increases in population and *per capita* demand[143] could combine to create a rise in total demand for food of 40% by 2030 and 70% by 2050[144]. The challenge could be greater if projections for drivers of change relating to population and income growth, climate change, and governance of the food system prove to be underestimates. A further uncertainty concerns the extent to which demand will switch to foods such as meat, where production is often grain-intensive. The challenge of adequately balancing production with this rising demand is a critical requirement for the avoidance of excessive price rises.

Chapter 4 considers how this challenge could be addressed. A pluralistic approach will be required, with choices needing to be made from: better use of existing production techniques; the application of new science and technology; reducing waste; improving efficiencies through better governance; and influencing demand.

Box 3.5 Sustainability – a thread that runs through the Project

What the Project means by sustainability

The principle of sustainability implies the use of resources at rates that do not exceed the capacity of the earth to replace them. Thus water is consumed in water basins at rates that can be replenished by inflows and rainfall, greenhouse gas (GHG) emissions are balanced by carbon fixation and storage, soil degradation and biodiversity loss are halted, and pollutants do not accumulate in the environment. Capture fisheries and other renewable resources are not depleted beyond their capacity to recover. Sustainability also extends to financial and human capital; food production and economic growth must create sufficient wealth to maintain a viable and healthy workforce, and skills must be transmitted to future generations of producers. Sustainability also entails resilience, such that the food system, including its human and organisational components, is robust to transitory shocks and stresses. In the short- to medium-term non-renewable inputs will continue to be used, but to achieve sustainability the profits from their use should be invested in the development of renewable resources.

143 See Chapter 2
144 Alexandratos (2006)

The many difficulties – and questions – in making sustainability operational

Over what spatial scale should food production be sustainable? Clearly global sustainability is an overarching goal, but should this goal also apply at lower levels: regions (or oceans), nations and farms? For example, high levels of consumption or negative externalities in some regions could be mitigated by improvements in other areas, and some unsustainable activities in the food system might be offset by actions in the non-food sector (through carbon-trading, for example). Timing is important. How fast should the move be from the *status quo* to a sustainable food system? The challenges of climate change and competition for water and resources suggest a rapid transition is required, but it is also legitimate to explore the possibility that superior technologies may be available in the future, and that later generations may be wealthier and hence better able to absorb the costs of the transition than is currently the case.

There are few transparent or sufficiently agreed metrics to inform the evaluation of alternative strategies or to drive consistent progress. The lack of metrics is apparent even for relatively circumscribed activities such as crop production on individual farms, and is more difficult when the complete food chain is included or for complex products that may contain ingredients sourced from around the globe. These are areas at the interface of natural and social science, engineering and economics that urgently need more attention.

Sustainable intensification

The Report argues: (i) that there is relatively little new land for agriculture; (ii) that more food needs to be produced; and (iii) that food production must become sustainable. As developed in more detail in Chapters 4, 7 and 8, this logically implies sustainable intensification: the pursuit of the dual goals of higher yields with fewer negative consequences for the environment.

Challenge B: Addressing the threat of future volatility in the food system

Future price volatility in food markets is a cause for concern because of the adverse effects it has on both consumers and producers, with risk implications for production, the macro-economy and public finances. These effects are especially important for low-income countries and the poor. Some of the drivers described in Chapter 2 will act to increase volatility (e.g. extreme weather events resulting from climate change), whereas other factors (such as new technology leading to new varieties of crop that are resistant to diseases, drought or flooding) will tend to reduce volatility. Chapter 5 appraises these different factors and assesses the prospects for future volatility and the implications for policy-makers.

Challenge C: Ending hunger

Hunger is a central concern to policy-makers and is embodied in the first Millennium Development Goal (MDG), which seeks to halve the number of hungry people in the world between 1990 and 2015. With the notable exception of China and a number of other countries that have made impressive progress, this MDG is unlikely to be met on a global level without decisive action. Though food prices are at a historical low and the majority of the world's population have access to cheap food, approximately 925 million people have access to insufficient calories and perhaps a further one billion have diets deficient in one or more micronutrients[145]. The number of people hungry (using the FAO definition) has remained approximately constant in recent decades (though declining as a fraction of global population)[146]. The susceptibility of the poorest to changes in global food prices is reflected in the jump in global hunger numbers in 2008 coincident with the food price spike.

Hunger is influenced by a range of factors, not all of which are encompassed by the food system. Important drivers include the price of food commodities and their relationship to local incomes[147], as well as local access to food. However, issues of conflict and human displacement are also important,

145 See Chapter 1
146 See Chapter 6
147 See Chapter 2

as well as a range of issues concerning governance, such as subsidies, protectionism, and the political will to address hunger.

This chapter has described the use of the IMPACT model to assess the possible consequences of the different scenarios of economic growth, population growth and climate change on the numbers of hungry people. While these results should be interpreted cautiously, the modelling suggests that climate change will make the goal of eliminating hunger more difficult to achieve[148].

The issue of hunger is also addressed in Chapter 4, which considers issues concerned with stimulating food production in low-income countries. However, that is only part of the picture. Chapter 6 explores the political, social and economic issues that particularly affect questions of hunger. Here, particular attention is paid to the role of agriculture in rural development and the needs of smallholder farmers – three-quarters of the world's poor live in rural areas and agriculture is critical to their livelihoods. Indeed, of the three billion rural people in low-income countries, 2.5 billion are involved in agriculture, of whom 1.5 billion live in small-farmer households[149].

Challenge D: Meeting the challenges of a low emissions world

While the issue of sustainability in food production and distribution is integral to addressing Challenge A, there are further challenges for the food system in operating in a low emissions world. The food system is a major emitter of greenhouse gases, and this contribution could rise as it expands over the next 40 years. It is therefore vital that agriculture and food production, along with other elements in the food system, play their part in addressing the mitigation of climate change which, alongside adaptation to climate change, is arguably the greatest challenge facing humanity over the next century. Policies for climate change mitigation will affect the food system with intended and possibly unintended consequences for: patterns of food production; the amount of food produced with different carbon footprints; the ability of the food system to compete for critical resources such as land, water and energy[150]; and ultimately food security. The interaction between the food system and measures for climate change mitigation is discussed in Chapter 7.

Challenge E: Maintaining biodiversity and ecosystem services while feeding the world

The food system has a pervasive effect on ecosystem services (the benefits humanity obtains from the environment[151]) and biodiversity, not least through its dominant effect on land use, which affects a major part of the global land surface[152]. Conversely, the provision of ecosystem services and biodiversity – both on land and in aquatic habitats – plays a crucial role in enabling agricultural productivity. For example, vital components from the environment to ensure good agricultural productivity include access to water (70% of the world's abstracted water supply is used for agriculture), healthy soils, and predator pests as well as insect pollinators. Policy-makers need to consider the food system in the context of its interactions and inter-dependence on ecosystem services and biodiversity, in addition to wider economic and ethical grounds for adopting policies that feed the world yet also deliver these public goods.

The need to produce more food is perhaps the greatest threat to the preservation of biodiversity, both on land and in aquatic habitats. There are complex trade-offs between reducing yields in favour of biodiversity versus maximising yields to allow land to be spared for protected areas. Chapter 8 considers these issues further.

148 See Chapter 3 for a more detailed discussion of these modelling results. Full results can be found in WP6 (Annex E refers).
149 World Bank (2008)
150 See Chapter 1
151 For full definition see Box 8.1
152 Chapter 2

4 Challenge A: Balancing future demand and supply sustainably

Chapter 4 considers the levers that are available for increasing the global food supply, influencing demand, developing more sustainable production, and, particularly, driving the need for intensification on broadly the existing land area. They include:

- Improving productivity sustainably using existing knowledge and technologies.
- The use of new science and technology – to increase sustainable production.
- Reducing waste.
- Improving governance of the food system.
- Influencing demand.

4 Challenge A: Balancing future demand and supply sustainably[153]

This chapter explores how the food system can meet the challenges outlined in Chapters 2 and 3. It begins by arguing that the threats are so great that no single solution will be sufficient and that coordinated actions are needed throughout the food system. On the supply side, the chapter examines how more food can be produced today in a more sustainable way by the application of existing technologies and knowledge, especially in low-income countries. But new science and knowledge are also required, especially to meet the challenges of a changing environment. The chapter goes on to ask how waste in the food chain can be reduced, and how national and international food system governance can be improved in the face of much greater demand for food. Finally, it examines the policy options on the demand side. Throughout it stresses the interconnectedness of the food system and that successes in one area reduce the pressures to act elsewhere.

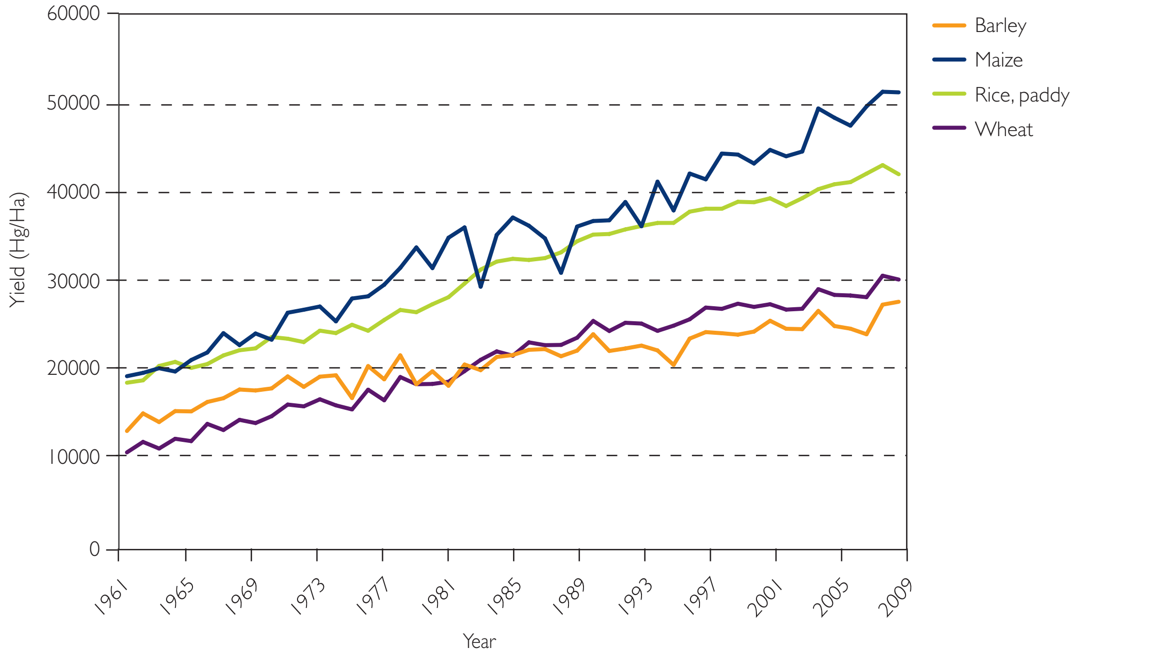
4.1 Multiple interventions are required to address the challenge of balancing supply and demand sustainably

A significant increase in agricultural and fisheries production could be achieved today without new knowledge, simply by spreading current best practice (see Section 4.2). Nevertheless, substantial innovation will also be needed not only to increase production to the scale required, but to achieve this sustainably, in a world where there is growing competition for resources (Section 4.3). The translation of new science and knowledge into applications in the field is often a lengthy and uncertain process and requires investment now to anticipate future needs. Similarly, building the infrastructure that allows food producers to capitalise on new and existing knowledge to achieve growth in productivity in the decades ahead requires commitment beyond the short term. Hence concerted action across several policy domains must be initiated now to solve the problems of 2030 and beyond.

Not withstanding present volatility, food prices have remained low in recent decades because growth in productivity has kept pace with rising demand. For example, Figure 4.1 shows the substantial increase in yields for major cereals of between 100% and 200% achieved since 1961, while Figure 4.2 shows the global trends in intensification of crop production achieved through greater use of mechanisation, irrigation, labour, and inputs such as fertilisers. However, there is evidence of a slowdown in yield growth in both high-income and low-income countries (though, as Box 3.4 describes, there is an important distinction to be made between different measures of productivity). For example, while maize yields continue to rise, wheat yields are beginning to decline[154] as yield ceilings are reached on an increasing proportion of agricultural land. The rates of yield gains for major rice-producing countries in South East Asia have also been variable. For example, much of the increase in China and Indonesia occurred during 1960–90, while in Bangladesh and Vietnam yields have shown greater improvement between 1990–2007[155].

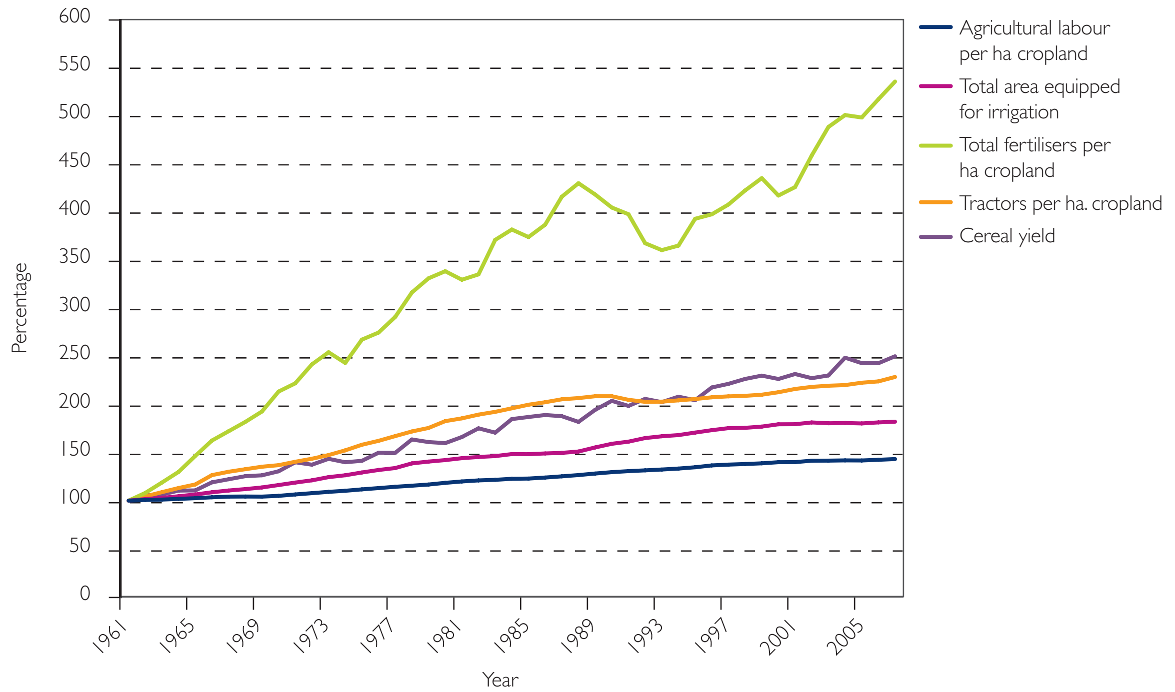
153 See Project Synthesis Report C1 for a more detailed discussion of food demand, production and prices (Annex E refers).
154 USDA (2009b)
155 Deutsche Bank Group (2009); Project Report C1 (Annex E refers)

Figure 4.1: Global changes in yield (Hg/ha)[156] for major cereals, 1961–2009



Source: FAOSTAT (2010)

Figure 4.2: Global trends in the intensification of crop production (index 1961–2002/2005)



Source: DR4. Updated from Hazell and Wood (2008), based on FAOSTAT (2010).

Action is required on the demand as well as on the supply side. Policies that bring about changes in diet have the potential to play a significant role in balancing supply and demand (Section 4.6), as well as addressing other policy goals such as improving sustainability, helping the world's poorest people, and achieving better human health.

Humans require an adequate and balanced intake of food for a healthy life but the nature of what they consume to obtain this energy has very different consequences for the global food system. The

156 Hg/Ha = Hectogram/Ha 1 – Hectogram = 100g.

production of some foods requires much more land, water and energy per calorie consumed, when compared to alternatives. How different foods are produced also has different impacts on the environment, through, for example, greenhouse gas emissions and other negative externalities such as nitrate run-off from excess fertiliser application, and soil degradation/erosion.

Actions aimed at cutting inefficient practices within the food system also have great potential. For example, interventions that reduce waste in the food system have multiple benefits (Section 4.4), while improvements of the food system governance could provide incentives for greater sustainability (Section 4.5).

Coordinated actions on the supply and demand side, and on waste and the working of the food system, will together ensure that demand does not outstrip supply to such an extent that food prices rise to unacceptable levels, the numbers hungry dramatically increase, and the incentives to make the food system sustainable disappear.

4.2 Improving productivity sustainably using existing knowledge[157]

There is substantial potential to increase global food production by promoting better use of existing skills scientific knowledge and technology. Both within and between countries there are differences in productivity that are not explained by local physical conditions – what has been called the 'yield gap'. These differences occur everywhere but are particularly marked in low- and middle-income countries, due to poorly developed infrastructure, whether in roads, storage and markets, or in input and services. **It has been estimated that the application of existing knowledge and technology could increase average yields two to three fold in many parts of Africa, and two fold in the Russian Federation. Similarly, global productivity in aquaculture typically could, with limited changes to inputs, be raised by around 40%[158].** There are questions to resolve around ways to stimulate greater innovation and risk-taking amongst producers, so that they start to bridge the yield gap. In some cases, it may require better access to insurance, and in others better outreach or farmer exchanges which allow for a practical demonstration of what changes in practice can deliver.

Yield gaps exist for numerous reasons. They can occur for reasons completely outside the food system: food production may be severely disrupted in countries subject to conflict and political turmoil, while political or economic mismanagement can discourage farmers and fishermen from making long-term investments in raising farm productivity. However, in some production systems, it may not be economically rational to increase productivity given the cost of inputs and prevailing output prices. In other cases yields are low because lack of human, physical and financial capital restricts the application of existing knowledge. The gap in agricultural yields is expected to contract as prices increase, but decisions made by policy-makers will be important in enabling production systems to respond efficiently to increasing demand.

Among the major wheat producers, only the EU countries (the UK, Denmark, France, Germany) have actual yields close to, or even higher than[159] those attainable for their agro-ecological endowments under rain-fed high-input farming. In all other major producers with predominantly rain-fed wheat production the gaps between actual and attainable yields are significant (Figure 4.3). This illustrates the large room for growth in productivity that might be achieved if socio-economic, institutional and political conditions were more favourable to the uptake of new technologies and practices. The implication is that in many places, under the right conditions, yields could double. Major investment in infrastructure, market development, and technology would be required over the long term in many of these countries to

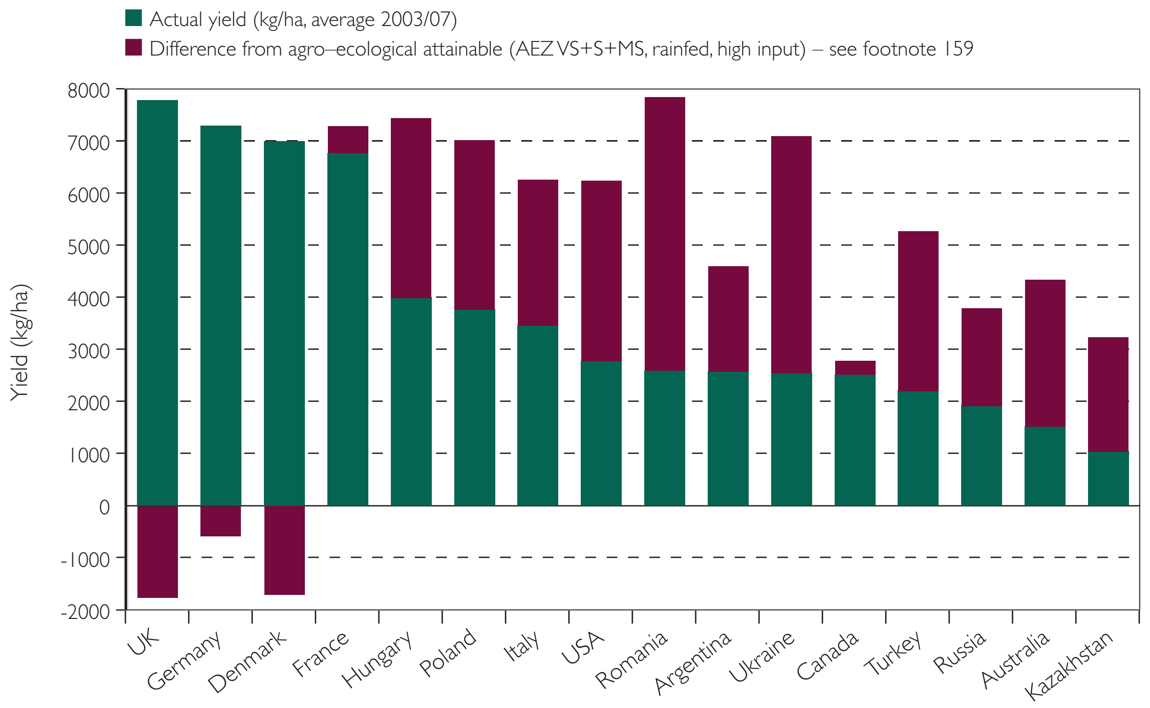
157 See Project Synthesis Report C5 (Annex E refers) for a more comprehensive discussion of how the spread of existing knowledge and technology can benefit the food system.

158 DR16 (Annex E refers)

159 That actual yield levels in the United Kingdom, Germany and Denmark exceed the average S + VS + MS AEZ attainable yield can in part be explained if one assumes that all wheat is grown only on VS area. AEZ is the agro-ecologically attainable national average yield.
The Global Agro-Ecological Zone (GAEZ) analysis models land suitability for cropping on a grid square by grid square basis across the globe, using climate, soil and land use information to calculate available land area and attainable yields for cropping under very suitable (VS), suitable (S), moderately suitable (MS) and marginally suitable (mS) classifications for all the major crops under irrigated or rain-fed conditions and under low, intermediate or high levels of inputs.
Global Agro-Ecological Zone (GAEZ) analysis undertaken by IIASA and FAO (Fischer et al. 2002)

generate higher returns and push actual yields closer to the attainable level. This is without counting the potential yield gains that could come from further improvement in varieties.

Figure 4.3: Actual and agro-ecologically attainable yields for wheat in selected countries



Source: Bruinsma (2009)

The principal challenge is not only to use existing knowledge to produce more food but to do so sustainably. A major issue is how to assess a spectrum of production methods that may differ simultaneously in yield and in how they impact the environment in terms of greenhouse gas emissions, pollution of surface water[160], impacts on biodiversity[161] and other processes. Though yield and some impacts such as water usage and greenhouse gas emissions can be measured, defining metrics for others such as biodiversity impacts is much harder, and there is no current agreement on single aggregate indices of sustainability. Operational definitions of sustainability are also complicated by issues of geographical scale and levels of uncertainty, as well as by their long-term or inter-generational implications (see Box 3.5).

A different approach is to develop a set of standards to govern food production that may be based on an empirical evidence base or on a more general philosophical position on how food should be produced. Examples of these include those developed for conservation agriculture, and by the 'Fairtrade' and organic production movements. Of these, organic production is perhaps the best known and its potential to provide a general solution for sustainable food production is explored in Box 4.1.

160 Pretty et al. (2003)
161 For example, see Chapter 6

Box 4.1 Food security and organic agriculture[162]

Organic agriculture is an approach to food production that seeks to develop humane, environmental and economically sustainable production systems with a strong emphasis on the use of local, renewable resources and the minimal use of external inputs. Organic in this context means treating the farm and its environment as an interacting system and not, as often assumed, a description of a preferred type of input (for example non-synthetic chemicals). Since the 1970s, markets have been developed for organic products in high-income countries, and to protect the consumer legally enforced production standards have been introduced, which to many are now a *de facto* definition of organic farming.

Building on organic agriculture. The organic agriculture movement contributes to food security in researching and developing specific production methods that can be implemented on both organic and non-organic farms. This Report considers that all food production systems can incorporate elements of organic agriculture to help increase sustainability. Possible examples include:

- Effective use of local or farm-derived renewable resources and in general improving the efficiency of input utilisation.
- Management of nitrogen inputs in ways that reduce leaching.
- Practices that improve soil quality.
- Although organic agriculture does not invariably lead to quality food there are specific cases where this is so and where the causal basis is understood sufficiently that the lessons learned can be applied in other production systems[163].
- Measuring the relative greenhouse gas emissions of organic and conventional agriculture is complex and affected by the metric used (for example, emissions per acre versus emissions per kg of food, the time scale employed, and whether changes in land use caused by changing production strategies are included); again there is no evidence that organic agriculture invariably has lower emissions but some organic practices certainly do (for example the use of legumes to supply nitrogen inputs to pastoral-based livestock production) and could be applied more widely in other production systems[164].
- Increasing on-farm biodiversity.

Organic agriculture also provides a model for the public engagement and recognition of production systems that address sustainability and equitability.

Organic agriculture as the single solution to food security. Advocates of organic production systems have suggested that it represents a complete system for achieving sustainable food production. Organic agriculture is a single system with high brand recognition that explicitly aims to address many of the sustainability and equitability goals highlighted in this Report. However, production costs are higher and yields from organic agriculture in high-income countries are typically lower than those from other production systems[165] (implying that significantly more land will be needed to produce the same amount of food as conventional agriculture). Scenarios suggest organic production systems can satisfy expected future global food demand but would require major changes in consumer diets[166] which may be unachievable.

Conclusion. The Report concludes that organic agriculture as currently codified should not be adopted as the main strategy to achieve sustainable and equitable global food security. The challenges as outlined here are so great that a flexible response involving all possible options based on the rigorous use of evidence is essential. The universal adoption of organic agriculture would close off too many important approaches, though the wider application of specific practices will make a significant contribution to integrated and sustainable approaches to food production.

162 See also Lampkin (2010)
163 Lampkin (2010); Dangour et al. (2009)
164 Audsley et al. (2010); Pimentel and Pimentel (2003)
165 Lampkin (2010)
166 The Soil Association (2010)

In determining where and how much to invest in producing more food, policy makers will need to consider a range of criteria, rather than increases in production alone. These criteria will need to acknowledge the existence of both positive and negative externalities associated with different forms of food production, and, as Chapter 6 describes, the particular needs of poor rural communities whose livelihoods depend very largely on food production. The development of better metrics and a new more embracing set of standards for sustainable food production that incorporates best practice from all types of production systems should be a priority.

Four classes of intervention aimed at raising productivity using existing knowledge, which apply both to agricultural and fisheries production, are considered below. These relate mostly to middle- and low-income countries because it is here that policy interventions are likely to have greatest influence in bridging the yield gap sustainably. However, it should be stressed that in a changing world, new science and knowledge are likely to be needed merely to maintain, let alone increase yields, for example, in the face of new pests and diseases[167] and the increasing likelihood of extreme climatic events – these issues are covered in Section 4.3.

4.2.1 Extension services

The revitalisation of extension services to increase the skills and knowledge base of food producers (often women) is critical to achieving sustainable increases in productivity in both low-income and high-income countries[168]. Recent experience with models for extension, which make use of new forms of social infrastructure, should be applied to increase producers' knowledge about best practice, and expand the social capital within and between institutions and communities in the food supply chain.

- Traditional extension services in agriculture and fisheries have generally been publicly-funded, but good models also exist of mixed public, private and charitably-funded services in both high- and low-income countries.
- Where social capital provides good linking and bonding between different organisations and between farmers, then food production systems tend to be more innovative and adaptive. The participation of farmers and fishers in technology development and participatory extension is known to be effective; new approaches such as Farmer Field Schools, cooperatives, business groups, micro-credit groups and catchment groups improve links between researchers, extension workers and farmers.
- Whereas traditional extension services were chiefly concerned with production, a revitalised service should have as a priority, support for producers to enable them to improve sustainability alongside yield. The generation of public goods and innovative farm systems is an argument for government contributions to the funding of extension services.
- The skill set required by producers is expanding, from traditional agronomy, husbandry and related subjects, to include an understanding of the environmental impact of agricultural and fisheries production and their place within the wider market economy. Much more could be achieved through promoting peer-to-peer advice between producers and along supply and value chains, facilitated by extension services.
- Access to modern information communication technology (ICT) in rural communities offers substantial potential for the dissemination of knowledge and good practice. Most producers live in a world of imperfect information, and are subject to considerable uncertainty with regard to weather conditions, pest attacks, and market options; some of these could be mitigated by better access to ICT.
- The notion of 'farming as a business' has become a more widespread theme in the national agricultural strategies of several African countries including Uganda and Ethiopia, and has been shown to increase rural incomes where farmers are sufficiently organised to be able to capitalise on new commercial opportunities[169]. This also has application in improving value from fisheries and extending aquaculture.

167 See section 4.3
168 Pretty (2003)
169 SR16B (Annex E refers)

Box 4.2 The role of women in agricultural production

In trying to improve the knowledge and skills base of low-income agricultural producers, recognition that women often constitute the majority of the labour force in many countries is essential. With significant male out-migration, farming has become a female activity in many areas. Women also take responsibility for household nutrition and involve their children in acquiring skills and sharing work. They often have a role in marketing, adding important value to production. Research, extension and other services need to listen to and learn from women's priorities, special knowledge and insights, and avoid gender biases. Women may have difficulties accessing such services if it requires time away from the family, or if there are cultural prohibitions about seeking advice, particularly from men outside the family. Investment in improving human capital needs to consider these realities.

4.2.2 Improving the functioning of markets and providing market access, particularly in low-income countries

- In many low-income countries food markets function poorly or only very locally. Business and financial reform designed to facilitate entrepreneurship in the food production sector can increase food production, household revenue, livelihood diversification and the strength of rural economies.
- Individual producers, particularly smallholders, often require access to a range of financial services to enable them to save, borrow, and insure. Access to capital enables them to invest in new and better farming or fishing methods, diversify into new activities such as aquaculture or specialist crops, and access markets. Excellent microfinance initiatives exist in some countries and continue to evolve; best practice could and should be spread much more widely.
- Producers must learn how to link to markets, identify market niches and consumer requirements, and work together (e.g. through cooperatives) to navigate the complexities of national and international regulations involving food safety, food quality and environmental sustainability. Extension services, farmer field schools and other initiatives have a critical role in promoting social learning, and should be encouraged. All need to pay particular attention to the need to offer gender-appropriate support.

Issues of access to international markets, and whether low-income countries should be allowed temporary protection from imports, are discussed in Section 4.5.

4.2.3 Natural resource and land rights

Uncertain rights to land and natural resources, such as water, fisheries and forests are a major disincentive to investment in food production in many low-income countries. Strengthening these rights at individual local producer and collective levels should be a high priority, building on customary rights.

- Reforms to land tenure in China have given farmers far stronger rights over their land and have been a major factor in this country's very substantial increase in agricultural production[170]. In Africa, the Ethiopian Government, amongst others, has similarly introduced changes to land tenure to strengthen land users' rights and, thereby, provide greater encouragement for investment in building terraces and reducing erosion[171].
- In Asia and Africa, community co-management of fisheries, the establishment of community rights, and links with NGOs and agencies in the public sector have been successful in reducing over-fishing, allocating access amongst fishers, creating refuges for brood fish and young stock, rebuilding production, adding value to catches, and opening up other livelihood options[172].
- In India and Nepal, joint forest management programmes that have allocated rights to forest products to local groups have been highly effective in increasing both biodiversity of forests and off-take of some products: some 100,000 groups have been formed in both countries.

170 Bruce and Li (2009)
171 Deininger (2006); Kanji (2006)
172 DR14, DR15 (Annex E refers); SR3, SR9 (Annex E refers)

4.2.4 Infrastructure

Physical infrastructure must be improved in middle- and low-income countries to facilitate access to markets and investment in rural economies.

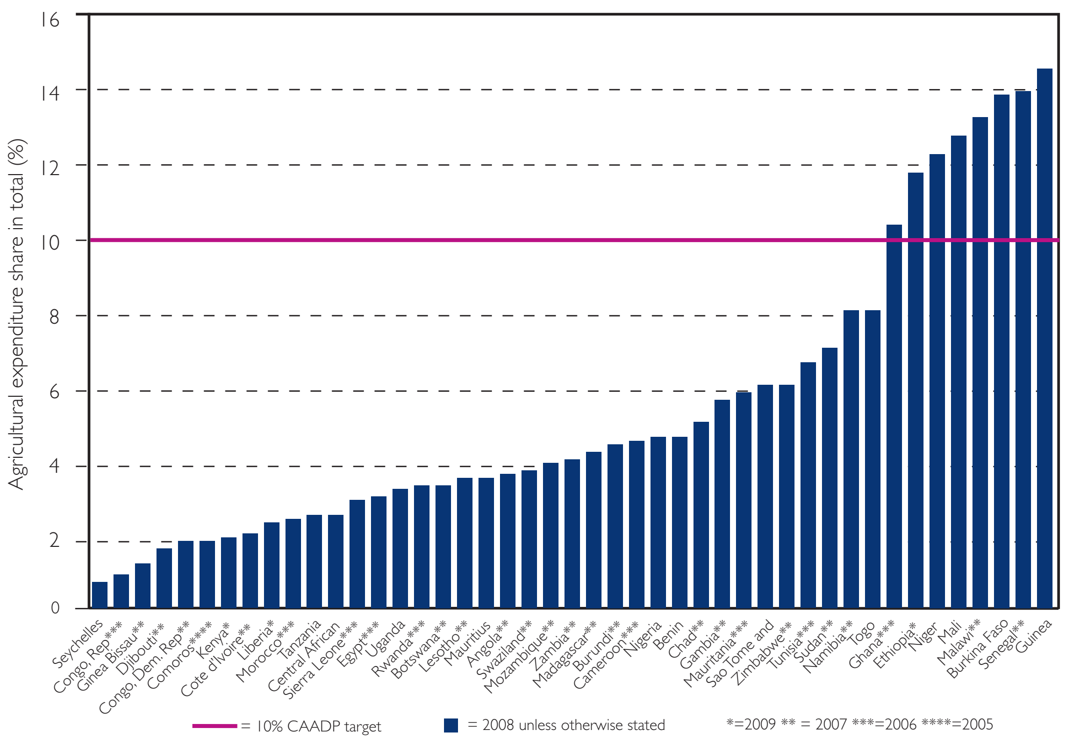
- Such infrastructure includes roads, ports, irrigation projects, storage facilities and ICT systems. The establishment of development corridors linked to major ports can be a very effective way of stimulating local economies For example, in much of Africa, there have been low levels of investment in small- and large-scale irrigation, as well as road and rail infrastructure. This means that for landlocked countries in particular, transport costs can be as high as 77% of the value of their exports. Farm production in central Russia faces similar difficulties given the enormous distances and poor state of railway freight systems. Investment in infrastructure has long been a major component of aid to low-income countries, opening up great improvements in the cost and speed of transport between rural and urban areas. For perishable higher-value products such as fish and fruit, access to urban or export markets can transform local opportunities, but requires adequate facilities for storage and refrigeration, and efficient supply chain management.
- More generally, some governments (e.g. China) aspire to bridge the yield gap by strengthening the agricultural sector, including restructuring the agricultural market, promoting agricultural infrastructure, raising rural incomes, and alleviating poverty through development. This is achieved by increasing central funding for rural areas, increasing subsidies, improving services for agriculture, and stabilising land contract relationships. In addition, the role of science and technology is promoted through increased central government funding to accelerate the programme for scientific and technological development, encouragement of enterprises to work with universities, strengthening the equipment supply industry, and promoting science education, and intellectual property (see Box 4.3). In the case of China, along with policy reform and infrastructure development, agricultural technology is considered to be a key factor in China's success in providing food security for 20% of the global population and lifting its people out of poverty, with less than 9% of the global population. The evidence to date from other countries presents mixed experience from such investment, with much depending on the government framework for support to the agriculture sector, the distribution of returns between investor and government, and the extent to which local people, including women, retain rights over their land, and gain access to employment and any yield-enhancing technologies[173].

173 Cotula and Vermeulen (2010)

Box 4.3 The importance of investment by government

The yield gap can be bridged by sound investment by governments in a range of support measures. After many years in which agricultural expenditure had been falling and farmers had been heavily taxed, in 2003 members of the African Union (AU) through the Comprehensive Africa Agricultural Development Programme (CAADP) pledged to devote 10% of national budgets to agricultural development. Progress to date has been mixed, as can be seen in Figure 4.4. but African governments have shown a far greater level of interest in making agriculture a political priority, and reconfirmed their adherence to this target at Ouagadougou in July 2010.

Figure 4.4: Agricultural expenditure as a share of total spending against the CAADP 10% target



Source: Fan et al. (ReSAKSS 2009)

4.3 New science and technology to raise the limits of sustainable production and address new threats[174]

Investment in research and development is critical to:

- Producing more food.
- Increasing efficiency of food production and sustainability.
- Securing ecosystem services.
- Keeping pace with evolving threats (for example, the emergence of new and more virulent pests and diseases).
- Addressing new challenges (for example, the development of new varieties of crops that are resistant to increased drought, flooding and salinity arising from climate change).
- Meeting the particular needs of the world's poorest communities.

174 See Project Report C6 (Annex E refers) for a more comprehensive discussion of how new science and technology can benefit the food system. See also the Science Reviews SR1–SR55 (Annex E refers).

Box 4.4 Brazil and China: demonstrating the effect of research on agricultural productivity

Recent growth in agricultural productivity in Brazil and China has been built in particular on a significant and expanding domestic research base. This is in contrast to many other countries, where the priority given to agricultural research has tended to decline in recent decades.

The Brazilian agency EMBRAPA (Empresa Brasileira de Pesquisa Agropecuária), for example, has become one of the world's biggest funders of agricultural research and development, with a budget of nearly R$2billion in 2009[175] (roughly US$1.11 billion)[176]. Productivity growth in recent decades has allowed Brazil to become one of the world's largest agricultural exporters.

China's spending on agricultural R&D increased by about 10% per year between 2001 and 2007, reaching RMB12.3 billion in 2007 (around US$1.78 billion)[177]. This investment is already reaping benefits – it has been estimated that every RMB10,000 (US$1,500) of investment in agricultural R&D helps seven people move out of poverty[178]. The Project's detailed case study of China (R2)[179] indicates that the influence of Chinese agricultural research is likely to become more widespread, especially if, as expected, South-South contacts continue to grow in importance.

Looking across the entirety of the work commissioned by the Project[180], the following strategic conclusions on research and development can be drawn:

- **There is a strong case for reversal of the low priority accorded to research on agriculture, fisheries and the food system in most countries. A study of the impact of agricultural research in developed and developing countries indicated economic rates of return of around 40%**[181]. Another independent study concluded that the annual value of benefits from improved yield stability in maize as a result of research investment by the Consultative Group on International Agricultural Research (CGIAR) is estimated at US$149 million, and for wheat is US$143 million, with rates of return to research investment of at least two to one across the CGIAR system[182].
- **Recent scientific and technological advances offer significant new opportunities to address major environmental challenges such as climate changes, water scarcity, and soil degradation.** Major developments in the life sciences, in chemistry and in engineering offer significant new opportunities for rapid progress on multiple fronts, though they also require multidisciplinary approaches and a breaking down of many traditional barriers[183]. Research is also required simply to protect the food system from emerging threats such as new pests and diseases, and climatic events (flooding, drought etc).
- **Research on climate change adaptation and mitigation in the food system is a priority**. Agriculture and food production will need to adapt to a changing world with a higher likelihood of extreme and volatile weather events. For example, the water for irrigation used extensively by India and Pakistan may decrease at the same time as supplies of groundwater are diminishing. The sector must also contribute to a major reduction in global greenhouse gas emissions. Knowledge about how this can be achieved needs to be linked to diversified objectives for production, in an accessible and gender-appropriate form for producers and others, particularly in more vulnerable areas.

175 Expressed in Brazilian real of July 2010. Source: communication with EMBRAPA

176 Note that due to historically large currency fluctuations between the Brazilian real and the US dollar, a dollar comparison is illustrative only. This rate was converted at the interbank rate quoted by www.oanda.com for 15 July 2010 based on figures provided by EMBRAPA of R$1,953,585,000/

177 R2 (Annex E refers). Conversion at interbank rates of 15 June 2007 at www.oanda.com

178 R2 (Annex E refers)

179 Annex E refers

180 Annex E refers

181 Alston et al. (2000)

182 Estimates of the benefits from CGIAR research since 1989 range from nearly US$14 billion to more than US$120 billion. Even under the most conservative assumptions, they far outweigh total research expenditures of US$7.1 billion since 1960 (expressed in 1990 dollars) CGIAR (2009). See http://www.cgiar.org/pdf/pub_cg_corp_folder_inserts_IMPACT_10_09.pdf

183 A recent report to the UK All-Party Parliamentary Group on Science and Technology in Agriculture has laid emphasis on the need to partition more of the available resources to support applied research focused on specific challenges for producers in achieving sustainable intensification, Leaver (2010).

- **Investment in food production research needs to focus on raising yields in conjunction with improving sustainability and maintaining ecosystem services.** This shift must recognise that special measures will often be needed to incentivise research that produces public goods to link with more market-oriented objectives. Existing structures of research groups and organisations may need to be redesigned to achieve the integrated, cross-sectoral and cross-disciplinary work required.

Box 4.5 Advancing wheat research via a public-private partnership approach

Wheat is the most internationally-traded food crop and the single largest food import in low-income countries. A public-private partnership between Syngenta and the International Maize and Wheat Improvement Center (CIMMYT) will focus on the development and advancement of technology in wheat through joint research and development in the areas of native and GM traits, hybrid wheat and the combination of seeds and crop protection to accelerate plant yield performance.

The partnership will leverage both Syngenta's genetic marker technology, advanced genetic traits platform and wheat-breeding for the high-income countries, as well as CIMMYT's access to wheat genetic diversity, global partnership network, and wheat-breeding programme targeted to the low-income countries[184].

- **A pluralistic research portfolio is essential.** Views on the way that food production is carried out have become more polarised over the past decade. This is particularly the case for some forms of modern technology, such as cloning and genetic modification. However, evidence from a wide range of studies indicates that no single approach is capable of delivering sustainable, resilient high levels of productivity, and value. A broad perspective that encompasses the whole food system is needed and a careful blend of approaches will therefore be required. This should include biotechnology, but also areas of science such as agronomy and agroecology that have received less recent investment. Research in the social sciences is also essential to understand how best existing and new knowledge can be implemented by food producers.
- **New ways are required to incentivise research and development that meets the needs of low-income countries.** As noted earlier, a significant increase in food production in low-income countries could be attained by applying existing skills and knowledge. The needs for research on the food production constraints confronting lower-income countries are also likely to increase, particularly in the area of climate change[185] and the greater pressure on resources arising from population growth. However, public sector funds may be limited, the lag time between R&D investment and potential use/'commercialisation' too long, and market returns on investment too low to attract R&D expenditure from the private sector. High-level political commitment, strategic investment, plus better coordination of research funding across public, private and third-sector agents will be critical to achieve these goals. Better civil society and end user engagement will also be critical to delivering outcomes that address the real challenges of food security and tackling hunger (see Chapter 6). It is clearly important to ensure that low-income countries can have appropriate access to new technologies such as GM to enhance traits (such as drought and heat tolerance, and also pest resistance), by encouraging more public/private Partnerships (see Box 4.6) to support capacity-building initiatives to help manage these technologies and build research, regulatory and policy capacity. For example, Product Development Partnerships (PDP) knit together partners from academia, industry, the public sector and international agencies into long term partnerships, building trust and leveraging each partner's strengths towards a common goal. Each PDP is focused on a specific technological goal, for example, the development of drought-tolerant wheat varieties for low-income countries. Evidence emerging from the health sector, where PDPs have been established to develop new health technologies for neglected diseases, suggests that these partnerships result in quicker, less costly development of the technologies, with superior public health benefits relative to existing technologies. They also improve the overall enabling environment for other actors to do the same[186].

184 Syngenta (2010), see http://www.syngenta.com/global/corporate/en/news-center/news-releases/Pages/en-100406.aspx
185 DR2 (Annex E refers)
186 Grace (2010)

Box 4.6 Water Efficient Maize for Africa (WEMA)

Maize is the most widely grown staple crop in Africa – more than 300 million Africans depend on maize as their main food source – and it is severely affected by drought.

The African Agricultural Technology Fund (AATF) is leading a five-year (2008 –13) public-private partnership to develop drought-tolerant African maize using conventional breeding, marker-assisted breeding, and biotechnology. Funding partners are the Bill and Melinda Gates Foundation and the Howard G. Buffett Foundation.

The International Maize and Wheat Improvement Center (CIMMYT) will provide high-yielding maize varieties that are adapted to African conditions and expertise in conventional breeding and testing for drought tolerance. Monsanto will provide proprietary germplasm, advanced breeding tools and expertise, and drought-tolerance transgenes developed in collaboration with BASF.

The varieties developed through the project will be distributed to African seed companies through AATF without royalty and made available to smallholder farmers. The national agricultural research systems, farmers' groups, and seed companies participating in the project will contribute their expertise in field testing, seed multiplication, and distribution. The benefits and safety of the maize varieties will be assessed by national authorities according to the regulatory requirements in the partner countries: Kenya, Mozambique, South Africa, Tanzania and Uganda[187].

- **Where incentives do not currently exist for investment in research that provides public goods, new models of delivery are needed to mobilise the considerable strengths of private sector research and scientific entrepreneurship.** Where new science can offer benefits for which there may not be an easily definable market, new models of delivery need to be established. There are now excellent examples of public and private sector funders coming together to deliver new and appropriate technologies, especially to benefit the very poor, which can be accessed more economically. Advance Market Commitments (AMCs) are a new initiative designed to spur vaccine innovation for developing country use. Donors provide money to guarantee a predetermined price for a specific vaccine once it has been developed, assuring companies that a market will exist for that vaccine. In exchange for the guaranteed market, companies make binding commitments to provide the vaccine at a lower price once the donor funds have been depleted, ensuring long-term country access. Before the programme is launched for a particular disease, an independent advisory group establishes the target product profile (TPP) for eligible vaccines, as well as the price and availability.
- **The contribution of funders to research from the public, private and third-sector organisations needs better coordination.** New partnerships and better coordination and integration are needed between the three sectors engaged in research and development to create and drive the multiple processes required to achieve sustainable productivity. A good example can be found with the Borlaug Global Rust Initiative (see Box 4.7). It is the role of governments along with industry to set long-term goals on reductions in greenhouse gases emissions, water conservation and other environmental challenges based on the best available scientific and other advice. For example, the UK Cross-Government Food Research and Innovation Strategy sets out to provide a framework to facilitate a more coordinated and collaborative approach between those public sector bodies involved in funding, commissioning and delivering research in the UK, linking with the private sector, consumer and other organisations wherever relevant[188]. Public funding is essential to provide the fundamental science and technology base for practical applications, but decisions on how best to deliver value through research outcomes need to involve *inter alia* agribusiness, small producers and NGOs.
- **The preservation of multiple varieties, land races, rare breeds and closely related wild relatives of domesticated species is very important in maintaining a genetic bank of variation that can be used in the selection of novel traits.** Initiatives such as the Millennium Seed Bank (2000) operated by the Royal Botanic Gardens, Kew and the Svalbard Global Seed Vault (2008) which preserve the seeds of wild and cultivated species respectively, as well as living collections of plant, animal and micro-organism varieties, are critical to protecting this heritage. Novel sources of genetic resistance are even

187 See http://www.aatf-africa.org/wema
188 Government Office for Science (2010)

being discovered in modern commercial cultivars of well-characterised crops and there is now an increasing focus on producing Diversity Fixed Foundation Sets (DFFS) based on core collections that systematically sample the relevant gene pool.

Box 4.7 Initiatives addressing wheat stem rust

The Borlaug Global Rust Initiative was established by CIMMYT, ICARDA, FAO, USDA-ARS and Cornell University as an outcome of the May 2005 assessment of race Ug99 of wheat stem rust in Kenya and Ethiopia and the potential for impact in neighbouring regions and beyond. It aims to consider the feasibility of rendering wheat as a non-host to stem rust by exploiting recent advances in functional and comparative genomics, and is driven by the fact that rice is immune to rust. It serves as an overarching umbrella through which rational, integrated, and appropriately funded global rust research can be achieved, by bringing together academic institutions, governments, donor agencies, private sector organisations, and associations that are active in wheat rust or supporting research in wheat rust through events supported by a website resource.

The Durable Rust Resistance in Wheat Project, with funding from the Bill and Melinda Gates Foundation, is a collaborative effort initiated in April 2008 by 17 research institutions around the world and led by Cornell University. It seeks to mitigate the Ug99 threat through coordinated activities that will replace susceptible varieties with durably-resistant varieties, created by accelerated multilateral plant breeding and delivered through optimised developing country seed sectors. It recognises the potential and essential need for immediate impact through expanded investments in the scale and coordination of the applied, conventional breeding and seed sector efforts as promoted by the Borlaug Global Rust Initiative. The project also aims to harness recent advances in genomics to introduce non-host resistance (immunity) into wheat[189].

- Investment in research and development is not enough in itself. Communication is critical – not just to spread new knowledge to policy-makers and potential users, but also to the public, specifically to engender trust in the new science and its application. There is a clear need to ensure that the benefits and dangers of new developments are articulated in an open and transparent way so that public trust is promoted and an inclusive and informed debate on new advances can be achieved. The history of international development is littered with examples of inappropriate models of technological diffusion. Where new scientific or technological interventions are proposed to support the development of agriculture and food supply chains in low-income countries, it is critically important that potential beneficiaries are involved in decisions from the outset – new technology cannot simply be introduced without regard to the existing social and political structures of the likely users.

The Project commissioned approximately 40 reviews of the state of the art in diverse areas of the natural and social sciences from leading experts across the world[190]. They cover, for example, crop management, agroecology and agronomy, organic and inorganic chemistry, engineering and biotechnology, as well as social sciences. Many of these reviews also discuss research advances that could occur over the next 10–20 years. They are written in a way that makes them accessible to experts in other fields.

Based on the 40 science reviews commissioned by the project and on other recent work, in particular, The Royal Society's report *Reaping the Benefits,* which explores in more detail research challenges in crop production, Project Report C6[191] summarises some of the most promising areas of new science that can contribute to sustainable intensification. For example:

- Development of new varieties or breeds of crops, livestock and aquatic organisms capitalising on recent advances in the biosciences. Modern genetics offers new ways to select for desirable traits (for example, marker-assisted selection) that are far more efficient than traditional breeding. They make use of information about an organism's genome but are not restricted to species whose complete genome is known, offering the prospect of the improvement of relatively neglected species. These new techniques, which make use of low-cost DNA sequencing technologies, facilitate the enhancement of multiple traits, offering the prospect of selecting for improved productivity, resilience and sustainability

189 See http://www.globalrust.org

190 All project papers are being made freely availably through www.bis.gov.uk/foresight – see also Annex E.

191 Annex E refers

at the same time. Much can be done using well-established techniques about which there is little controversy. Yet some advances would also require, or could be done faster or more efficiently, using genetic modification or techniques such as animal cloning.

- Advances in nutrition and related sciences offer substantial prospects for improving the efficiency and sustainability of animal production (both livestock and aquaculture). For example, improving grass quality through traditional breeding or manipulating the bacterial flora of ruminant digestive systems can increase productivity and reduce the release of methane, a powerful greenhouse gas. Novel crops can be bred to act as feed for aquaculture that both increases the nutritional quality of the fish and reduces reliance on fish meal or oil, thereby reducing impacts on valuable marine resources.
- Scientific and technological advances in soil science, relatively neglected in recent years, offer the prospect for a better understanding of constraints to crop production and better management of soils to preserve their ecosystem functions, improve and stabilise output, reduce pollutant run-off and cut greenhouse gas emissions.
- Substantial increases in productivity and sustainability can be achieved by targeted research in modern crop, animal and aquaculture management, often known as agroecology. Research into better management is as significant as that into plant and animal genetics, and can be applied at all levels of scale and intensification. The long-established disciplines of agronomy, soil science and animal husbandry need revitalising and expanding to address the integration of sustainability into agricultural systems much more explicitly.

Project Report C6[192] considers other more revolutionary advances, such as the development of perennial grain crops, the introduction of nitrogen fixation into non-legume crops, and re-engineering the photosynthetic pathways of different plants. These are important areas for study, though are unlikely to contribute significantly to raising agricultural productivity until at least the latter end of the 40-year period considered by the Report. In parallel with the development of the science, it is critical to consider how such advances would be commercially sustainable and hence could be deployed at large scale.

It should also be stressed that research is required to maintain productivity at current levels because weeds, pests, diseases and pathogens continually evolve. Intensification increases the opportunity for diseases to spread, and globalisation heightens the risk that these agents are transported around the world. Recent scientific advances (for example, in entomology, disease resistance, immunology and vaccine development) offer great potential to develop new ways to protect food production[193].

192 Annex E refers
193 SR4 (Annex E refers)

Box 4.8 The Top 100 questions of importance to the future of global agriculture

The Project commissioned an exercise on horizon scanning to identify the 100 most important questions for global agriculture[194]. The aim was to improve understanding between agricultural research and policy, and to guide policy-makers in the future direction of priorities for agricultural research.

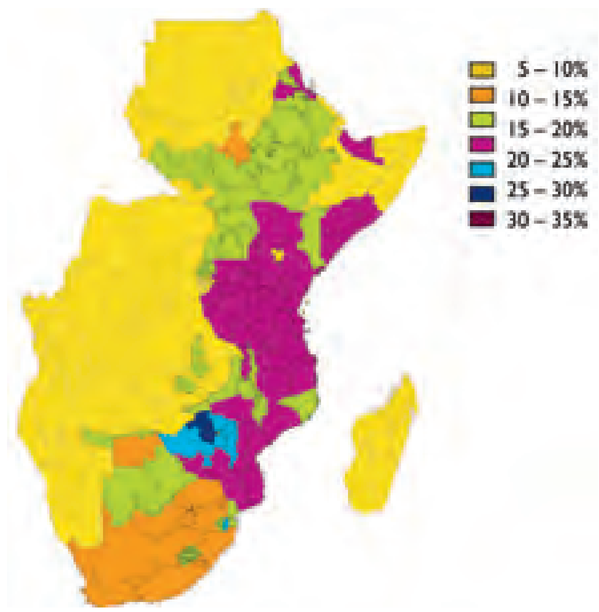
With support from the FAO, the questions were compiled in consultation with senior representatives and experts from the world's major agricultural organisations, professional scientific societies, and academic institutions worldwide. They covered natural resource inputs (agronomic practices, agricultural development, and markets and consumption) from work in 23 countries within universities, UN agencies, CG research institutes, NGOs, private companies, foundations and regional research secretariats, and covered natural resource inputs, agronomic practices, agricultural development, and markets and consumption. These questions are designed to help researchers and practitioners agree on future research agendas. Example questions include:

- How much can agricultural education, extension, farmer mobilisation and empowerment be improved by the new opportunities afforded by mobile phone and web-based technologies?
- What steps need to be taken to encourage young people to study agricultural science?
- What practical measures are needed to lower the ideological barriers between organic and GM, and thus fully exploit the combined potential of both GM crops and organic modes of production in order to achieve sustainable intensification of food production?
- What part can reclamation, restoration and rehabilitation of degraded land play in increasing global food production?

4.4 Reducing waste[195]

Food waste is defined here as edible material intended for human consumption that is discarded, lost, degraded or consumed by pests as food travels from harvest to consumer, or, as some put it, 'from field to fork'[196]. This definition includes food that is fit for human consumption but intentionally used as animal feed[197 198 199], and it spans the entire food supply chain. While such a broad definition is appropriate, it creates problems in gathering accurate estimates of the *total* global food waste. This is because it is difficult to obtain accurate estimates of all its components. For example, food waste can occur at every stage from the grower's field, or pond, market yard or fishing net through to post-harvest handling, processors, transporters, retail or catering outlets to storage, preparation and consumption at home. The capture and discard of fish stocks

Figure 4.5: Post-harvest loss in maize in 2007 in parts of Africa



Source: Post-harvest Loss Information System http://www.phlosses.net

194 Pretty et al. (2010); WP6 (Annex E refers)
195 See the Project Report C7 (Annex E refers) for a more detailed discussion of waste, and also DR20 (Annex E refers).
196 FAO (1981)
197 Food 'waste' used for other purposes such as feeding animals, producing compost or for bio-energy is not completely wasted. Nevertheless, it is referred to here as waste as the benefits are relatively small compared with the value of the original food product.
198 Stuart (2009)
199 A broader definition of food waste also encompasses food eaten by humans beyond their biological need. This is difficult to measure, and therefore not considered here.

that are not intended for consumption and therefore not landed also need to be considered – a loss that is not normally included in post-harvest accounting of food waste.

While global estimates of waste are reliant so far on a weak evidence base, there is little doubt that the scale is substantial. It has been estimated that as much as 30% of all food grown worldwide may be lost or wasted before and after it reaches the consumer. Some estimates have placed it as high as 50%[200].

In middle- and low-income countries, where infrastructure for storage and supply is often inadequate, losses are greatest in post-harvest storage and the food supply chain. Figure 4.5 illustrates post-harvest losses for maize in parts of Africa, where losses over a substantial area are between 10–20%, and sometimes as much as 30% or more. Growing urbanisation lengthens the food supply chain and in countries with poor infrastructure may lead to an increase in the volume of waste generated[201].

Box 4.9 Post-harvest losses – background and diverse estimates

The quality of preparation, storage and transport infrastructure is the primary cause of losses in the early stages of the food supply chain. These losses are partly a function of the technology available in a country, as well as the extent to which markets have developed for agricultural produce. The development of post-harvest infrastructure closely reflects how urbanised a country is and how diverse are the diets of its citizens. In many low-income countries, most of the rural poor rely on short food supply chains with limited post-harvest infrastructure and technologies, leading to substantial losses of food after harvest. Grain is lost from spillage, poor separation and drying, contamination and consumption by rodents, insects and fungal and bacterial diseases. If stored long enough under poor conditions it may become inedible, even though grain is normally regarded as non-perishable[202]. Interventions within these systems are focused on improving technical capacity to reduce losses, increasing efficiency, and reducing labour intensity of the technologies used[203]. Attempts to reduce post-harvest losses will need to take account of cultural and financial implications of any innovations in post-harvest technologies.

Grain losses vary considerably among Asian, African and South American countries. They typically range from 10–25%[204]; 13–15% is quoted as the Asian average[205]. A particularly troublesome issue is that unfavourable seasonal conditions resulting in low yields and product quality may be followed by poor temperature and humidity conditions for storage.

The losses for perishable crops, especially fresh fruit and vegetables in low-income countries, are even higher than those for grains[206]. Estimates for Egypt[207], Venezuela[208] and a number of Asian countries[209] are typically in the range of 30–40%.

Much less data are available for wastage in the food service sector, though in countries where eating out is becoming more common, this form of waste is likely to be increasing. Estimates suggest that 20–30% of food is wasted in schools in the USA[210], and 20% in food service institutions in Sweden[211]. Cultural factors such as displaying wealth by leaving food uneaten, or only eating specific parts of banquet food, will also influence results.

As incomes rise relative to food prices, there are fewer incentives to avoid wasting food, and rising wealth brings increased consumption of food with a shorter shelf life. Future income growth, particularly

200 Lundqvist et al. (2008)
201 For a fuller discussion of losses arising from post-harvest waste in low- and middle-income countries, see Synthesis Report C7
202 DR20 (Annex E refers)
203 DR20 (Annex E refers)
204 DR20 (Annex E refers)
205 Grolleaud (2002)
206 DR20 (Annex E refers)
207 Blond (1984)
208 Guerra et al. (1998)
209 Rolle (2006)
210 Getlinger et al. (1996)
211 Engstrom and Carlsson-Kanyama (2004)

in the emerging economies, is likely to increase consumer and food service industry waste, although losses from waste earlier in the food chain from harvest to market may diminish.

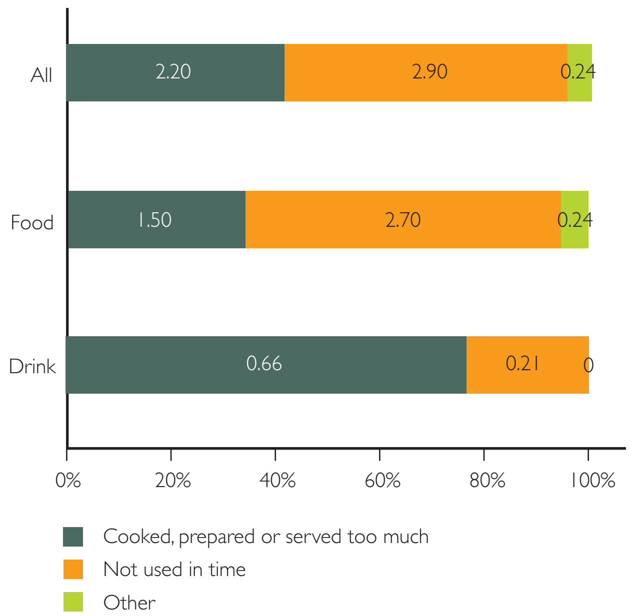
In high-income countries, the greatest losses are incurred by the food services industry and the consumer. In the UK, for example, by 2008 as much as 25% of purchased food was found to be wasted in the home[212]. In other high-income countries, the scale of food waste in the home has been found to be similar, ranging from 15–25% in, for example, the USA[213 214] and Australia[215]. Difficulties of measurement suggest that the scale of consumer food waste in high-income countries is probably underestimated.

A small number of in-depth studies in the UK, USA and Australia have considered why high-income countries waste so much food in the home. Leaving aside the low cost of food as a primary driver, they highlight a complex array of underlying consumer attitudes, values and behaviours towards food and how varying degrees of food knowledge affect individuals' propensity to waste food. These studies attribute most of the avoidable waste to two factors:

Too much food was prepared and cooked in the home – a growing problem, as the knowledge of how to use leftovers has declined, or food was prepared badly and discarded.

Food was discarded because it had visibly spoiled or smelled or tasted bad, but also because although it appeared palatable, it had passed date marks. While consumers are right to discard food that has passed dates relating to food safety such as 'use by' dates, consumers are also interpreting other date marks such as 'best before' as meaning food is unsafe to eat, rather than the actual meaning, which is to indicate the period during which food is of optimum quality.

Figure 4.6: Weight of food and drink waste generated in the UK, spilt by reason for disposal



Figures within bars state waste in millions of tonnes per year
Source: WRAP (2009)

These studies have suggested that the great majority of household food waste could be avoided (see Figure 4.6). For example, a family in a high-income country such as the UK could save around £680 a year by managing its food better[216].

Addressing waste across the entire food chain will be critical in any strategy to feed nine billion people sustainably and equitably by 2050. Making the food chain more efficient will reduce pressure on resources required for food production, lower greenhouse gas emissions, and contribute to other policy agendas, such as cutting the need for further space set aside for landfill, which in turn would reduce GHG emissions.

Halving the total amount of food waste by 2050 is considered to be a realistic target, in view of the evidence collected by this Project. If the current global figure of 30% waste is assumed, this would reduce the food required by 2050 by an amount approximately equal to 25% of today's

212 WRAP (2009)
213 Griffin et al. (2009)
214 Lundqvist et al. (2008)
215 Morgan (2009)
216 WRAP (2009)

production[217]. Making waste reduction a strategic target would benefit strongly from high-level international political support, and from being championed by an international body. This is because many diverse organisations would need to come together to tackle the highly variable levels of waste that occur in the food supply chain in different parts of the world.

Rising food prices should act as an incentive for waste reduction. However, there are a number of areas where the market alone will not achieve what is possible, and where other interventions will be required. The following are considered particularly promising[218]:

Reducing post-harvest waste, chiefly in low-income countries

- **Deployment of existing knowledge and technology in storage and transport infrastructure.** There are many examples of relatively simple and often traditional technologies that can substantially reduce post-harvest waste. One example is an FAO project that provided simple effective sealed storage drums for grain farmers in Afghanistan and elsewhere[219]. Other relatively low-cost interventions that are effective in reduction of food waste include: basic packaging for transport of fresh produce; innovation in low technology storage to reduce grain losses on small farms; and simple cool chain options (for both perishable foods and fish) that are not fuel-intensive[220, 221].
- **Investment in new, appropriate technology to reduce post-harvest waste.** Examples would be the use of modern scientific advances to produce crop varieties that are less susceptible to pests and spoilage, and to develop natural and synthetic insecticides to manage storage pests. In addition, development of simple low-cost technologies such as mini combine harvesters, grain-drying equipment, mechanical rice threshers/winnowers, or better fish-smoking kilns that reduce losses and demand less fuel.
- **Infrastructure, financial and market reforms to reduce waste[222].** The use of information and communication technology (mobile phones in particular) could help improve market information and allow producers to make better decisions about timely supply to markets to achieve best prices, avoiding or at least reducing seasonal gluts and product waste, particularly during months of peak production. Better financial support for smallholder farmers would allow them to store produce rather than sell when prices are at their lowest. Better information about fisheries stocks, fishing activities, surveillance and market prices could improve value, reduce or improve usage of by-catch, and reduce gluts by allowing stocks to be fished more steadily over longer time periods.

Reducing consumer and food service sector waste, chiefly in high-income countries

- **Campaigns to highlight the extent of waste and the financial benefits of reducing it.** Specific programmes aimed at consumers, companies in the food supply chain, and those providing meals in restaurants, firms, hospitals, schools and other institutions[223].
- **The development and use of cheap, mass-produced sensor technology that can detect spoilage in certain perishable foods.** This would allow more sophisticated food management by consumers than reliance on estimated 'best before' dates in retail food labelling, and have the potential to ensure food quality as well as reduce waste. Food quality and freshness is affected by heat, light and oxygen. Employing nanotechnology to detect very small molecules can help in predicting the shelf life and best before date, and be incorporated in smart or 'intelligent' packaging. Medical applications in terms of new devices that measure, for example, *Salmonella* and *Listeria* in food are already being explored.
- **The development of better and appropriate packaging to extend shelf and storage life.** For example, lightweight packaging is not only commercially and environmentally sensible, but it can extend the range of shelf life. Longer shelf life packaging, for example, frozen foods and cans, can give consumers more flexibility and reduce the waste.

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217 This estimate is only intended to be indicative. It assumes that total waste in the food chain is reduced from an estimated 30% down to 15%. It also assumes that without waste reduction, food production would need to increase by around 70% by 2050, as broadly suggested in Chapter 3.

218 See DR20, SR15 and W4 (Annex E refers)

219 FAO (2008)

220 FAO (2003)

221 Kader (2005)

222 For example. the Common Code of the Coffee Community, the Fairtrade scheme and the investments China is making in African and Brazilian farming to ensure their future food needs.

223 Example of SODEXO and Chinese/Brazilian initiatives, see W4 (Annex E refers).

- **Productive recycling of surplus food deemed as non-premium quality, either through redistribution of good-quality surplus food to consumers via schemes such as Fareshare in the UK[224], or the use of food no longer fit for human consumption as animal feed or a source of energy through processes such as anaerobic digestion.** The former will ensure that food that is perfectly edible is not diverted unnecessarily to waste streams, so reducing consumer demand. The latter means that food that is inedible by man is converted to waste but then converted to animal feed or energy. Waste food used in this way would then make a positive contribution to the global food and energy balance, rather than producing greenhouse gases from landfill.
- **Spreading best practice** For example, a project in the Netherlands involving modest funding shows how waste from in the supply chain from food processing through to the home can be significantly reduced by a combination of education and simple technology[225].

4.5 Improving governance of the food system[226]

The food system operates within the formal set of rules and practices determined by national and international governments, institutions, treaties and agreements. This section considers ways in which these rules and practices could be changed so that affordable food continues to be available to most of the world, the number of hungry people currently failed by the food system is reduced as quickly as possible, and the sustainability of the food system is strengthened. It focuses on the governance[227] of trade and the food supply chain. Other aspects of governance are explored in subsequent chapters, including addressing the needs of very poor people (Chapter 6), adapting to and mitigating climate change (Chapter 7), and preserving ecosystem services (Chapter 8).

4.5.1 National food sovereignty, global trade and the food system

Two competing philosophies on trade, globalisation and food security have dominated discussion of governance of the global food system. The first argues that national food security can best be met by pursuing a policy of self-sufficiency in which a country aims to feed its population from its own resources – a strategy often pursued under the banner of 'food sovereignty'. The second advances the view that more open markets in agricultural commodities help increase resilience and efficiency and hence reduce the risks of shortages and volatility in food prices.

Disruption of the food system by crop failures and volatility of food prices have in both 2008 and 2010 led to the temporary imposition of trade barriers by countries, often in response to internal political pressures. For example, several countries in Asia implemented export restrictions on rice. In early 2008, Vietnam banned commercial sales and India banned export of non-basmati rice.[228]

Such trade barriers have led to the classic contagion of economic disruption, and most likely to the exacerbation of the underlying problem[229]. Trade barriers distort agricultural markets, as measures such as export restrictions in isolation may keep domestic prices down, they interfere with price signalling, muting the supply response and increasing international prices[230].

Protectionist national policy responses to global market volatility can be explained in terms of domestic political pressures or historical experience. **However, such reactions reveal the need for a system of global food and trade governance in which medium- and low-income countries can invest their**

224 FareShare, an independent UK charity, promotes the message that 'No Good Food Should be Wasted'. It provides quality food – surplus 'fit for purpose' product from the food and drink industry – to organisations working with disadvantaged people in the community. In addition, training and education around the essential life skills of safe food preparation and nutrition, and warehouse employability training through FareShare's Eat Well Live Well programme. The redistribution of food by FareShare minimises surplus food going to landfill and in 2009/10 helped businesses reduce CO_2 emissions by 12,600 tonnes. See http://www.fareshare.org.uk/about-us.php

225 W4 (Annex E refers)

226 See Project Report C3 and also WP8 for a more comprehensive discussion of governance in the food system (Annex E refers).

227 While the term governance is open to many different interpretations, it is defined here as the institutionalised social, economic and political processes – the formal and informal rules and procedures – which govern the organisation of the food supply chain and trade – DR6 (Annex E refers). It thus includes consideration of the way that power and authority and particular interests are exercised and formulated in the various rules, institutions and laws associated with the food system.

228 HMG (2010)

229 HMG (2010)

230 HMG (2010)

confidence. Otherwise, each future period of volatility may lead to policy responses that exacerbate global volatility in order to protect ever-stronger national interests.

The possibility of other countries imposing trade barriers at times of shortages in supply is also one of the major arguments for self-sufficiency and a reduction in reliance on global markets, regardless of the inefficiencies and costs of doing so. There are two main and interrelated ways such restrictions can be avoided: first, by actions that reduce food price volatility (see Chapter 5), and secondly, by a coordinated response by the international community.

Greater powers need to be given to international institutions to intervene to prevent trade restrictions at times of crisis. Such interventions should include economic incentives and penalties designed to stop the erection of trade barriers that exacerbate price rises. In the absence of new institutional structures it is likely that the G20 will play a key role in the short term. Even with this coordinated response, humanitarian reserves and mobilisation capacity may need to be strengthened or introduced in vulnerable regions.

Where arguments remain for self-sufficiency they can be addressed within a system of global trade that allows for the pursuit of public goods and sustainability where this does not threaten to distort prices. For example, it has been argued that:

- *Locally grown food is more sustainable because it has reduced transport costs.* This generalisation is misleading. The full 'life cycle' cost of foods needs to be assessed – fruit and vegetables grown locally in heated greenhouses may cause more greenhouse gas emissions than those grown outside in warmer countries and imported. As discussed below and in Chapters 6 and 7, a major though challenging imperative for the governance system is to include the costs of externalities in food prices so that more sustainable production, whether local or more distant, is incentivised.
- *Self-sufficiency supports the nation's farming and rural communities.* Supporting one particular economic sector *per se* is not justifiable. But where there are strong social or environmental grounds for supporting specific communities engaged in food production, interventions should be designed to avoid distorting global food markets. In high-income countries, over the long term, subsidising the most marginal producers is not the best use of scarce economic resources. Subsidies more generally may act as a barrier to new entrants joining the sector in high-income countries (particularly younger entrants with less access to capital), as subsidies tend to capitalise into land values, raising them and making it harder to purchase or rent agricultural land.

Food security is best served by fair and fully functioning markets and not by policies to promote self-sufficiency. Placing trust in the international system does not mean relinquishing a country's sovereignty, rights and responsibilities to provide food for its population.

Production subsidies, trade restrictions and other market interventions used by high-income countries have become of huge significance because of the financial and political powers of the nations involved. This political significance has allowed subsidies and barriers to trade in agricultural markets to assume levels far in excess of those applied in any industrial sector. In the EU, for example, the average of tariffs applied across all agricultural goods is around three times higher than the average across industrial goods[231], but particular key commodities are protected by much higher tariffs (in some cases upwards of 70%).

In high-income countries, food production subsidies and related interventions act as a disincentive to efficient global food production, raise consumer prices in protected countries, and are ultimately harmful to global food security. The current trend to reduce them (for example, in the last decade's reform of the EU Common Agricultural Policy) should be accelerated to encourage the self-sustaining improvements in productivity that are necessary to meet future increase in demand sustainably. In addition to direct interventions, careful international monitoring and sanctions against the use of sanitary, phytosanitary (SPS) and other standards as deliberate or unintentional non-tariff barriers to trade should continue, with further support for poorer producers to meet the growing and confusing array of these requirements. Where there are strong reasons to support rural communities and the

231 WTO/ITC/UNCTAD (2008)

provision of environmental public goods via agriculture, nations should do this in a way that does not distort food prices.

The argument that globalisation and more liberal trade in agricultural commodities will help ensure future adequate supplies at both national and international levels must also be tested against two other guiding principles of sustainability and equitability recognised in this Report. As was noted in Chapter 1 and will be discussed in more detail in Chapters 6 and 7, the food system today is not sustainable because of its negative externalities. These are not included in the cost of food and hence there are relatively few market incentives to reduce them. A danger of globalisation is that countries with the poorest regulations obtain an unfair trade advantage, with corresponding adverse effects on local and global sustainability. Conversely, as direct subsidies and market interventions by high-income countries diminish, there is the danger that sustainability becomes a new battleground for future agricultural protectionism.

Future reform of international institutions such as the World Trade Organization cannot ignore the issues of sustainability and climate change. But there are risks that allowing sustainability to be reflected in trade rules may lead to environmental protectionism. Whether or not trade rules eventually do change, reaching agreement between low-, middle- and high-income countries on baseline standards for sustainability in food production and processing that can be implemented at national scale will be an important first step.

Further liberalisation has complex ramifications for low-income countries, depending on whether they are currently net food producers or food consumers, and on the state of their agricultural, economic and physical infrastructure. Where a country has access to world markets (ports and other transport infrastructure exist) and favourable factors of production (for example, cheap labour) it may be an immediate beneficiary of further multilateral liberalisation. Where these conditions do not exist, or where the country has been a historical beneficiary of 'preferential trade agreements', the effect is more uncertain. As prices in global markets are generally lower, the urban poor usually benefit (but may be the first to suffer from rises in food prices). However, an uncontrolled and rapid influx of imports may also suppress investment in local food production. Indeed, the poorest countries that have failed to establish a productive agricultural sector may find it very hard to catch up with other low-income countries that have capitalised on cheap labour and their natural capital and can now export low-cost food. Export subsidies leading to the dumping of food surpluses by high-income countries (sometimes in the guise of untargeted food aid) is a further problem.

An essential first step towards a more equitable global trading system for poor agricultural producers is the realisation of a *genuinely* pro-development Doha Development Agenda agreement via the negotiations of the World Trade Organization. The principles of special and differential treatment, which allow 'developing countries' and the 'least developed countries' (using WTO terminology) to protect vulnerable sectors where they are essential for rural livelihoods, or more generally to liberalise at a slower and less steep pace, are essential in this regard.

Were there to be a substantial breakdown in world trade negotiations followed by countries adopting the maximum levels of intervention allowed under the Uruguay trade round, there would be a major risk of a recession in the agricultural sector of many middle- and low-income countries. Decreased global production would raise prices and threaten food security, risking a large increase in the numbers of people suffering hunger.

4.5.2 Capture fisheries

The governance of capture fisheries in inland, coastal or open waters faces particular problems[232]. Fishery resources are commonly held as public goods, at national level or by international treaty, but harvesters have insufficient incentives to restrain them from overexploitation. Regulation is complex, monitoring, control and surveillance (MCS) is difficult and expensive to implement, and few authorities have the means or sanctions to control over-fishing. In contrast, technological advances have greatly increased fishing power, and subsidies for fleet replacement and operating costs (particularly fuel) have distorted incentives and returns for fishing activities, often well beyond the point at which potential biological yields

232 DR14 (Annex E refers)

can be maintained, or stocks can reproduce adequately to avoid collapse. The harvesting capacity of the world's fleets greatly exceeds the fish available to be caught and declining catches are greatly reducing financial returns. At the same time, IUU (illegal unregulated and unrecorded) fishing is commonplace, as is the discarding at sea of lower-value catches. **Faced also with challenge of meeting increased demand from higher and wealthier populations, notably from those countries (e.g. in Asia) where fish is traditionally a significant part of diets, and also the potentially immense challenges of the effects of climate change (changing temperatures and ocean acidification) on aquatic ecosystems and fish stocks (changes in fish abundance and distribution), governance of fisheries requires major reform to address poor practice and allow the fishing industry to adapt and better manage fish stocks within a sustainable ecosystem.**

For coastal and inland fisheries in national waters, governments commonly operate a mix of quotas, gear and vessel restrictions, and days at sea limits, although levels are frequently set higher than are recommended by fisheries experts because of political pressures, while some fisheries are effectively unregulated. Fisheries in international waters are managed by a complex network of treaties and organisations where consensus to enact unpopular regulations is even harder to achieve. Few of these mechanisms have worked, and many simply compound the risks of stock failure. A further issue is that of access agreements by foreign fleets for national waters, particularly if local fishing capacity or infrastructure is less developed. These can have important impacts on local fisheries and, if badly structured, can invite corruption and poor governance of exploitation.

More effective options can be built on approaches which link traditional community-shared management of common property with economic arguments of responsible ownership and efficient production. Using longer-term and sometimes tradable allocation of resource rights to individuals or community groups, incentives can be created for reducing effort and building resource value, landing and recording all catches, transparently acquiring and sharing data on resources, improving returns to harvesters, reducing management costs, and increasing economic returns to the resource (resource rents). Adaptive management approaches based on efficient ecosystem-based concepts also need to be adopted, and temporarily or permanently protected areas may be required. As climate change impacts are likely to become a key feature in fisheries, these approaches will become even more critical in maintaining resilience.

Responsible fishing can also be incentivised by pressures from consumers and retailers, international initiatives for controlling illegal fishing and restricting landing locations, and campaigns to sanction non-compliant fleets. Where used, access agreements need to be well designed and implemented, with better science, monitoring control and surveillance, and delivering clear and transparent benefit to national interests. Resource-related, social, technical and political features of fishery systems vary widely, and change in governance will require careful planning and committed institutional capacity building. Commercial fleets with smaller numbers of higher-capacity vessels can more easily be brought into rights-based management with financial incentives, and a range of intermediate measures such as shared sector allocations can be applied within stronger governance systems. Sustaining adequate systems to ensure equity and opportunity for livelihood amongst large numbers of artisanal fishers will require more sensitive approaches.

More broadly, governance approaches in fisheries are strongly connected with those for the food system, in issues such as marketing, government investment, development of new technology, and the critical need to improve sustainability, with many of the same people involved in crop production, animal husbandry and in seasonal fishing. However, although the nutritional, social and economic value of the sector is widely recognised, poor levels of support and commitment at national and multilateral level have compounded the problems of governance and weakened its future potential.

4.5.3 Corporate governance in the global food system

Project Report C3 describes how over the last two to three decades, a relatively small number of companies have come to dominate globally in the global food supply chain. This trend is apparent all along the supply chain, from production (seeds, crop protection etc.) through to commodity wholesalers, manufacturers and retailers. For example, in retail, there are around 10 leading global companies which have become dominant in developed-country markets and which have an increased presence in emerging markets in middle-income countries[233 234].

The growth and concentration of corporate power in the food sector has led to a wide debate over the ways in which transnational corporations (TNCs) exercise power and influence over the global food system[235]; with particular concerns over:

- The power TNCs exercise in both retail markets and in purchase contracts with suppliers[236] (including through the proliferation of public and private standards[237]).
- The allocation of intellectual property (IP) rights to a relatively small number of companies dominating agricultural R&D[238].
- The transparency with which TNCs operate and exercise power within and over national governments and multilateral governance rules and regulations[239].

In response to these concerns it has been argued that:

- TNC consolidation and integration of supply chains has led to a more resilient food system as a whole, providing cheaper, more diverse and more readily available goods to the consumer[240].
- The high costs of research, development and innovation in the food system require very significant resources for investment and thus it is not surprising that only large companies have sufficient economies of scale to create significant levels of IP[241].
- TNCs would be equally criticised if they did not engage with national governments and multilateral institutions in agreeing the rules of food system governance.

Provided there are a sufficient number of major companies in each area and region of the food system so as not to threaten competition, and provided that all organisations adhere to high international standards of corporate governance, it does not seem necessary to limit the concentration of companies[242]. **However, given the above concerns, continuing open and transparent dialogue, and increased collaboration between governments, the private sector and civil society, with commitments to robust standards of action and performance to achieve this, will be essential to achieve future sustainability and equity in the global food supply chain.**

At the workshop Foresight held on Developments in the Global Food Supply Chain it was concluded that there is very considerable scope for the food industry to play a significant role in facilitating greater sustainability. While acknowledging that competitive constraints, pressure for quick returns on investment and fast-changing consumer preferences are often overriding drivers, there was also a recognition of the need to increase resilience to and preparedness for the future challenges being considered by the Project and to anticipate the growing health and environmental concerns that are driving some high-value segments of consumer demand. The workshop explored a number of promising initiatives currently undertaken by companies to improve the sustainability of their own processes within the food supply chain (see, for example, Box 4.10)

Extending best practice in this way has the potential to radically improve sustainability across the food system. To encourage this shift, food industry leaders have called for a 'level playing field' in standardising sustainability best practice[243]. These behavioural shifts will entail government support

233 Fuchs et al. (2009)

234 The EU and the US have led the development of the organised retail sector, but large indigenous retail chains now command a substantial proportion of the retail market in Brazil and China (where in the latter companies are partly state-owned).

235 Clapp and Fuchs (2009)

236 Food Ethics Council (2010)

237 See Section 4.5.4 and Project Report C3 (Annex E refers)

238 Driver Review DR8 (Annex E refers)

239 Clapp and Fuchs (2009)

240 DR10B (Annex E refers)

241 Bigman (2002)

242 Though, as described earlier in this chapter, finding new ways to diversify the creation and use of IP to the benefit of low-income countries is still of prime importance.

243 See W2 (Annex E refers)

for the development of new metrics of sustainability, strong direction setting and a consensus for action amongst diverse actors.

Box 4.10 Embedding sustainability in supply chains – an example

The *Field to Market* initiative run by *The Keystone Alliance for Sustainable Agriculture*[244] is a US-based organisation bringing together producers including large agribusiness, food companies and environmental groups to develop more sustainable food supply chains. The alliance has developed a series of metrics for quantifying the sustainability of agricultural systems. One of the most innovative outcomes of the work so far is a web-based, free, 'fieldprint calculator' which allows producers to input details of their land, productivity and resource use and determine their *fieldprint,* or the ratio of outputs to inputs allowing for externalities such as land and soil use, water and energy, and overall climate output. The fieldprint calculator is a useful tool allowing farmers to benchmark their annual performance against industry averages and helping suppliers to increase their sustainability as part of wider supply-chain initiatives. It is possible that such systems may one day be used to reward more sustainable farming systems in terms of receiving carbon credits and other incentives for sustainable growth.

4.6 Influencing demand[245]

In addition to increasing supply, reducing waste, and improving the efficiency of the global food system by strengthening governance, the balance between supply and demand can also be influenced by measures aimed at influencing demand – changing people's diets. This approach has potential because different foods vary considerably in the resources required for their production. For example, the high feed conversion rate of ruminants means that approximately 7kg of feed grain is consumed for every 1kg of beef produced, or the average 'water footprint'[246] of 1kg of beef has been calculated at 15,000 litres, as compared to 250 litres for 1kg of potatoes[247] [248] . The critical importance of a balanced diet has led to a substantial body of research on achieving dietary change. A number of different levers have been identified in the literature[249]. They include :

- Economic interventions including taxing non-preferred food types.
- 'Choice editing' – regulatory or voluntary actions including purchasing guidelines by retailers and the food service sector to restrict choices by consumers or selectively enhance access to better foods.
- Campaigns to change individual behaviour involving public education, advertising, targeted programmes in schools and workplaces, and the provision of better labelling to enable the public to make more informed decisions.

Evidence from the health sector shows that changing diets is difficult but not impossible. It requires concerted and committed actions, possibly over long timescales. Constraints on modifying consumption include:

- Resistance from consumers: the unwillingness of individuals to forgo favoured food types (which may be influenced by personal, cultural or religious reasons), and their lack of receptivity to advice from government or other agents.
- Resistance from business and producers: changing diets inevitably favours the producers of one food type over another. However, the types of food most likely to be least recommended are those further along the food chain (meat, processed foods) where more value has been added. Larger and more powerful corporate entities and lobby groups are more likely to suffer disproportionate economic impact and this asymmetry is likely to act against change. Advertising by the private sector is designed

244 http://www.keystone.org/spp/environment/sustainability/field-to-market

245 See Project Report C8 for a more comprehensive discussion of issues relating to modifying demand for food (Annex E refers)

246 Hoekstra et al. (2008)

247 Hoekstra and Ashok (2007)

248 The source of water can also be an important consideration. For example, global wheat production in the period 1996–2005 required about 1,088 billion cubic metres of water per year. The major portion of this water (70%) comes from green water, about 19% comes from blue water, and the remaining 11% is grey water. The global average water footprint of wheat per tonne of crop was 1,830 m3/tonne. Mekonnen and Hoekstra (2010).

249 See Project Report WP2 (Annex E refers)

to influence consumer preferences and involves sums of money unlikely to be available to public and third-sector organisations.

- Public good campaigns can sometimes be undermined by commercial interests; for example, the five-a-day message promoting consumption of fruit and vegetables in the UK has been used to promote foodstuffs that do not belong to these categories nor offer the same nutritional benefits.

Dietary change can have multiple benefits on both public health and environmental sustainability, with synergies across different areas of policy. Advocating the consumption of foods that use fewer resources (land, water, fertiliser and other inputs) usually increases sustainability and reduces greenhouse gas emissions[250]. Guidelines on changing diets to achieve health nutrition and sustainability aims include:

- The UK Sustainable Development Commission has identified guidelines for effecting changes to diets that will contribute the most towards sustainability, while encompassing existing guidance on public health nutrition. Recommendations include a reduction in the consumption of highly-processed energy-dense foods that produce more GHG emissions than fruit and vegetables, the latter having a clear health benefit[251].
- Oxfam's '4-a-week' report highlights the need for a change in consumption in the UK to militate against climate change and reduce global hunger. To deliver environmental and social justice Oxfam argues for a change in consumer behaviour to waste less food, reduce the consumption of meat and dairy products, buy fairtrade produce, and buy foods from low-income countries[252].

If policy-makers decide to seek to influence patterns of consumption, there are a number of guiding principles that should be considered

- **Better decisions are made by an informed consumer.** Improving food-literacy and food-craft skills, and promoting better diets at all levels of school education are important. Also, more should be taught about the environmental and ethical aspects of food production and the food chain, although this needs to be based on sound science. Social marketing campaigns can help produce social norms leading to positive food system outcomes.
- **Simple, consistent and trusted information on food is important.** The evidence suggests that simple, qualitative information such as 'traffic lights' are more effective than more complex quantitative information; consumer trust in the organisations responsible for food labelling is also critical[253].

Government fiscal and regulatory intervention ideally requires societal consensus. Tobacco provides several lessons: a consensus can take time to develop; it is important to develop a firm evidence base about the advantages of modifying consumption; a consensus can be developed even in the face of strong industry lobbying; and a combination of strong fiscal and other regulatory interventions can be highly effective.

These principles are invoked in Chapter 6, where changes in diet that might benefit low-income food producers are explored, and in Chapters 7 and 8, when the interaction of the food system with climate change, ecosystem services and biodiversity are discussed.

250 The Food Ethics Council's Food and Fairness Enquiry also reported recently on the role of consumers in ensuring a sustainable supply chain, Food Ethics Council (2010). See Project Report C8 (Annex E refers)

251 UK Sustainable Development Commission (2009)

252 Oxfam (2009). See project report C8 (Annex E refers)for full details of Oxfam's guidance.

253 See Project Report C8 for a further discussion (Annex E refers)

Box 4.11 Policies on meat production and consumption

It has been argued that a reduction in the amount of meat consumed in high- and middle-income countries would have multiple benefits: reducing the demand for grain, leading to lower greenhouse gas emissions, and having a positive effect on health[254]. This is a complex issue and a summary of the evidence is given below.

There are three unequivocally beneficial policy options:

- There is little dispute about the importance of a balanced diet and the role of a moderate intake of livestock products[255]; communicating this to the consumer should be a priority for public health (recognising the power of vested interests in promulgating contrary messages).
- There should be investment in, and incentives for, production systems that maximise efficiency of inputs such as water and energy and minimise the trade-off between the production of animal feed and crops for human consumption.
- Reducing greenhouse gas emissions (and other negative externalities) from livestock production is an important global good; developing regulatory frameworks and incentives, and publicly-funded investment in research and development aimed at reducing emissions and other environmental harm is a priority.

However, policy-makers should recognise that more proactive measures affecting the demand and production of meat may be needed in the future. The triggers for further actions would include: the clear identification of a rising trajectory of global demand for livestock products leading to substantially higher food prices; the failure to reduce the increase in atmospheric concentrations of greenhouse gases to a level that avoids the risk of substantial climate change; and continuing deforestation to provide feed for livestock for global trade. Depending on the observed trends, policy-makers would need first to consider regulatory and fiscal interventions to introduce disincentives for the types of livestock production most responsible for the identified negative outcomes; and secondly, consider the full spectrum of options for demand modification to reduce consumption of the most damaging types of meat in high- and middle-income countries where consumption is highest. To be effective and avoid protectionism would require international cooperation by countries that are major centres of production and consumption of meat.

It has been argued that the triggers for more proactive action to curb the consumption of meat may already be present. The evidence does not fully support this, but continued research and careful monitoring of the global food system and its interaction with the broader economic and climatic systems is needed to help policy-makers make decisions in this difficult area. Policy-makers involved in public health and in particular with tackling the obesity epidemic may also want to take more active steps to reduce the consumption of meats containing saturated fats. This Report does not discuss in detail how public health measures can reduce these health-related problems (see the Foresight report on obesity[256]), but there is potential for positive outcomes for strategies to limit excessive meat consumption on both health and sustainability.

Two final points to note:

- In many low-income countries there are pastoral and other communities where food derived from livestock is nutritionally and culturally critical. Livestock may also be critical in maintaining biodiversity and ecosystem function in certain habitats (for example, in areas where natural grazers are now absent). Such situations call for a more nuanced approach to production and consumption than implied by the general approach identified above.
- Much livestock is maintained on grasslands that are unsuitable for arable crops. Such production systems will, if managed well, sequester and store significant amounts of carbon in their soil (though total carbon storage is normally higher in forests due to woody biomass accumulation)[257]. Policy decisions on consumption modification, land use and greenhouse gas reduction thus need to be made together.

254 For a more detailed discussion about the health-related aspects of eating meat, see Project Report C8 (Annex E refers).

255 Public health messages on nutrition in many high-income countries advise consumers who eat more than 100g per day of red and processed meant to limit consumption to 400g per week.

256 Foresight (2007)

257 Schulze et al. (2009)


Cur P/E Level
Est P/E Level
Price USD

5 Challenge B: Addressing the threat of future volatility in the food system

Chapter 5 analyses how volatility in the global food system could evolve. In so doing, it assesses lessons from past spikes in food prices, and discusses the various factors that could act to increase and decrease it in the future.

Options for influencing volatility and for mitigating its potential impacts on the poor are also discussed.

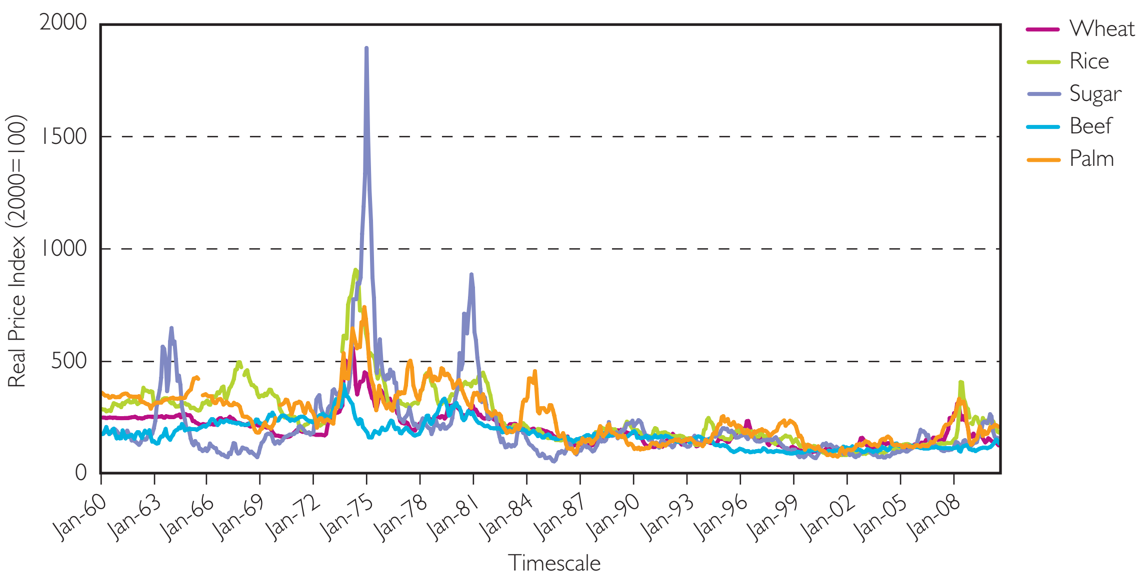
5 Challenge B: Addressing the threat of future volatility in the food system[258]

Volatility is an entirely natural characteristic of agricultural markets given that demand is relatively inelastic and that supply is both variable (for example dependent on meteorological factors) and cannot respond in the very short term due to the production cycle of agricultural commodities.

High levels of volatility in global food markets are an issue because of the adverse effects they have on consumers and producers, because of the disruption they cause to the global food system and, when particularly severe, because of the general economic and political instability that can occur. These effects will be most severe for low-income countries and the poor[259], and spikes in food price can be a major cause of increased hunger.

As for any market-traded commodity, food prices exhibit volatility[260] on different temporal scales, for example from day to day, reflecting transaction flows and changes in sentiment, and in the longer term (month to month, year to year) as market conditions and expectations change, or because of the effects of unpredictable events, or 'shocks', perturbing the system[261].

Figure 5.1: Global real price indices for major agricultural products since 1960



Source: HMG (2010) Data sourced from UNCTAD, BEA

Figure 5.1 shows fluctuations in the prices of five major commodities over the last 50 years and illustrates several points:

- Fluctuations in commodity prices are often correlated, but not perfectly.
- Food prices can be strongly affected by shocks from outside the global food system, for example the oil crises of the early 1970s.
- Overall, the last 20 years have been a period of relatively low volatility compared with the previous three decades , although volatility has increased recently[262].

258 This chapter is based upon a more detailed Project Report C10 (Annex E refers)
259 DR18 (Annex E refers)
260 Pure price volatility can be defined as 'a directionless measure of the extent of the variability of a price' at particular frequencies.
261 DR18 (Annex E refers)
262 See http://www.fao.org/worldfoodsituation/FoodPricesIndex/en/ and C10 (Annex E refers)

The food price spike of 2007-08, despite receiving considerable political and media attention, was relatively small compared with the fluctuations in the 1970s. Given the complex interaction of different forces, it is impossible to identify the direct causes of the 2007-08 spike in agricultural prices. However, it is possible to identify a number of factors that combined to generate the price spikes[263]: low global ratios of stocks (inventories) to use; uncertainty in early 2008 about the size of the 2008 crop; the significant increase in energy prices; and a weakening of the US dollar. A number of factors beyond these more immediate causes also played a role. In particular, changes in stocks reflect market forces, and stock depletion by definition is the result of demand exceeding supply. Factors behind the outstripping of supply by demand in the years leading up to the 2007-08 price spike included the following:

- A combination of population growth and economic growth in low-income countries, transitional and emerging economies (including the BRIC countries), increasing demand for animal protein.
- Poor wheat harvests in 2006 and 2007.
- Biofuels: the use of grains, especially maize in the United States, has grown significantly in the last 10 years.

It has also been argued in some quarters that commodity speculation was an important causal factor[264]. Data imperfections, and the nature of the statistical tests that can be performed, make it impossible to prove or disprove such arguments. However, while theory allows for the possibility of speculation having an impact on prices in various ways, a review of the potential mechanisms whereby speculation might have distorted international agricultural commodity markets suggests that speculators probably did not play a significant causal role in the price spikes[265]. The height of the 2007-08 spike was undoubtedly exacerbated by the introduction or tightening of export restrictions by governments in some important producer countries[266].

5.1 Volatility in the future

Food prices will certainly continue to show fluctuations but it is very hard to predict whether volatility will increase or decrease. Work commissioned by the Project explored the different classes of drivers that will affect volatility in the future[267].

5.1.1 Non-economic factors

- Droughts, floods, hurricanes and other extreme weather events can lead to sharp fluctuations in food production in particular regions. A general prediction from climate models is that the frequency and severity of extreme weather events is very likely to increase as the world warms and will be one of the first manifestations of climate change[268].
- Wars, major civil strife and breakdown of governance obviously affect the nations concerned but their consequences can also have large effects on the global food system. Such shocks have declined in frequency in recent decades but some commentators have warned that this trend may reverse due to rising population pressure and greater competition for limiting resources (especially water).

5.1.2 General economic factors

- Globalisation has complex effects on volatility. International trade can compensate for regional production shocks (see Section 4.5), but linked financial and capital markets can transmit economic shocks rapidly throughout the world.
- Shocks in other commodity markets are often correlated with price fluctuations in agricultural markets, as price movements are transmitted from one sector to another. In general, food price

263 HMG (2010) provides an excellent survey of the issues.

264 SR22 (Annex E refers)

265 HMG (2010)

266 New modelling commissioned by this Project has demonstrated the effect of such restrictions more generally. See Working Paper W8 (Annex E refers) and also Project Report C10 (Annex E refers)

267 DR18 (Annex E refers) and HMG (2010) discuss possible changes in the degree of volatility in the medium to longer term.

268 DR2 (Annex E refers)

volatility will be influenced both by fluctuations in general economic activity and the governance regimes concerning national and international commodity markets.

- The single external commodity that has the greatest effect on food prices is oil; it is also one of the most volatile. Oil prices affect food production through changes in the costs of energy, petrochemicals and fertilisers used in agriculture. Market forces will drive increased production of first-generation biofuels if the ratio of energy prices to grain and oilseed prices increases, and could be a significant driver of volatility in food prices. Where biofuel production is a function of renewable energy policy, inflexible biofuel mandates may exacerbate volatility in grain prices, while flexible mandates could have the opposite effect[269]. Oil prices also affect transport costs, and hence the degree of international market integration and price transmission.

5.1.3 Factors within the food system

- The level of food stocks held by private and public sector agents has declined in recent years, in part as a response to reduced volatility, changes in agricultural support policies and a more efficient food system. Stocks held by governments have fallen relative to those held by private agents, which potentially affects how they are managed in response to changes in market conditions. In any case, if stocks are low, agents are less able to cushion the market when supply unexpectedly falls relative to demand, pushing more of the response onto prices. Therefore, levels of future stocks within the global food system will have a significant effect on volatility.
- As consumers enjoy higher incomes, they tend to consume food that is more processed and where basic agricultural commodities account for a smaller share of the retail price. So even quite large changes in world prices may have only small effects on retail prices. Therefore, as many consumers become more affluent, prices of agricultural commodities have to increase further to achieve a given reduction in consumption[270].
- The use of food commodity exchanges facilitates efficient markets and allows producers and others in the supply chain to hedge risk – although this assumes to some extent that investor behaviour is always rational (Box 5.1 discusses whether speculative behaviour might affect volatility in the future).
- The degree to which governments intervene in international trade at times of high prices has a large feedback effect on volatility by weakening the ability of world markets to adjust to shocks. The extent to which this will amplify volatility in the future will be affected by nations' confidence in the international governance of trade and the food system (see Section 4.5).
- Continuing improvements in crop protection and biotechnology may increase yield stability, for example through resistance to new and newly emerging pests and diseases, and through the development of varieties of crops that are resilient to extreme conditions such as drought and flooding. Globalisation and intensification, on the other hand, increase the risk of the emergence and rapid spread of these biotic challenges.

5.1.4 Commodity-specific factors

- The 'depth' of the relevant markets – the volume of transactions in relation to the scale of the shocks hitting the system – affects the extent to which international trade can dampen volatility. Some international markets, such as rice, are particularly shallow, and volatility in such commodities will be affected by changes in future levels of trade.
- Certain food items have particular cultural importance and hence are politically sensitive, leading governments to take steps to reduce price volatility, which can sometimes have the opposite effect. Rice in South East Asia is a classic example. Changes in patterns of consumption, such as the possible adoption of wheat alongside rice as a staple grain, will determine the importance of this factor in the future.

The number of factors affecting volatility and the levels of uncertainty associated with each make it very difficult to predict whether the magnitude of fluctuations in food prices will fall or rise in the

269 The potential to switch production from biofuels to food at times of scarcity has the potential to reduce fluctuations in food prices – see, for example, HMG (2010).

270 DR18 (Annex E refers)

coming decades. Analysis commissioned by the Project[271] found no strong evidence for either greater or lesser future volatility, but others[272] conclude that although there are factors pulling in both directions, volatility may well increase in the future.

Box 5.1 Speculation and its controversial effect on volatility

It has been argued that uninformed, or 'irrational', speculation in agricultural markets exacerbates price fluctuations, and that in 2007-08 this activity artificially raised prices beyond the levels justified by market fundamentals, significantly increasing the height of the price spike[273]. In conventional finance theory, the effects of such speculation should be largely offset by the actions of informed speculators, but this assumes that operators in such markets are generally able to distinguish between informed and uniformed trades and that informed speculators have access to sufficient capital. These assumptions may not always be entirely valid, and some have argued that index-based swap transactions by institutional investors may have transmitted price changes across commodity markets and amplified the extent of price movements[274].

However, the empirical evidence is not clear cut and, arguably, such effects may be confined to high frequency (i.e. intra-day) fluctuations. Speculation is necessarily constrained by the need for eventual physical delivery or spot market transactions. Thus purely speculative effects tend to be relatively short-lived. But the issue is, how short-lived? Others have argued[275] that market fundamentals can fully explain the scale of the spike in prices in 2007-08, casting doubt on a causal connection between speculative activity and price movements. Statistical tests and analyses of speculative flows do not provide convincing evidence that they caused, rather than followed, price movements over this period. In sum, while the major drivers can be identified, the empirical evidence is mixed, and does not allow the relative importance of the various factors in causing or exacerbating the price spikes to be distinguished, particularly the role of speculation[276].

5.2 Decisions for policy makers

While the amount of future volatility remains uncertain, future spikes in food prices are inevitable. The key issues are:

- **What levels of volatility are considered 'acceptable', and should governments intervene to attempt to control volatility within defined bounds?**
- **How can the negative consequences of volatility be mitigated, and which interventions would be most effective?**
- **Is it better to develop mechanisms to protect producers or consumers from the effects of volatility and, if so, how?**
- **To what extent should collective action and planning at the international level (for example by the G20) occur to protect the poorest from the worst effects of volatility?**

5.2.1 Acceptable levels of volatility

Determining acceptable levels of volatility in food prices is a political judgement that needs to consider the following negative effects:

- Periods of high food prices particularly impact low-income countries and the poor everywhere.
- They risk political and social instability.
- They distort investment decisions by making returns harder to gauge and incurring costs in hedging risk.

271 DR18 (Annex E refers)
272 HMG (2010)
273 von Braun and Torero (2009); Robles et al. (2009); de Schutter (2010)
274 Index fund investors tend to see commodities as a single class, and their activities result in greater financial intermediation in these markets, which tends to link individual prices more closely together.
275 HMG (2010)
276 Project Report C10 (Annex E refers)

- They exacerbate problems of macroeconomic and fiscal management.

But there are also costs to interventions to reduce volatility in food markets:

- They are expensive and require resources that could be used elsewhere.
- They risk distorting markets or being used for political reasons.
- They may not work or could make the problems worse through unintended consequences.

Protection of the most vulnerable groups from the worst effects of food price volatility should be a priority, especially those in low-income countries where market and insurance institutions are weak. This can be done indirectly through intervention to try to influence market prices, but is likely to be more effective through the provision of safety nets for poor consumers or producers that are designed to stabilise real incomes.

5.2.2 Reducing the threat of volatility

The promotion of liberalised international trade in food will help to dampen volatility, because a production shock in one region can be compensated for by output and trade adjustments in others.

Box 5.2 describes modelling commissioned by the Project that illustrates this effect. The importance of liberalised trade to the efficiency of the global food system has been discussed in Section 4.5. As explored there, it is essential that mechanisms are put in place to give governments the confidence in the global trade system to resist what will often be intense political pressures to impose export restrictions at times of high food prices.

Box 5.2 Modelling: Future shocks – no action versus a protectionist response

The Project commissioned new modelling to investigate the broad nature of impacts that could result from shocks to the food system. As the real effects will depend upon many additional, interacting factors, the following results should only be regarded as illustrative[277].

Drought in South Asia between 2030 and 2035[278]: Using the IMPACT partial-equilibrium dynamic model, rain fed crop areas in Bangladesh, India and Pakistan were modelled as falling by 2% per annum from 2030 to 2035 and then returning to the baseline after the simulated drought.

The world prices of major crops all show a sharp increase during the drought – maize (67%), rice (16%) and wheat (32%) – and although they return to trend afterwards, these higher prices contribute to a 1% increase in the number of malnourished children in 2050, equivalent to nearly three quarters of a million children.

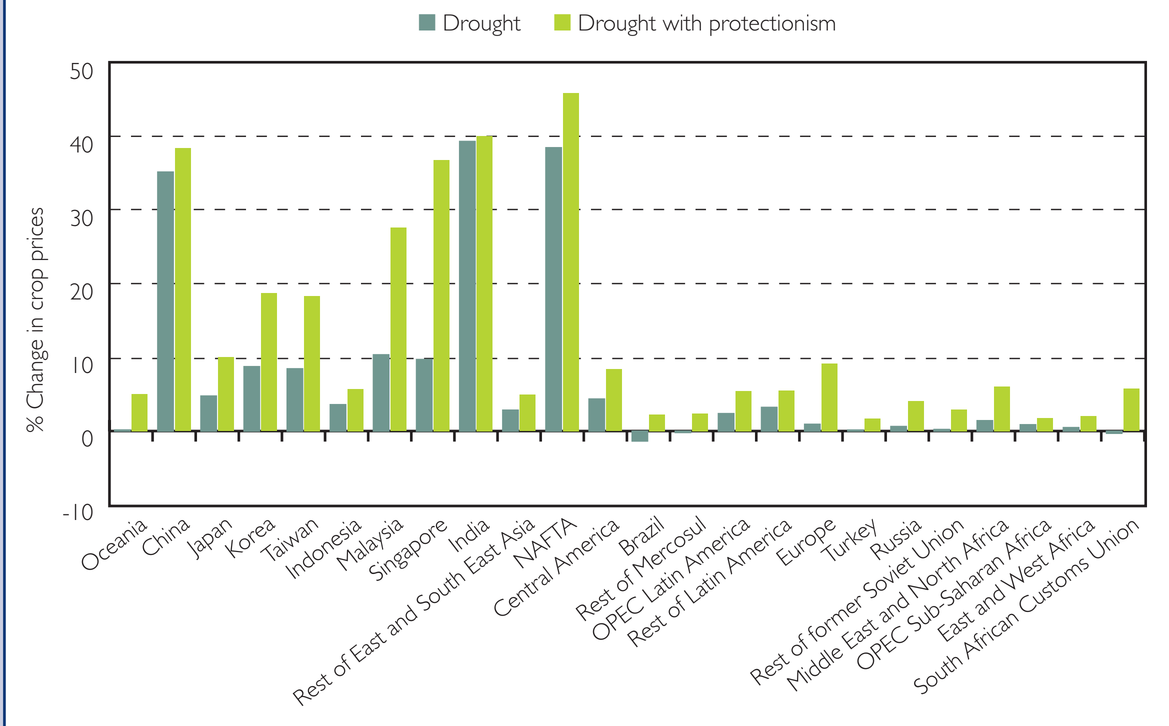
In this analysis, international trade plays an important role in lessening the drought-induced impact of the loss of rainfed production. Without the drought, South Asia is a growing rice exporter, and wheat and maize imports are increasing. During the drought, the region becomes a substantial rice importer and imports of maize become much larger.

Drought in the North American Free Trade Agreement area, China and India, and a protectionist response: Using the Globe static computable general equilibrium (CGE) of the global economy, this scenario assumes a 20% yield drop in the USA, Canada, Mexico, China and India, followed by a 25% export tax in exporting regions[279].

277 See Section 3.1 for further details of methodologies used for modelling.
278 C4 (Annex E refers)
279 WP6 (Annex E refers)

There are high rises in crop prices (around 35-40%) in the domestic markets of the regions directly affected by the drought (Figure 5.2). Net importers in East Asia also face price rises because drought-affected regions export less to them and compete more for imports (Malaysia, 10%; Korea and Taiwan, 8%). Increased incentives to produce crops in regions not directly affected by the drought, together with international trade, limit the fall in global crop production to less than 2%. However, if food exporting regions impose a protectionist response, crop prices are significantly higher in all regions and trade is harshly impeded (e.g. price rises are 27% in Malaysia, 18% in Korea and Taiwan). Global crop production does not fall under this scenario, since high crop prices provide an incentive to producers to grow more, but often in areas with a comparative disadvantage. Restrictions on exports thus lead to inefficient, high-cost production.

Figure 5.2: Real domestic food price changes under Drought scenario with and without export restrictions (% change in crop prices relative to each region's overall consumer price index)



Source: GLOBE results Robinson and Willenbockel (2010)

Improving the functioning of commodity markets can reduce the element of volatility that does not reflect underlying market fundamentals.

Well-functioning markets require access to accurate information. Information on international production and the size of commodity stocks[280] is generally poor and in some cases deliberately withheld. Stocks are held both by governments and private agents, and the latter have little or no incentive to provide information about their holdings. A theme throughout this Report is that the operation and planning of the global food system could be more efficient if data were collected and made available in a more systematic and useable way. Chapter 9 of this Report describes some concrete proposals.

It is beyond the scope of the Project to make technical recommendations about the workings of commodity markets. Issues such as the incorporation of commodities in more complex markets and over-the-counter traded derivatives and the effect of automatic computer trades need to be explored further. There is active debate on the different incentives and actions of private and public agents managing stocks when market conditions change. The effects of these, if any, on excess volatility should be explored to determine if action is needed from policy makers. At the same time, care should be exercised. Agricultural futures and options markets play an important role in facilitating price risk

280 HMG (2010), Annex 2

management and sending signals to producers. Their effectiveness relies on high levels of liquidity. All policy proposals need to be carefully tested to ensure that they do not have perverse results on the scope for farmers and others in the supply chain to manage their risks. However, in low-income countries such futures and options markets either do not exist or are very limited, so other forms of insurance need to be considered to support incomes of poor farmers.

There have been calls for a global system of virtual or actual international grain reserves to help dampen price fluctuations on global markets. This proposal risks addressing the wrong issue, is likely to be expensive, and it is far from clear that it would have a positive impact[281].

In most circumstances the costs and policy risks of using international food reserves, virtual or real, to dampen volatility (as opposed to protecting the poor directly) will tend to outweigh the benefits. Past experience with international agreements, such as those for coffee and sugar that followed the 1970s price spikes, were not successful as they broke down when divergent interests of the participants emerged as markets recovered. There can be a case, however, depending on the specific circumstances, for higher public stockholding at the national or regional level, as noted below.

5.2.3 Protecting consumers and producers from excess volatility

Governments and regional systems of support (such as the EU) have a clear role in improving education and awareness of the options available to improve risk management.

There is much that can be done to help individual producers appropriately hedge their own risks, whether via insurance, futures, the right balance between specialisation and diversification. In particular, advice on these topics could be provided through revitalised extension services that the Report calls for in Section 4.2.

For most consumers in high- and middle-income countries (i.e. except the very poor) modest temporary increases in food prices will cause increased expenditure and may possibly give rise to political pressure. For most individuals, these rises will generally be an inconvenience rather than damaging or life-threatening. However, the ability of the very poorest to have access to a healthy and adequate diet may be put at risk. In such circumstances, interventions through the social welfare system (through either income support or more targeted interventions such as food stamps) would need to be considered.

5.2.4 Special measures for the most vulnerable countries

Targeted food reserves for vulnerable (typically low-income) countries should be considered.

There is a strong case for establishing an emergency food reserve and financing facility for the World Food Programme to help low-income countries facing sudden increases in bills for food imports when price spikes occur. This has already been proposed by others[282]. It may also be appropriate for individual states to consider creating strategic reserves of food commodities. This is most likely to be the case where infrastructure and markets are poorly developed, and poverty is pervasive. Where markets and infrastructure are more developed, the risk that strategic reserves may be counter-productive is more significant. It should be recognised that the presence of such stocks may not be sufficient in themselves to protect the poor – during the 2008 food price spike, the greatest hunger in India occurred in several states that had significant reserves. Issues such as how the reserves are managed and distributed, or whether the problem is an increase in poverty due to catastrophic income loss ('entitlements') are potentially important. Policy attention should not focus on prices alone.

The poorest food producers need specific assistance to obtain insurance against risk and volatility.

Project Report SR22[283] reviews the different options available and the evidence for their effectiveness. Area-based index insurance, written against specific perils or events (such as drought, hurricane or flood)

281 HMG (2010), Annex 6

282 Sarris (2009)

283 Annex E refers

and recorded at regional levels, may have a useful role in helping individual farmers, although these would require public subsidy for the poor[284].

Safety nets will be required at times of unusually high food prices.

As in high-income countries, social safety nets will be needed to prevent the worst effects of temporary spikes in food prices from having severe effects on poor people in low-income countries. The main problems are likely to occur among the urban poor who cannot grow their own food or do not have access to 'wild food'. Failure to address these problems may lead to social strife and political instability, as seen in 2008.

While social safety nets are the responsibility of national government, where countries are unwilling or unable to provide safety nets relating to food/agriculture, it will be important for international bodies such as the World Food Programme or major non-governmental organisation with public support to continue to provide the safety net of emergency food resources.

284 SR22 (Annex E refers)

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6 Challenge C: Ending hunger

This chapter discusses different types of hunger. It outlines current trends but recognises the limitations of current measures of hunger and critical gaps in evidence (relating, for example, to indicators). It considers the likely pressures affecting hunger over the next 40 years and where it might occur in the future.

It is unlikely that hunger will be eradicated by 2030. Options for improving how hunger is addressed are therefore critical and are discussed in this chapter. Particular emphasis is given to the role of agriculture and other parts of the food system, the role of non-food policies that are critical for the reduction of hunger, and how the constituency for accelerated hunger reduction could be built.

6 Challenge C: Ending hunger[285]

Ending hunger is one of the greatest challenges to be considered by this Project.

Today, there are an estimated 925 million people hungry[286], and perhaps an additional one billion who are not hungry in the usual sense but suffer from the 'hidden hunger' of not having enough vitamins and minerals. This challenge is already recognised in the target of Millennium Development Goal 1 (MDG 1) of halving the proportion living in hunger by 2015. Looking out to 2050, this chapter considers levers both within and outside of the food system that will be critical to addressing hunger over the next 40 years.

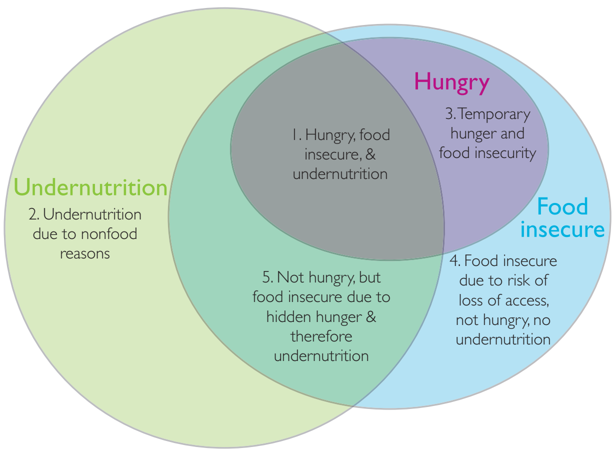
Many of the factors that enable poor people to access money and other resources to consume, purchase or grow good-quality food lie outside the food system. However, there is still much more that national and international organisations can do to tackle hunger through the food system itself. These interventions will require the deliberate generation of a more robust and consistent consensus on tackling hunger. Strong levels of political courage and leadership will be required to carry this agenda through.

Hunger is the antithesis of human development. It is important for policy makers to take a broad view of the nature and causes of hunger and its many impacts, including the severe and long-lasting nature of the effects that hunger and undernutrition can cause, particularly in children.

Hunger results in increased morbidity and mortality, through diseases caused by nutrient deficiency, and a greater susceptibility to disease more generally. It leads to distress behaviour that undermines development, including the sale of assets, the withdrawal of children from school (particularly girls) and into the labour force, the prompting of outmigration and, at worst, permanent destitution, prostitution and child trafficking. It also contributes to the onset of armed conflict[287]. The food price rises of 2007-08 and their impacts, particularly on the poorest households, highlighted the inability of the current global food system to protect the most vulnerable from food price volatility, despite this being less marked than that of the mid-1970s.

Most people think they know what hunger means. Yet it intersects with food insecurity[288] and undernutrition[289] in complex ways (Figure 6.1). Food insecurity is more pervasive than hunger. A person can be food insecure but not hungry for two reasons: (a) sufficient access to food today but at risk of loss in the future (sector 4, Figure 6.1) and (b) sufficient access to food that can stave off hunger, but of a quality that is not good enough to provide sufficient vitamins and minerals for health (sector 5, Figure 6.1). Undernutrition overlaps imperfectly with food insecurity, because there are non-food causes of the former, including poor water, sanitation and care and health services (sector 2, Figure 6.1). Someone can also be food insecure but not suffer from undernutrition, because food

Figure 6.1: The overlapping concepts of hunger, food insecurity and undernutrition



Source: Haddad 2010

285 The focus here is on chronic hunger. This chapter is based upon a more detailed Project Report C11 (Annex E refers).

286 See Figure 4.1.

287 Pinstrup-Andersen and Shimokawa (2008)

288 'Food security [is] a situation that 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'. Food insecurity exists when people do not have adequate physical, social or economic access to food as defined above. FAO (2001)

289 Undernutrition refers to poor growth, manifest as low weight for height (wasting), low height for age (stunting) or low weight for age (underweight) due to a combination of deficits of food, care, water, and sanitation and health services.

access is either temporarily interrupted (sector 3, Figure 6.1) or is at risk only in the future (sector 4, Figure 6.1).

This chapter focuses on the problems of chronic hunger. These are distinct from hunger caused by crisis, such as conflict and displacement. However, if disaster relief is handled badly, those damaged by crisis may become part of the longer-term hungry. There is growing concern that insufficient attention is given to the more difficult processes of recuperation and reducing vulnerability to further crises[290].

6.1 The causes and incidence of hunger

There is a widespread consensus on the causes of hunger.

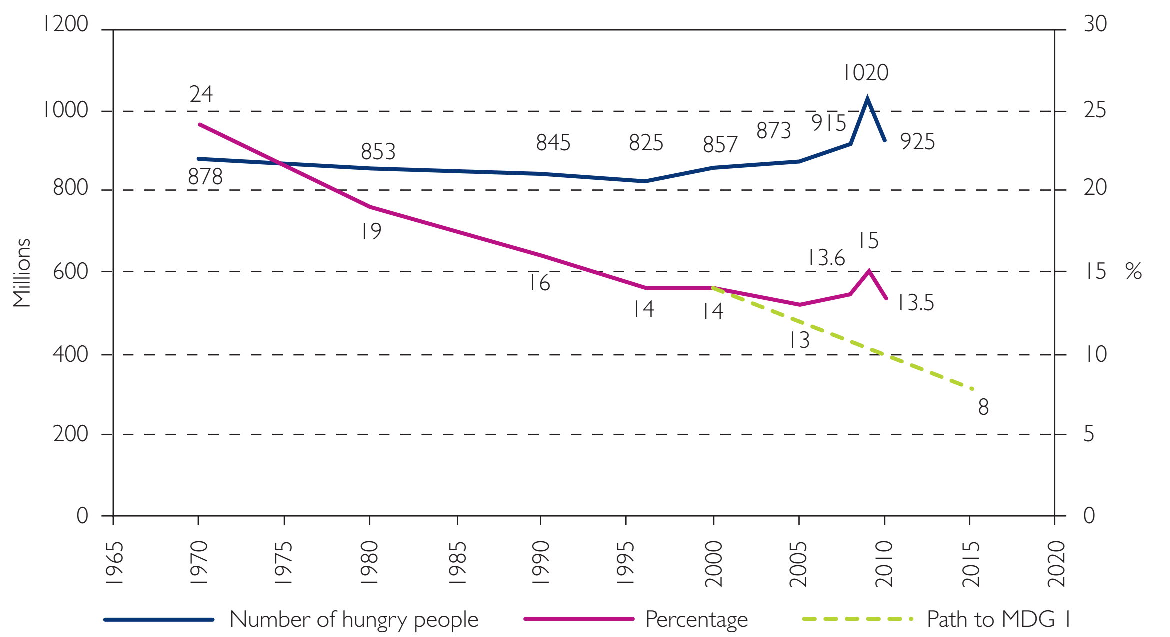
For people to be free of hunger, three conditions need to be filled:

- There has to be physical access to food: it has to be hunted or foraged, or for the most part, produced and available in fields, ponds and markets. This requires the right mix of technologies, infrastructure, institutions and incentives.
- There has to be economic access to food: a healthy diet has to be affordable. It is well established in the literature that food intake responds positively to income growth[291].
- There has to be social access, which manifests itself in many ways. Often it is the exclusion of women from production, purchasing and consumption decisions which aggravates hunger.

The international community is off track to meet MDG 1.

MDG 1 stated a commitment to halve the proportion of people who are 'undernourished' from 16% in 1990 to 8% in 2015. China achieved this goal in the early 2000s[292], but many countries in Africa and South Asia are unlikely to meet this target. Despite the fall noted by the Food and Agriculture Organisation (FAO) (from 1020 million to 925 million over the 12 months to September 2010) the world is off track – the current global figure is 13.5%[293].

Figure 6.2: Undernourishment data versus the MDG target



Source: Oxfam (2010) Data cited from FAO Hunger Statistics (from 1969 to 2006); UN (2009)

290 Haddad and Frankenberger (2003)
291 Bouis and Haddad (1992)
292 Ministry of Foreign Affairs of the People's Republic of China and United Nations System China (2008)
293 This global picture masks regional successes and failures. See Project Report C1 (Annex E refers) for a regional breakdown.

Figure 6.2 also shows that the numbers of hungry people had steadily increased prior to the 2010 decline. These increases were driven by the food, fuel and financial crises of the past four years. The FAO data indicate that in 1970 the numbers of hungry people globally were 878 million. This declined over the next 25 years to 825 million, at an average rate of two million per year. The next 10 years saw an increase in hunger from 825 million back to 873 million, a rate of increase of nearly five million per year. Between 2005 and 2009 this rate of increase jumped to 25 million per year. These data illustrate how vulnerable the poor are to market prices for food, as well as the rapid rise in hunger when prices increase.

There are substantial methodological issues associated with defining and measuring hunger, undernutrition and food security, which are reviewed in Project Report C11 and in the study by Waage *et al.* commissioned for the Project[294]. These reveal a worrying disconnect between the widely accepted need to focus on hunger and the actual evidence and data available. For example, household surveys have demonstrated that in some countries FAO data may underestimate the number of hungry by as much as a factor of three.

6.2 Making agriculture work harder to reduce hunger

In the regions where hunger is most chronic – South Asia and sub-Saharan Africa – agriculture can make the biggest contribution to ending it, but only if this goal is a driver of how agriculture is positioned and incentivised.

6.2.1 The role of food production in ending hunger

Food production, whether from terrestrial or aquatic sources, has a powerful potential triple role in ending hunger:

- Production is essential for the physical access to food. Technologies, institutions, infrastructure and information that support increases in the productivity of agriculture that are sustainable (i.e. involve manageable amounts of risk for farmers and do not degrade the environment) and equitable (i.e. are desirable, available and practical for the poorest farmers to adopt) can increase the supply of a diverse and locally desirable food bundle[295], at affordable prices.
- These technologies, institutions, infrastructure and information sources can improve economic access for all by raising farm income, generating employment on and off farm, and reducing food prices.
- Production can address issues of social access by deliberately empowering women and other socially excluded groups.

In the poorest countries, agriculture is not just about food production, but a very important means of broad-based income production. Recent empirical evidence suggests that, compared to growth from other sources, growth in agriculture generates welfare gains that are much stronger for the poorest parts of the population. Cross-country econometric work reported in the 2008 World Development Report[296] shows that a 1% gain in GDP originating in agriculture generates a 6% increase in overall expenditures of the poorest 10% of the population. This compares with a 4% increase in overall expenditures for the next poorest, and 3% for the subsequent decile. In stark contrast, GDP growth originating in non-agriculture sectors generates zero growth for the poorest 10% of the population, a 1% increase in expenditures for the next 10% and a 2% increase thereafter[297]. Similar conclusions have been drawn from other cross-country studies[298].

There are causes for optimism that agriculture can become a more powerful force for the reduction of hunger and poverty in the decades ahead.

The potential for agriculture to have a bigger impact on hunger has been apparent for some time. There are strong grounds to argue that this potential should now be grasped. First, there is a new wave of

294 Project Reports C11 and WP2 (Annex E refers)
295 Please see Annex D for definition of food bundle.
296 Ligon and Sadoulet (2007)
297 SR27 (Annex E refers)
298 Christiaensen et al. (2010)

donor interest in food and agriculture. Major donors are providing more support than has been the case for many years (for example, USAID's Feeding the Future Initiative, and the Bill and Melinda Gates Foundation's commitment to agricultural development). Secondly, climate change has alerted many to the critical moderating or exacerbating role that terrestrial and aquatic food production can play, depending on policy choices. Thirdly, there has been a relaxation of the post-Washington consensus, partly driven by China, Brazil and India's growing roles in development. This has led to new thinking on options for technology and policy, creating space for more innovation and a tolerance for more unorthodox approaches. Fourthly, there are growing commitments in many countries to give agriculture a higher priority (see Section 6.4). Finally, a new generation of flexible, adaptable, democratic, mobile technologies offer much potential in terms of monitoring, innovating and responding to hunger[299].

These contextual factors suggest that agricultural growth has the possibility of becoming a more powerful force for hunger and poverty reduction. But what would be the features of a more empowered agriculture? These are described in the following section.

6.2.2 New institutional mechanisms for prioritising agriculture's triple role in hunger and poverty alleviation and the empowerment of women

Agriculture needs to be repositioned within governments as a profession dedicated to multiple ends, of which hunger and poverty reduction are central.

For many governments, the purpose of agriculture is seen primarily as food production. In reality, it is much more: it requires flexibility to adapt to multiple agro-ecological niches; social analysis to understand issues of equity and exclusion; environmental skills to, among other things, work with the new climate agenda, and political resourcefulness to forge new alliances with those in areas in which the sector might leverage additional funds and influence. This means a repositioning of agriculture as a profession dedicated to multiple ends, of which hunger and poverty reduction are central. Food production is the means, not the end. Such a repositioning would mean changing the formal and informal training of agricultural development professionals, the ways in which Ministries of Agriculture are located, organised and staffed, and how the media perceives agriculture.

Innovation to improve ways of listening to producers is as important as innovation in research – there is still a need for far greater involvement of producers in defining and monitoring success.

International development's 'Achilles' heel' has long been its weak feedback loop from intended beneficiary to funders and implementers. The same is true for agricultural development. A recent study of stakeholders involved in agricultural monitoring and evaluation found that 57% thought that it satisfied the accountability needs of donors, compared with 28% who thought it met the accountability needs of beneficiaries[300]. Donors and implementers need to create more opportunities for producer organisations to influence prioritisation of research for agricultural development, and to monitor and feed back on downstream implementation. Research shows that while not a panacea, these mechanisms can have significant positive effects[301].

In particular, with much technology development taking place ever more distant from the farmer's plot, stronger mechanisms are needed to ensure that representatives of poor farmers and groups experiencing chronic hunger are able to influence decision-making.

Choices among existing and new potential technologies (such as those outlined in Project Reports C5 and C6[302]) will be made in a political context. Much agricultural investment in R&D is private, where commercial imperatives will not have hunger reduction as their principal focus. And while publicly funded R&D in the agriculture and food sector is more likely to address the needs of people living in poverty, it is also subject to capture and self-interests that divert it from hunger reduction as its principal objective.

299 See http://www.kiwanja.net/products.htm for examples of these innovations.
300 Lindstrom (2009)
301 Haddad et al. (2010)
302 Annex E refers

Producers need to be involved in assessing R&D priorities, the benefits and risks of different options, development of regulation, and ways to widen access to the gains that science and technology can bring[303, 304].

Smallholder farming, which has been long neglected, is not a single solution, but an important component of both hunger and poverty reduction.

Opinions about the role of smallholder farms in the future of agriculture and hunger reduction are strongly divided. Advocates argue that: (a) growth and poverty reduction have to start with agriculture, (b) smallholder farming is efficient at poverty reduction and (c) improvements in technology and markets are needed to make it even more efficient at reducing poverty. Sceptics argue that the evidence for these assertions is mixed and that an 'exclusive' focus on smallholders is unwise[305].

It is counter-productive to be absolute or overly ideological about agricultural strategy, especially in Africa. Farming contexts are heterogeneous, and different types of investment and focus are needed[306]. Nevertheless, 'half of the world's undernourished people, three-quarters of Africa's malnourished children, and the majority of people living in absolute poverty can be found on small farms'[307]. There is convincing evidence from China and India[308] that investments in agricultural R&D in less favoured (as opposed to more favoured) areas, which tend to have smaller farms, is better for growth and often poverty reduction, but because of limitations in data there is less evidence from Africa[309].

On balance, there are many existing technologies and interventions that would enhance the impacts of smallholder agriculture in sub-Saharan Africa, and elsewhere on the reduction of poverty and hunger. Many involve building social capital (through which knowledge can be shared, stronger recognition of rights to the basic resources of land and water on which smallholders depend), as well as investment in improved access to markets, from better infrastructure, credit and information systems[310]. African countries require the right blend of smallholder and larger-scale commercial agriculture.

Women play a critical role in agriculture, and agriculture plays a critical role in women's livelihoods. Purposively empowering women and focusing on their unique challenges will bring much wider gains in terms of poverty and productivity.

The food system's reliance on female labour is often not matched by the power women have to influence decisions over what is grown and how it is used[311]. Detailed analyses[312] of careful time-use studies from selected countries in Africa indicate that women contribute more than 60% of the total time spent in agricultural activities. In addition, of those women in the least developed countries who report being economically active, 79% of them report agriculture as their primary economic activity.

Given the important role women play in agricultural production around the world, and the provision of food in their own families, focusing on the unique challenges women face and the resources they lack is critical to increasing overall agricultural productivity and access to food. However, opportunities to do so may be constrained. For example, productivity on female-managed plots in Burkina Faso was found to be 30% lower than on male-managed plots within the same household because labour and fertiliser were more intensively applied on the latter[313].

Male-female power imbalances and asset gaps are a hindrance to agricultural productivity and, subsequently, poverty reduction. A wide-ranging body of empirical work suggests that increasing the

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303 Global Author Team (2010)

304 Project Report C11 (Annex E refers) discusses further the conclusions of an international research programme based in the UK that has been exploring the politics of food and agriculture (STEPS Centre), see also http://www.steps-centre.org/

305 Ellis (2005); Collier and Dercon (2009); Collier (2010)

306 Hazell and Haddad (2001)

307 Pingali (2010a)

308 Pingali (2010b); Project Report R2 (Annex E refers)

309 Though see in particular Project report C9 (Annex E refers), which summarises the 38 case studies of sustainable intensification commissioned by the Project, many of which involve substantial gains made by smallholder farmers when benefiting from the right mix of knowledge, support and investment.

310 See Project Report C9: (Annex E refers)

311 Meinzen-Dick et al. (2010)

312 Doss (2009)

313 Udry (1996)

resources controlled by women could promote increased agricultural productivity[314]. Table 6.1 highlights a wide range of policy and legal measures that should be implemented to enhance the agency of women. **Thus, a revitalised agricultural research and development system[315] is dependent on, and can contribute to women's enhanced agency, equal access to credit, stronger rights to land and water use and inheritance, and also their ability to be involved in the design and use of technology, extension services and farmer cooperatives.**

Table 6.1 Policy and legal measures to enhance the agency of women

Action level	Eradicate discrimination	Proactively promote catch-up in women's status
Basic	Reform legislation to equalise civil, political, economic, social and cultural rights ● Voting ● Land inheritance and ownership ● Employment, unemployment, benefit laws ● Membership in savings and credit organisations ● Mobility to promote social capital	Monitor efforts to review gender bias in public policy (for example, South Africa) Target access to new resources to women ● Credit programmes to poor women (for example, Bangladesh) ● Affirmative action programmes to actively recruit women in formal employment ● Ensure women's equal representation in formal and informal institutions
Underlying	Reform service delivery ● Equalise access to education (quantity and quality) ● Equalise access to agricultural extension services ● Equalise access to water and sanitation services ● HIV/AIDS prevention programmes ● Equalise immunisation rates ● Increase availability and access to reproductive health services, including family planning information ● Equalise access to preventative and curative health care Introduce legislation to enforce the international code on breast milk substitutes Introduce flexible working hours, crèches for working parents, and maternity and paternity benefits paid by state	Implement cash transfer programmes that promote the entry of girls into education and healthcare systems ● Food for schooling of young girls (for example, Bangladesh) ● Cash transfers to women in return for health and education behaviours favouring girls (for example, Mexico) Introduce labour-saving technologies when investigating in new water and fuel technology (save women's time and energy in water and firewood collection) Subsidies to encourage the promotion of childcare crèches to allow working women to provide their children with good childcare substitutes (for example, Guatemala City) Child benefits targeted to women (for example, the UK) Nutrition programmes to improve the nutrition status of adolescent girls and young women

Source: Smith et al., 2003.[316]

314 Saito et al. (1994); Udry et al. (1995); Quisumbing (1996)
315 Meinzen-Dick et al. (2010)
316 Smith et al. (2003)

6.3 Measures in the broader food system

While hunger cannot be ended without a vision for agriculture that deliberately sets out to tackle it, hunger cannot be ended by agriculture alone. Other policies and investments to increase food access, income, reduce gender power differences and improve nutrition status are vital and are discussed below. Likewise, the policy decisions discussed in Chapters 4 and 5 in the areas of trade, research and development, training and extension are thus critical to address hunger as well as general questions of global food security.

There has been considerable recent innovation in different forms of social protection to improve access to food.

There is a plethora of programmes aimed at reducing the price of staple foods (such as bread price subsidies in Egypt[317], wheat price subsidies in India and food for work programmes in sub-Saharan Africa[318]). Their effectiveness is highly contested[319, 320]. As a consequence, many are being replaced by cash transfers. For example, the Indian Government is exploring replacing many of its programmes for reduction of food poverty with conditional cash transfers[321].

Cash transfers – with or without recipient behaviour change conditions attached – are quickly becoming the main type of programme for social protection to help vulnerable households be less exposed, less sensitive and more adaptive to a range of shocks. They have risen up the political agenda in the past 10 years, ever since the results of the Mexican conditional cash transfer programme PROGRESA (now OPORTUNIDADES) showed positive effects on poverty, hunger, nutrition and education.

There are over 20 conditional cash transfers (CCT) programmes in operation[322] and many additional transfer systems that are unconditional. The FAO's State of Food and Agriculture report 2009[323] describes two of the largest: Brazil's Bolsa Familia – which provides conditional cash transfers for school attendance, vaccines and prenatal care, extended from 10.6 million to 11.9 million people in 2008, following the fall in GDP; and Ethiopia's Productive Safety Net Programme, the largest in Africa, offering cash or food to seven million people. The latter has had some delivery problems[324] and depends largely on support from the World Food Programme, but there is evidence that the scheme has had a positive effect overall on hunger outcomes[325, 326].

It is important not to view social protection policies uncritically.

Social protection competes with agriculture for political support, especially in government budgets, as they are seen as simpler and more amenable to demonstrating impact. They are typically affordable only for the poorest 10% of the population, and this means they are politically difficult to sustain and can be divisive at the local level[327].

In addition to placing gender power relations at the heart of the agricultural research and development system[328] there is a wide range of complementary measures that can be undertaken to promote the agency of women in ways that will accelerate hunger reduction.

Project Reports C9 and C11 highlight a number of options that can be undertaken[329], from actions to eradicate gender-based discrimination (such as land and water user and ownership rights) to actions that

317 Ahmed and Bouis (2002)
318 von Braun (1995)
319 Barrett (2002)
320 Demeke et al. (2008)
321 Merotra (2010)
322 Leroy et al. (2009)
323 FAO (2009)
324 Gilligan et al. (2008)
325 Preliminary evidence of impact of PNSP in Ethiopia indicates a positive effect on food security. See Sabates-Wheeler and Devereux (2009).
326 There is very little evidence available on the effectiveness of unconditional cash transfers, see Project Report C11 for a wider discussion. Annex E refers.
327 Molyneux (2009)
328 Meinzen-Dick et al. (2010)
329 See in particular Table 11.3 in Project Report C11.

actively promote catch-up in women's status (such as quotas for representation in agricultural decision-making bodies), with both sets of measures applying at the basic and underlying levels of hunger reduction determinants.

Nutrition outcomes need to be tackled directly and indirectly given the importance of adequate nutrition to health and human capital throughout the lifecourse.

If the quality of the diet is poor in terms of vitamins and minerals, then it will contribute weakly to physical and physiological development. If the prevalence of diarrhoea is high, then the nutrients that are ingested will not be absorbed by the body to their full extent. There are two sets of interventions that can strengthen the quality of the diet and the ability to used ingested nutrients for growth: direct nutrition interventions and nutrition-sensitive interventions.

Direct nutrition interventions have an exclusive focus on improving nutrition status. These include the promotion of exclusive breastfeeding for the first six months of life, the introduction of healthy complementary foods at six months, micronutrient supplementation using tablets, food fortification and hand-washing[330]. The main issue for these types of programmes has been the challenge of scaling up. This is partly a technical issue – the capacity and infrastructure to scale up is completely different to that of demonstrating efficacy; and partly political – nutrition is often given a low political priority.

The class of nutrition-sensitive interventions refers to programmes and policies that do not state improved nutrition status as their core outcome, but their proximity to nutrition outcomes and their large budgetary allocations means that they have the potential to do so. These include programmes on agriculture, social protection and women's status. For these programmes, empowering women will go a long way to accelerating hunger and nutrition outcomes, but so too will embedding direct nutrition components within larger resource flows. Examples of promising innovations include biofortification of staple food crops with micronutrients[331] and the health conditionalities embedded in cash transfers[332].

6.4 Efforts to end hunger

A stronger constituency for hunger reduction needs to be built. The international community must challenge itself over the apparent ease with which hunger is ignored and ask itself why hunger is so easy to neglect.

Reducing the number of hungry people rarely receives political priority, since the poorest section of society exercises little leverage, nationally or globally. Building a stronger constituency for hunger reduction is therefore critical to addressing the long-standing hunger crisis, represented by the fact that the world has had at least 800-900 million people hungry at any one time since the 1970s.

Hunger's chronic nature contributes to its lack of visibility until there is a major food crisis, which registers on television screens. Ending hunger requires broad cross-sectoral action, so it may seem too complex for politicians to address. In non-crisis contexts, civil society does not organise well around hunger, because there is no single solution around which to assemble and lobby, unlike in fields such as HIV/AIDS or malaria.

Brazil's experience of the past 10 years shows that if the political will is present, poverty and hunger can be substantially reduced.

In the absence of the Brazilian Government's commitment to social policies, its head count poverty rate in 2004-05 would have been 13% instead of the actual rate of 8%[333]. This commitment was driven by a combination of strong leadership from two successive presidents and a strong civil society.

Arguably agriculture gets even less attention than hunger reduction.

As argued in Project Reports C5, C6 and C9, agriculture in low-income countries can become highly productive, even for smallholders. In particular, the potential for aquaculture as a new micro-enterprise is

330 The standard package of nutrition interventions is listed in Bhutta et al. (2008).
331 Meenakshi et al. (2010)
332 LeRoy et al. (2009)
333 Ravallion (2010)

significant. Agriculture has also lost its infrastructure: agricultural parastatals, networks of extension agents, and national agricultural research have been depleted by structural adjustment[334]. This means African countries are starting from a low base. It has also been difficult to attract public investment to overturn decades of neglect. As Figures 6.3 and 6.4 show, this is changing in sub-Saharan Africa, although performance is highly variable within the region.

Figure 6.3: Progress towards the 10% share of public expenditure on agriculture for 38 African countries[334]

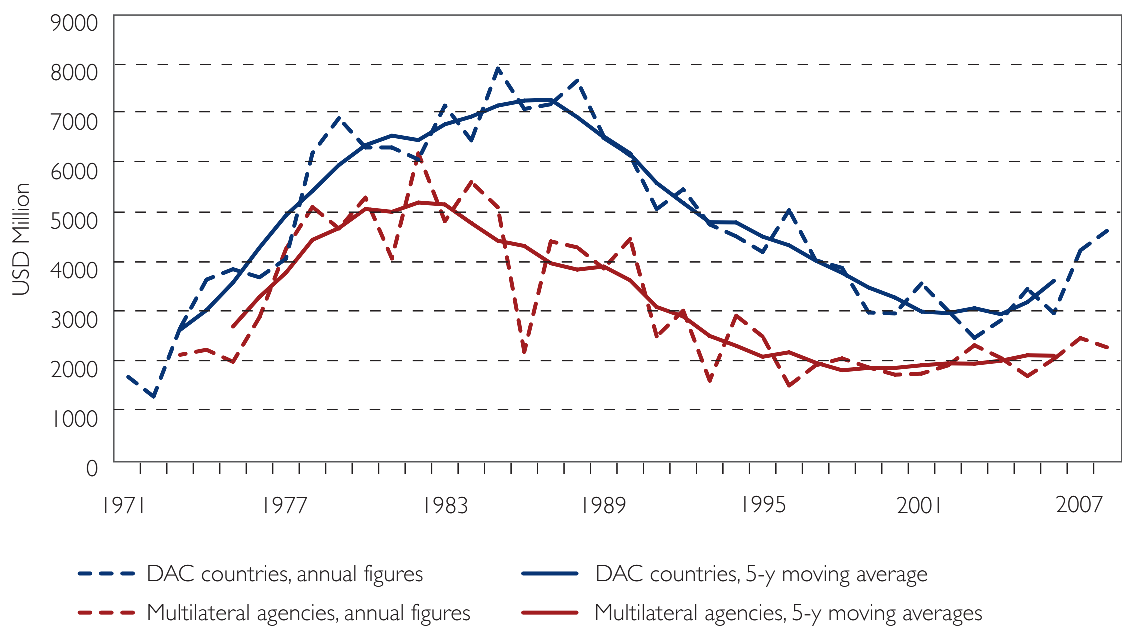
Source: Fan et al. (ReSAKSS 2009)

In the donor countries, investment in agricultural development in recent decades declined due to changing donor fashions, partly because of the rise of interest in social development and governance, and partly because those involved in agriculture did not invest sufficiently in impact analysis to defend it[336]. In the last few years, however, attention to agriculture is re-emerging, as can be seen with the focus of the World Development Report in 2008 and the aid to agriculture trends for DAC and multilateral agencies (Figure 6.4).

Despite this recent surge, the prolonged dip in investment means that agricultural training, infrastructure and research have suffered a 20-year period of underinvestment. Many in the donor community had thought that globalisation had reduced the need for production of local food. However, historical analysis[337] of past agricultural policies of today's high-income countries shows that political concern regarding national food security was an important factor in driving agricultural growth and technical innovation. In a world of perfect markets, national food security would be less dependent on national food production. But many of the most food-insecure countries today are poorly served by markets and have little room for error if markets, even when working well, generate significant price fluctuations. This reinforces the need for a bold and global consensus for tackling hunger and ensuring investment in pro-poor, anti-hunger agricultural growth.

334 Jayne et al. (2010)
335 Fan et al. (2009)
336 WP13 (Annex E refers)
337 Chang (2009)

Figure 6.4: Commitments to agricultural aid. 1973- 2008, 5-year moving averages and annual figures, constant 2007 prices



Source: April 2010, OECD-DAC, www.oecd.org/dac/stats/agriculture

6.5 What can be done to strengthen the enabling environment for hunger reduction?

To avoid fluctuations in international attention to hunger, an infrastructure for commitment to hunger reduction needs to be developed to make it harder for all stakeholders to forget about hunger. This needs to consist of the following actions:

1. Monitor more appropriate outcomes.

As described in more detail in Project Report C11[338], the data on undernourishment from the FAO are an anachronism from the mid-20th century. They probably provide a very inaccurate picture of the true level and pattern of hunger. The FAO and the World Bank should be tasked with working together to develop a new set of hunger outcomes. They can draw here on the example of the WHO, which recently revised all its growth standards on undernutrition[339] for children.

2. Monitor outcomes better and promote greater awareness of hunger.

Regardless of the accuracy of the annually released figures, governments need hunger data within the year to adjust and respond. New mobile technologies and GPS technologies have the potential to revolutionise hunger mapping[340]. This might include, for example, establishing bell-weather sentinel sites, equipping them with mobile technologies for weekly recording of hunger according to a simple scale of concern, relaying this to a GPS map and then making it widely available. This will allow for real-time hunger monitoring that is useful for policymakers and civil society.

338 Annex E refers

339 http://www.who.int/childgrowth/en/

340 See http://www.kiwanja.net/products.htm for examples of these innovations.

3. Monitor commitments and inputs: levels and perceptions about government action and spending on hunger reduction.

Constructing an index for measuring governmental commitment to hunger reduction could be of value, if it can set new incentives for governments to compete in achieving significant improvements. There are examples from elsewhere, monitoring donor commitments and good governance, including Freedom House's Freedom Index[341], the Mo Ibrahim Governance Index[342] and the Center for Global Development's (CGD) Commitment to Development Index[343].

Action Aid's HungerFree Index[344] is one example, described in more detail in Project Report C11. This monitors the commitments of donor and aid recipient countries in terms of their spending and policies, along with the subsequent outcomes relating to the incidence of hunger. The ranking records Brazil, China, Ghana and Vietnam as the most committed to hunger reduction. The indices have a potentially powerful role to play in focusing popular attention not only on hunger outcomes but on what citizens' own governments are doing to tackle the problem.

4. Strengthen the culture of monitoring, impact and learning in agriculture.

The measurement of, and learning about, the impact of agricultural interventions on human development outcomes is weak[345]. This stems from confusion as to what agriculture is for, the long causal chains from intervention to human development outcome and the climate uncertainty that agriculture is subject to. But they are not insurmountable barriers. Mixed method approaches to agricultural monitoring and evaluation are available. They must be used to understand what works, why, how and when. Agricultural organisations need to be incentivised to use these methods and to learn from them[346].

5. Enable greater strategic prioritisation and sequencing of hunger reduction actions to address hunger and undernutrition.

A common failure of recommendations on hunger reduction is that they end up as a laundry list of government actions. This is because many of the recommendations have been generated by regression models that stress the independent effects of different factors, and so complementarities between factors are overlooked. This way of thinking implies that all factors can contribute at all times in all places to reduce hunger.

A new approach recognises that in the real world some factors will depend on the significance and context of others. Also, improvements in some factors will have no impact on hunger, because the most binding constraints (for example a lack of roads) have not been dealt with. This 'growth diagnostics' approach is being widely used to help the ability of policy to stimulate economic growth[347]. Its value lies in acknowledging the complementarities and binding constraints found within any context, as well as bringing issues of politics and capacity to the fore. Similar diagnostic tools for hunger and undernutrition need to be developed.

6. Develop a culture that supports the emergence of anti-hunger leaders.

Hunger maps, commitment indices and diagnostics will be most useful if there is a committed government leadership behind them. These initiatives may well stimulate the demand for greater leadership but questions remain over how to generate the supply of leadership in the first place. Mexico, Thailand and Brazil are obvious examples. But very little is known about how to create leadership for hunger reduction, including the issue of whether such leadership will emerge independently or whether leaders might be encouraged by programmes on leadership for hunger reduction at the community and national levels. The lack of conclusive evidence suggests the need for experimentation and innovation across the field.

341 See http://www.freedomhouse.org/template.cfm?page=15
342 See http://www.moibrahimfoundation.org/en/section/the-ibrahim-index
343 See http://www.cgdev.org/section/initiatives/_active/cdi/
344 Narayan et al. (2010)
345 Haddad et al. (2010)
346 Haddad et al. (2010)
347 Hausman et al. (2008)

7. Mobilise mechanisms for systems accountability in hunger reduction.

At a local level there are many mechanisms for social accountability that have proved to be effective in improving service delivery and improving the agency of the poorest. Participation by the least powerful does not always lead to positive development and democratic outcomes, but a meta review of 1,000 case studies from over 20 countries demonstrates mostly positive outcomes[348]. At the national level, articulation of a 'right to food' may strengthen the capacity of civil society to make claims and the capacity of the state to deliver. A review of the emergence of 'right to food' legislation in India[349] shows the strong platform that it provides civil society to challenge current government approaches. Whether such legislation accelerates reductions in hunger and nutrition is not yet known.

At a global level, the UN is leading a worldwide effort to build enforceable international law recognising the 'right to food'[350]. Established in 2000 by the UN Commission on Human Rights, the mandate of the Special Rapporteur is to promote the full realisation of the right to food and adoption of measures at national, regional and international levels to ensure that people are free from hunger. The current Special Rapporteur has identified nine areas of priority, which include agri-business, climate change, food aid, land rights and trade. While this work is welcome in terms of affirming values, it remains to be seen whether it leverages resources to accelerate hunger reduction.

Box 6.1 Agriculture in Africa – the myth and the reality

Agriculture accounts for 65% of full-time employment in Africa, 25-30% of GDP, and over half of export earnings[351]. However, perceptions about African agriculture are mixed. It has been called stagnant[352], and assumed to have failed smallholders[353] – per capita production indicates that the amount of food grown on the continent per person has only just recovered today to the 1960 level. However, when account is taken of the substantial growth in demand from population increases, it can be argued that African agriculture has been dynamic and adaptive over decades[354]. Indeed, net production data show that there has been substantial growth in agricultural production across all regions of Africa, with output more than trebling over 50 years (with the greatest growth in North and West Africa), and growing faster than world output. Nevertheless, the challenge still remains substantial for African agriculture: continued population growth, rapidly changing consumption patterns and the impacts of climate change and environmental degradation are driving limited resources of food, energy, water and materials towards critical thresholds[355].

However, the promotion of further growth in the agricultural sector in Africa offers substantial benefits, not just in terms of food security, but in contributing to poverty alleviation. For every 10% increase in yields in Africa, it has been estimated that this leads to a 7% reduction in poverty: growth in manufacturing and service sectors has no such equivalent effect[356]. Also, countries will have to find novel ways to boost crop and livestock production if they are not to become more reliant on imports and food aid[357].

348 Gaventa and Barrett (2010)
349 Birchfield and Corsi (2010)
350 de Schutter (2009)
351 IFPRI (2004); World Bank (2008)
352 Inter Academy Council (2004)
353 Collier and Dercon (2009); Wiggins (2009)
354 Haggblade and Hazell (2009); see WP16 (Annex E refers)
355 Reij and Smaling (2008); DFID (2009); Haggblade and Hazell (2009); Toulmin (2009); Wright (2010)
356 World Bank (2008); Project Report SR27 (Annex E refers)
357 See Project Report C9 (Annex E refers); Pretty (2008); The Royal Society (2009); Godfray et al. (2010)

For these reasons, the Project commissioned over 40 examples of successes in sustainable intensification in agriculture, involving African experts across 20 countries[358], with a view to learning lessons and informing the spread of such practice. The cases included crop improvements, agroforestry and soil conservation, conservation agriculture, integrated pest management, horticulture, livestock and fodder crops, aquaculture, and novel policies and partnerships. By early 2010, these projects had documented benefits for 10.4 million farmers and their families and improvements on approximately 12.75 million hectares. They show that where there is political, institutional and economic domestic recognition that 'agriculture matters', then food outputs can be increased sustainably. Importantly, these examples also demonstrate the potential for benefits to flow into other areas, such as national domestic food budgets; the strengthening of environmental services; the development of new social infrastructure and cultural relations; the emergence of new businesses; and driving local economic growth. Many of these case examples have common approaches to working with farmers, involving agricultural research, building social infrastructure, working in novel partnerships and developing new private sector opportunities.

A major challenge to policy makers is to find ways to scale up these successes so that eventually hundreds of millions of people can benefit. In Africa – and in low-income countries elsewhere – evidence indicates that the greatest gains would be achieved through a range of parties working within an integrated framework to deliver the sustainable intensification of agriculture[359]: designed around local circumstances and drawing on both the interventions highlighted in this chapter and lessons from the case studies.

358 Of which 38 are included as part of the Project's publications (Annex E refers).

359 In the case of Africa, the Comprehensive Africa Agriculture Development Programme is intended to provide such a framework at both regional and national levels.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7 Challenge D: Meeting the challenges of a low emissions world

The food system will be strongly affected by the direct effects of climate change, and also by the policies adopted to mitigate its effects. The latter include measures outside the food system that will affect the economics of food production and distribution, and actions taken within the food system to reduce its substantial greenhouse gas emissions.

This chapter therefore explores the relationship between the food system and climate change mitigation and identifies future threats and opportunities.

7 Challenge D: Meeting the challenges of a low emissions world[360]

Greenhouse gas (GHG) emissions from the food system constitute a substantial fraction of all emissions, and need to be a key component of efforts to mitigate climate change. However, policy in this area is complex, as interactions to reduce and store carbon dioxide (CO_2) also involve the more powerful GHGs methane (CH_4) and nitrous oxide (N_2O), and differ across a wide range of production and distribution practices. There are substantial challenges in collecting the basic data required for monitoring, and in designing incentives and regulations to reduce GHG emissions.

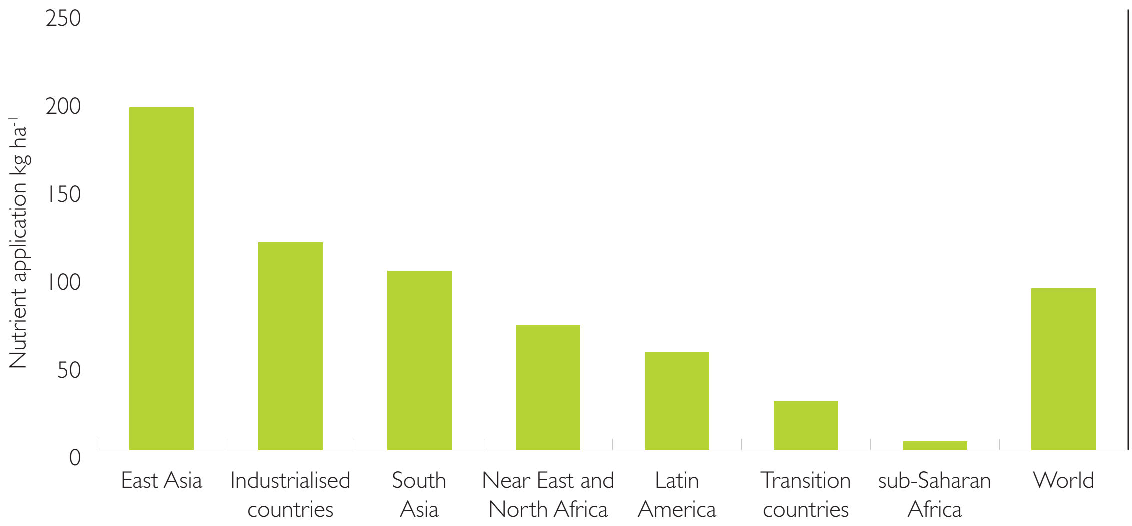
There is compelling evidence that anthropogenic emissions of GHGs is the dominant cause of observed global warming. There is a strong consensus that this warming trend will continue in the absence of substantial action to reduce GHG emissions. Increased temperature and changing patterns of precipitation and sea level rise will have a major impact on all aspects of human life, including the food system. It is not possible to determine exactly the scale or extent of global warming. However, because the potential impacts are so serious, and because it will take several years for mitigation and adaptation measures to be implemented and take effect, policy decisions cannot be delayed.

The contribution that the food system makes to GHG emissions depends critically on where the boundaries of the assessment are drawn. GHGs released during conversion of land to food production are a particularly important component of global emissions. Agriculture, including fertiliser production, directly contributes 10 –12% of GHG emissions; and this figure rises to 30% or more when land conversion and costs beyond the farm gate are added[361]. A study in 2006 estimated that 31% of the EU-25's GHG emissions were associated with the food system[362]. Moreover, agriculture contributes a disproportionate amount of high impact GHGs: approximately 47% and 58% of total anthropogenic emissions of CH_4 and N_2O respectively, though there is considerable uncertainty about the agricultural contribution as well as the total levels of emissions[363]. Low- and middle-income countries are currently responsible for about three quarters of agricultural GHG emissions (with land use change included) and their proportionate share is increasing (especially in Africa and Latin America)[364].

Project Report C12 describes studies that have tried to estimate how emissions from the food system will change in the coming decades. Unless major action is taken, substantial increases are very likely, especially in emissions associated with the increased production of artificial fertiliser. Fertiliser use is currently low in certain parts of the world, notably sub-Saharan Africa (see Figure 7.1, and also Project Report C2), and is likely to increase as countries become more wealthy and if food prices rise. As agriculture is currently not included in many national GHG reduction initiatives, the proportional contribution of emissions from this sector is likely to increase. However, a range of measures linked with the food system can also be applied to reduce or store CO_2, and there are important opportunities in almost all countries to do so.

360 This chapter is based upon a more detailed Project Report C12 (Annex E refers).
361 Smith et al. (2007); Stern (2006)
362 European Commission (2006)
363 Smith et al. (2007)
364 Stern (2006)

Figure 7.1: Annual average nutrient applications (nitrogen, phosphate and potash) to arable land: 1997–99.



Source: Data from FAO (Bruinsma 2003).

There is a clear case for substantially integrating and improving considerations of agriculture and food production in negotiations and implementation strategies on global emissions reductions, although the special features of this sector must be taken into account.

Food security is a prerequisite for committed action to address climate change. No democratic government will be able to introduce measures to reduce GHG emissions if they have significant effects on their citizens' access to food. This could be a particularly acute issue in low- and middle-income countries, where increased use of nitrogen fertiliser for expanded food output could add to GHG emissions. However, mechanisms for financing emission mitigation in the food system could also be important in rural economies. International policy in emissions reduction in the food system must take into account these realities, as well as the ethical questions concerning which geographical and economic groups should pay the costs of mitigation. Consideration also needs to be given to whether other sectors should set more ambitious emissions reduction targets – so that within global emissions goals, food production is less constrained, and economic development in low-income countries is not impeded.

7.1 GHG emissions in the food system

GHG emissions arise at all stages of the food system: they are associated with the generation of energy used directly in food production and in the synthesis of nitrogen fertilisers. Agricultural production uses 4% of global fossil-fuel energy (560 GW or 17.7 EJ) of which about 50% is required for nitrogen fixation in fertiliser production. Nitrous oxide and methane are produced in agricultural systems, and, beyond the farm gate, energy is expended in transport, storage, processing, retailing and preparation. Further emissions are associated with livestock manures and food waste. GHG emissions associated with fisheries and aquaculture production are relatively modest and mainly associated with vessel fuel and feeds (see Project Report C12).

Identifying the sources of emissions is important for targeting interventions. Using the common currency of carbon dioxide equivalents (CO_2e – which accounts for the varying warming effects and half lives in the atmosphere of different gases), Table 7.1 summarises global estimates of the major sources of GHG emissions from agricultural production.

Table 7.1 Contributions to GHG emissions from the main sources in agricultural production

Source	GHG	Mt CO_2e	%
Agricultural operations			
Enteric fermentation by cattle	CH_4	1792	27.0
Manure	N_2O	413	6.2
Nitrous Oxide from soils	N_2O	2128	32.1
Biomass burning	CH_4,N_2O	672	10.1
Rice production	CH_4	616	9.3
Sub-total		5621	84.7
Industrial factors			
Fertiliser production	CO_2, N_2O	410	6.2
Farm machinery	CO_2	158	2.4
Irrigation	CO_2	369	5.6
Pesticide production	CO_2	72	1.1
Sub-total		1009	15.3
Total		6630	100.0
Strategic factors			
Land use changes	CO_2	5900	
Grand total		12530	

Sources: IPCC 2007, Bellarby et al., 2008, IFA 2008, Stern 2006

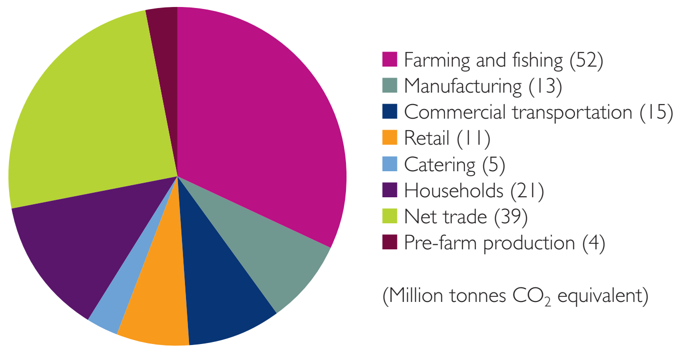
On a global scale, nitrous oxide (N_2O) emissions from soils, and methane (CH_4) from enteric fermentation of ruminants constitute the largest sources of GHG emissions from agriculture. In recent years, the consequences of land use change have also released into the atmosphere large quantities of ecosystem carbon as CO_2.

These highly aggregated figures mask a high degree of variation among food types and across regions. Likewise, GHG emissions associated with different crop production and distribution systems also vary. Those that involve growing crops under heated glass, air-freighting or refrigerated distribution are particularly energy-intensive. Across regions, N_2O from soils is the main source of GHG emissions from industrialised nations as well as from Africa and most of Asia. CH_4 emissions from livestock are dominant in Central and South America, Eastern Europe, Central Asia and the Pacific[365]. Rice production, which produces CH_4, and biomass burning, which produces NO_2 and CH_4 are important in South and East Asia, and in Africa and South America respectively.

Figure 7.2 illustrates how the GHG outputs of the food supply chain are divided up in the case of the UK (though it should be noted that the magnitude and relative importance of the different sources of emissions will vary widely across different countries). Total GHG emissions from the food supply chain were estimated to be about 160 million tonnes of CO_2 equivalent in 2007 (approximately 18% of the total UK GHG emissions[366]). UK farming and fishing accounted for about one third of emissions from the food supply chain. Of these, the majority were due to enteric fermentation in ruminating animals, and the oxidisation of nitrogen in fertilisers. GHG emissions in the UK food chain attributed to net trade[367] and commercial transportation of food for UK consumption are 25% and 9% respectively.

365 Bellarby et al. (2008); US-EPA (2006); FAO (2002)
366 Cabinet Office (2008)
367 Net trade covers emissions related to the production but not transportation of food imports, net of emissions related to the production of food exports.

Figure 7.2: Greenhouse gas (GHG) emissions from the UK food supply chain, 2007



Source: Defra statistics.[368, 369]

Every type of soil has a limited carbon storage facility, and the amount of carbon stored in a soil changes most rapidly (increases or decreases) just after a change in land use or land management. However, there is nearly as much carbon in the organic compounds contained in the top 30cm of soil as there is in the entire atmosphere, and so a vast amount of carbon is tied up in land used for food production[370]. Recent analysis by the Scottish Agricultural College (SAC)[371] found a range[372] of 8.6 to 18.9 $MtCO_2e$ of abatement potential from measures to reduce emissions from soil and livestock[373], at a cost of less than £70/tCO_2e (using the Climate Change Committee (CCC) projected carbon price for 2030) by 2022[374]. However, as discussed further in Chapter 8, when considering how land can be used for carbon sequestration, options involving planting forests to lock up carbon in woody biomass should also be included.

Changes in food production practices that affect the net flux of GHGs between the land, aquatic margins and the atmosphere could, depending on their direction, have significant positive or negative effects on global warming.

7.2 Developing smart policies to achieve multiple goals in the global food system

The primary international mechanism for reducing GHG emissions has been the Kyoto Protocol, which is linked to the United Nations Framework Convention on Climate Change. It seeks a global agreement between countries to limit emissions of greenhouse gases. The major feature of the Kyoto Protocol is that it sets binding targets for 37 industrialised countries and the European Community for reducing greenhouse gas (GHG) emissions. These amount to an average of 5% reduction on 1990 levels over the five-year period 2008-12.

The major distinction between the Protocol and the Convention is that while the Convention encouraged industrialised countries to stabilise GHG emissions, the Protocol commits them to do so. Recognising that industrialised countries are principally responsible for the current high levels of GHG emissions in the atmosphere as a result of more than 150 years of industrial activity, the Protocol places a heavier burden on industrialised nations under the principle of 'common but differentiated responsibilities'.

The Kyoto Protocol applies only to those countries that have ratified the protocol (and therefore excludes the US – a major industrialised country). Emerging economies such as China, India and Brazil are part of the international process but do not have targets for emissions reductions. How emissions reductions in low-income countries might be brought into an international framework is currently under

368 GHG emissions from food packaging, food waste and land use change are not included. Manufacturing includes emissions from electricity use and excludes emissions from road freight transport. Household does not include emissions from heating water for washing up or dishwashers.

369 Defra (2010b)

370 Batjes (1999)

371 MacLeod et al. (2010)

372 The range reflects uncertainties relating to the baseline against which the measures are applied, the technical effectiveness of abatement measures, and whether some measures would be permitted under future regulatory regimes.

373 Measures included: more efficient use of nitrogen fertilisers; breeding livestock for improved genetics, fertility and productivity; improvements in the efficiency of livestock feed and use of dietary additives; and improved manure management and anaerobic digestion.

374 UK Committee on Climate Change (2010)

discussion. The EU has enacted legislation to reduce emissions by 20% by 2020 (taking 1990 as the base) while the UK has set the legally binding target of reducing emissions by at least 34% by 2020 and at least 80% by 2050 against a 1990 baseline[375] (Scotland's targets are 42% and 80% respectively with the same baseline)[376]. These ambitious goals cannot be achieved without the food system playing an important part.

It has been estimated that, by 2050, through a mix of technical improvements, better management practices and specific carbon storage actions, the global food sector could reduce GHG emissions by some 5.5-6.0 Gt CO_2e annually[377].

The UK GHG inventory[378] estimates that agricultural emissions in 2008 amounted to about 48 MtCO_2e or 8% of total UK greenhouse gas emissions. Emissions have already fallen from 61 MtCO_2e in 1990[379]. The UK Government is aiming to reduce agricultural emissions by about 3 MtCO_2e in England over the next 10 years (a similar level of ambition in the devolved administrations would deliver an additional 1.5 MtCO_2e)[380].

There are four main ways in which impetus can be given to emissions reduction in the food system:

- Creation of market incentives to reduce emissions. These might include grants, subsidies, levies, carbon taxes or carbon cap and trade schemes.
- Introduction of mandatory emissions standards, or limits, by direct regulation, which may change production costs and be linked with market adjustments.
- Adoption of low emissions strategies through market pressures driven by consumer choice. This requires active and informed consumers, sources of accurate and trusted information, such as emissions labelling or product certification, and research into social and cultural barriers.
- Voluntary (non-profit driven) measures taken by industry through corporate social responsibility.

In designing, encouraging and facilitating such initiatives, it is essential to consider not only their effects on GHG emissions, but how they affect the amount of food produced, the quantity of inputs required, price and food access, and all the other externalities of the food system from ecosystem services to animal welfare. For example:

- **Considerable reductions in emissions are possible without loss of production or productivity through applying existing best practice, leading to increased efficiency and reduced costs of production.** Incentives that encourage more efficient use of water and fertilisers (including recycling) may both reduce emissions and increase value per resource unit, and also have other benefits, such as reducing nitrogen leaching and run-off, with positive effects for the environment and ecosystem services. Such measures would also reduce pressure on increasingly scarce resources such as energy and water, to the benefit of sectors beyond the food system. Reductions in the consumption of foods, such as certain forms of meat, may also have benefits for both health and emissions reduction, and are discussed in Project Report C8. There may also be multiple benefits of increasing soil carbon content, if it locks up carbon and increases soil fertility (see Project Report R2).
- **Developments in science or technology can influence and increase the efficiency of interventions to reduce GHG emissions**: for example, precision agriculture with improved timing and reduced volume of fertiliser application, breeding for improved nitrogen use by plants, breeding for reduced GHG emissions in beef and dairy cattle and via genetic improvements in their fodder, and the provision of high starch concentrates to reduce the production of methane in ruminants.
- **Where emissions reductions affect productivity in the food system, interventions should be chosen to achieve the greatest GHG reductions at the least cost.** To do this, it will be critical to understand how an intervention affects yield and productivity, how it might affect food costs, and also whether it will have an impact on the poorest and most vulnerable people, those least able to bear the cost of

375 HMG (2009)
376 http://www.scotland.gov.uk/Topics/Environment/climatechange/scotlands-action/climatechangeact
377 FAO (2009); Stern (2006); Wright (2010)
378 UK Greenhouse Gas Inventory National System http://www.ghgi.org.uk/
379 UK Committee on Climate Change (2010)
380 UK Committee on Climate Change (2010)

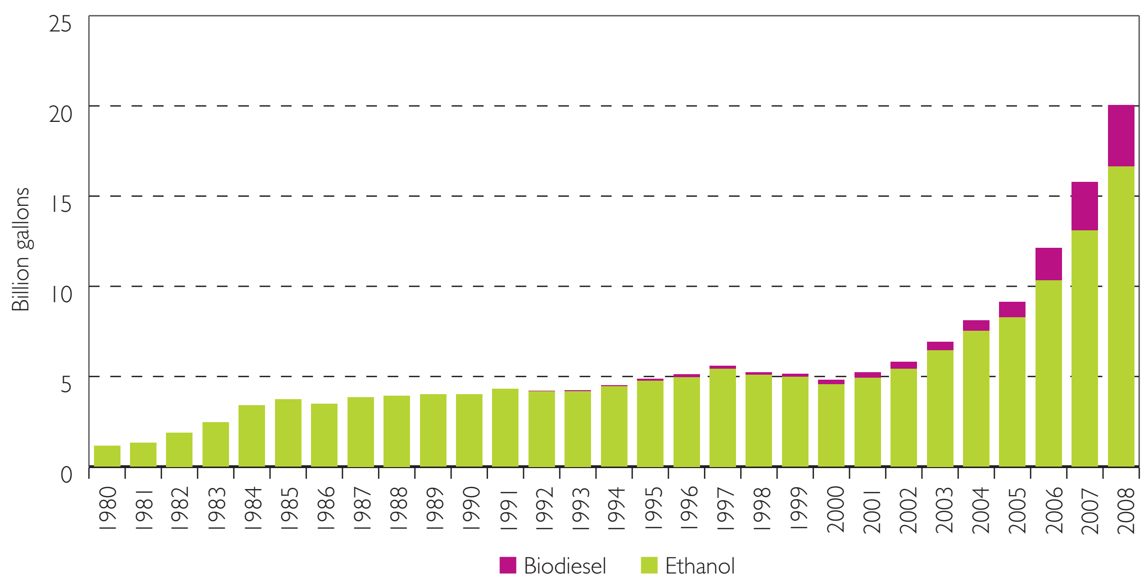
mitigation[381]. It will be particularly important to consider implications of interventions for smallholder producers, for gender issues, and, more broadly, how it will impact the many communities whose culture is intimately connected with agriculture and food production.

- **The need to recognise the importance of land conversion in policies to reduce GHG emissions.** Table 7.1 shows that the largest contribution to GHG emissions in the food system is through land conversion, and, in particular, the transformation of forest into farmland. One of the strongest arguments for the Project's conclusion that the increase in the global food supply must be based on sustainable intensification without significant new land being brought into cultivation is the emissions of GHGs that would otherwise result. Emissions policy for the food sector must be developed within the broader area of emissions from all land use types. It must also recognise that land use and land cover change can also influence climate by modifying the physical properties of the Earth's land surface (e.g. the type of vegetation covering the landscape affects climate through the water cycle and changes in evaporation, as well as the exchange of energy between the land and atmosphere). Hard decisions will need to be made, for example on whether increased use of nitrogen fertiliser with its associated emissions problems is justified to prevent demand for food outstripping supply and hence leading to inexorable pressures for very damaging land conversion.

The degree to which sustainable intensification, as discussed in Chapter 4, will succeed in maintaining the balance between demand and supply for food, will in large part determine the capacity of the food system to deliver cuts in GHGs.

- *The importance of the link between mitigation policies, biofuels and the food system.* It is essential to consider the consequences of climate change policy in other areas for the global food system. The most significant issue at present is the impact of first generation biofuels – using crops and cropland not for food but for energy production. Figure 7.3 shows the recent rapid increase in production of ethanol and biodiesel. The degree to which certain biofuels actually contribute to GHG reductions is contested, as is the argument that, by reducing food production, they contribute to increased food prices and price volatility. A more complex issue concerns whether farmers benefit financially from having the choice of using their land for food or fuel, or whether they suffer from becoming locked into contracts to supply biofuels.

Figure 7.3 Increases in ethanol and biodiesel production



Source: Conway and Waage (2010), sourced from IEA data

Although some biofuel systems have net positive effects for GHG emissions, many first generation biofuels reduce the area of land available to grow food and do not contribute to GHG reduction. The history of the introduction of biofuels illustrates the dangers of not considering either the

381 See Chapter 6

multiple consequences of a climate change policy, or the potential for their exploitation by vested interests.

- **There is strong potential for mitigation policies to incentivise the delivery of multiple public goods and benefits associated with the global food system**. A theme running through this Report is the importance of internalising within the global food system the negative consequences for the environment of different forms of production. This approach can not only incentivise best practice, but also provide the means by which food producers can be rewarded for supplying multiple goods without direct public funding. Much carbon is locked up in agricultural land and more could be sequestered; similar options could occur in aquatic systems. Payments for both terrestrial and aquatic stewardship could be important in protecting the environment, in supporting rural economies and societies, and enhancing their ability to adapt.

Finally, measures to reduce GHG emissions will require farmers and other food producers to learn new skills as well as the creation of novel social capital in their communities. Arguments for a revitalised new form of extension service were put forward in Section 4.3, and this will be critical in delivering real GHG reductions.

7.3 Reducing GHG emissions from the global food system

Different strategies are needed to reduce GHG emissions in the food system before and after the farm gate. Beyond the farm gate the food system more closely resembles other sectors and the primary imperative is to increase energy efficiency. Energy efficiency is also important at the beginning of the food supply chain, but here other approaches are equally significant; for example reducing non-CO_2 GHG emissions, sequestering carbon, and on-farm energy production. However, the food system comprises many interconnected parts and downstream factors, such as consumer choice for different food types, which can strongly influence the magnitude of upstream emissions.

According to Garnett[382], mitigation measures targeted at the food system can be divided into five categories:

- *Enhancing carbon removal*: restoring degraded lands; afforestation; zero or minimum tillage; incorporating organic matter into soils; and managing aquatic plants and sediments.
- *Optimising nutrient use*: more precise dosage and timing for organic and inorganic fertilisers; incorporating nitrogen-fixing legumes into rotations; and better management of aquatic systems, including integration with agriculture.
- *Improving productivity*: increasing edible/marketable output per unit of GHG generated (accounting also for non-consumed materials); crop and animal breeding for performance; optimising nutritional content of feeds; and pest and disease management.
- *Managing and benefiting from secondary outputs*, including: manure and plant biomass, wastes and by-products from fish and other animals; product recovery, slurry and manure management; composting; and anaerobic digestion.
- *Reducing the carbon intensity of fuel and raw material inputs* through improvements in energy efficiency, selection of materials, and use of alternative fuels such as biomass, biogas, wind and solar power; and improvements in transport, storage and consumer efficiencies.

Project Report C12 discusses in more detail many of these strategies (see also Project Reports SR31-33)[383]. Some general points are made here.

Many examples of the application of existing knowledge to increase sustainable food production, and for new knowledge to increase current yield ceilings in the most sustainable way[384], will have positive effects on reducing GHG emissions.

However, measures that are GHG-emission neutral but which increase productivity, reduce demand, or increase the efficiency of the food system are also beneficial, as they reduce pressure on the food system

382 Options for reducing GHG emissions are discussed more fully in SR32 and also C12 (Annex E refers).

383 Annex E refers

384 See sections 4.2 and 4.3 of this Report for a discussion of these.

to expand and otherwise increase GHGs. More widely, an audit of consequences for GHG emissions in the food chain should be carried out and become part of the decision-making process in allocating funds to different interventions or research topics.

Measures that are particularly likely to reduce emissions include:

- **Reducing waste** (Section 4.4) because this would increase the efficiency of the food system but also because waste disposal releases GHGs.
- **More efficient use of nitrogen in crop and livestock production** (synthetic fertiliser; animal manures and slurries; and biologically fixed nitrogen in swards and arable rotations), including more precise and timely application, and on-farm recycling – the use of fertiliser is the most important contributor to GHG emissions from agriculture (both in energy during manufacture and as N_2O emissions when applied to land). Advances in crop management, supported by modern information and communication technology, could lead to substantial N_2O reductions[385]. New varieties of crops that are less demanding of nitrogen and other inputs can also contribute.
- **Changing management practices for production of wetland rice** to reduce the amount of anaerobic decomposition that is a major source of methane. Issues involving integrated rice-fish culture need to be considered to optimise productivity and methane control.
- **Increased carbon sequestration through integrated management of soil and vegetation, and aquatic systems**. A variety of conservation agriculture and related techniques such as minimum and low tillage can affect soil carbon storage. Further research is needed to understand the full consequences of the very complex and context-specific impacts on GHG budgets of these different practices. A further important issue, especially for incentivising and rewarding soil carbon sequestration, concerns the guaranteed length of time that the carbon remains stored in soils. Continuing debate about the adequacy of monitoring, reporting and verification (MRV) procedures is likely to have an impact on the practicality of these mitigation options. Nevertheless, increasing organic carbon pools in the world's soils by 10% would be the equivalent of reducing atmospheric CO_2 by 100 ppm (c.f. the 450 ppm target for 2°C temperature rise limits)[386]. Gains could also be achieved through appropriate management of aquatic and aquaculture habitats, although less is known about the best strategies for doing so[387]. The value of mangroves, seagrass beds and saltmarshes for sequestration needs to be recognised more fully, and measures taken for their protection and restoration.
- **Long-term carbon capture on farmland through agroforestry** may also provide other benefits, such as reducing soil erosion and producing renewable fuels and animal feed. Production and storage of carbonised wood (biochar) may also be valuable, but needs wider assessment in a variety of conditions.
- **Reducing methane and nitrous oxide emissions from livestock production**. The issue of reducing demand for meat is explored in Section 4.6. For the same level of meat consumption, substantial reductions in GHG emissions could be obtained by switching between livestock species, by improving production systems, and by optimising nutrition. In the future, animal breeding facilitated by advances in the life sciences and a better understanding of gut flora and nutrition, will allow livestock systems to be developed that produce less methane per unit of production. Better manure management, or its use in the production of methane as renewable energy, can reduce the volume of this gas entering the atmosphere.
- **Increasing the efficiency of land use to harvest solar radiation for multiple purposes (food and energy) through second generation biofuels and the integration of biomass production**. In the medium-term future, energy crops based on algae or macroalgae (seaweed) could be cultivated in integrated systems linked to terrestrial or aquatic food production. An example is provided by seaweed production combined with intensive fish or shrimp culture in integrated multi-trophic aquaculture (IMTA) systems[388]. There are a number of technical challenges in the economic utilisation of these novel carbon sources, and their financial viability will be strongly influenced by oil and other energy prices.

385 DR4 (Annex E refers)
386 SR33 (Annex E refers)
387 PaCFA (2009)
388 See DR16 (Annex E refers)

Commitments or actions, including objectives for quantified emissions limitation and reduction, need to be measurable, reportable and verifiable (MRV). The very process of measurement can facilitate actions by establishing baselines and helping to identify potential progress in mitigation. The reporting of actions can also allow both national and international recognition. The review or verification of actions can enhance action through expert advice on opportunities for improvement. Finally, credible MRV can strengthen mutual confidence in the actions and in the regime, thereby enabling a stronger collective effort.

7.4 Enabling GHG reduction in the food system

Monitoring and evaluating reductions in GHG emissions from agriculture and the food system is complex, because of the several gases involved and the many sources and mechanisms of emission. Substantial progress has been made in recent years in developing metrics for measuring emissions, especially for high-income countries, although further research is required to provide the decision-making tools that policy-makers require. Two examples of international initiatives which will help in this regard are:

- The Global Research Alliance on Greenhouse Gases (a collaboration of countries, organisations and individuals), is focused on research, development and extension of technologies and practices that will help deliver ways to grow more food (and more climate-resilient food systems) without increasing greenhouse gas emissions. The Alliance will help improve the understanding and measurement of agricultural emissions, and will also find better ways to share research results, technologies and best practices, and make these available to farmers[389].
- The new Commission for Sustainable Agriculture and Climate Change[390] will identify the policy changes and actions needed now to help the world achieve sustainable agriculture. This will help food security and poverty reduction, and contribute to climate change adaptation and mitigation. It will also seek to build international consensus on actions relating to agriculture and climate change, using existing evidence to inform key national and international policy-makers.

As discussed above, it is critical to include not only the direct consequences of different strategies but indirect consequences, such as effects on land use conversion and on interactions through trade (for example production moving to countries with a less developed regulatory framework; see Section 4.5). New forms of modelling incorporating both economic and biophysical processes will be required to provide more robust evaluation frameworks.

In the broader food system, the full life cycle emission costs of different foods or processes will need to be assessed. Common approaches and methodologies will be essential to establish meaningful comparative measures, to define targets and design effective policy instruments. The metrics produced should be easily understood and transferable both within different areas of the food system and across sectors. There is a balance to be struck between comprehensiveness, accuracy, and simplicity that will vary across applications. For example, 'eat local food' could be a good rule of thumb to reduce emissions associated with transport and very often will be so. However, if local food is produced using methods that are not as efficient as imported food in terms of GHG emissions, or is routed through distribution centres some distance away, it may not be advantageous. There may be other reasons for sourcing food from particular localities, such as maintaining rural economies. For example, over one million livelihoods in Africa are supported by UK consumption of imported fresh fruit and vegetables while stopping air-freighted imports from Africa would reduce UK total emissions by less than 0.1%[391]. In determining policy, all environmental and social aspects need to be analysed, and trade-offs assessed.

Developing better and more comprehensive metrics of GHG emissions in the global food system should continue to be a priority.

389 http://www.globalresearchalliance.org/about-us.aspx

390 The Commission for Sustainable Agriculture and Climate Change is being established by the Climate Change, Agriculture and Food Security programme (CCAFS) – a strategic partnership of the Consultative Group on International Agricultural Research (CGIAR) and the Earth System Science Partnership (ESSP), with the support of the Global Donor Platform for Rural Development.

391 MacGregor and Vorley (2006)

Reductions in GHGs are a very important part of the sustainability agenda in food production. The maintenance of ecosystem services and the preservation of biodiversity[392] are further and often interlinked components. The non-GHG effects of land use and land cover change on climate are also important. Obtaining metrics of sustainability that incorporate these multiple dimensions is hard but essential.

As mentioned in Chapter 4, the views of senior representatives of the UK food retail sector were obtained on the potential role for sustainable intensification as part of this Project[393]. Several individuals had worked for companies that had developed product ranges that were produced in sustainable farming systems, and marketed as such. They felt that public trust in own-brand sustainable products was low, and that there was little capacity for charging a price premium and hence rewarding their suppliers for improved practice. They gave a clear message that they would welcome government-accredited national schemes that set standards for sustainability. They argued that the key to its success would be in setting a level playing-field in this intensively competitive sector, and that it would be critical for the definitions of standards to be in place for a sufficient time to encourage investment in sustainability.

Government-backed schemes setting sector-wide sustainability standards would obtain strong support from the retail food sector and be a very positive contribution to increasing sustainability.

392 See Chapter 8
393 Food Chain Workshop: Foresight report W2 (Annex E refers)

8 Challenge E: Maintaining biodiversity and ecosystem services while feeding the world

This chapter discusses the critical interrelationship between food production, biodiversity and ecosystem services.

It considers how land and aquatic ecosystems used in food production need to be managed to achieve multiple goals, including biodiversity and ecosystem services. More generally, it argues for the need to improve linkages between policies relating to the food system, and to the environment – at all levels – from landscape to global systems – and the critical importance of developing incentives for best practice.

8 Challenge E: Maintaining biodiversity and ecosystem services while feeding the world[394]

Until recently, policies in conservation and in food security were largely developed in isolation. However, they are increasingly being pursued together, driven by a growing realisation of their interdependence:

- The global food system already has a substantial effect on the earth's biodiversity (see Box 8.1 for definition) and on the functioning of natural and managed ecosystems. Food production takes up more land and has a greater impact on marine and freshwater ecosystems than any other human activity, effects that can only increase as demand for food expands over the next 40 years.
- Land used for food production provides a variety of other goods important for humankind, such as ecosystem services (see Box 8.1 for definition) as well as enabling the continued existence of many species of wild plants and animals.
- Food production requires ecosystem services, which are typically uncosted, and provided by land and aquatic ecosystems that are not primarily managed for food production.
- Many of the most important centres of global biodiversity are in low-income countries that suffer from widespread food insecurity. Addressing local poverty and hunger is essential for the successful protection of biodiversity.

There are both economic and non-economic arguments for why ecosystem services and biodiversity should be integral parts of decision-making in the global food system. It is only in the last few decades that the importance of these services to food production has been realised and efforts initiated to quantify their economic significance[395]. Different national and international 'ecosystem assessments' seek to understand how various drivers of change will affect the provision of services in both managed and unmanaged ecosystems.

The degree to which biodiversity *per se* enhances ecosystem services is a focus of active current research. Irrespective of this, species extinction is irreversible and represents the permanent loss of part of the earth's natural capital and cultural inheritance. It has been estimated that current rates of extinction are somewhere between 100 and 1000 times as high as background rates[396], driven largely by increased pressure on the earth's resources due to a rising population. As discussed in Chapter 2, and Project Report C1[397], it is now possible to envisage population growth reaching a plateau, and possibly declining in the second half of this century. This means that urgent decisions that need to be made now and in the years ahead to protect biodiversity will be critical in allowing its long-term persistence. The implications of failing to act are grave and potentially irreversible, not least for the global food system. This period, where opportunities for decisive action are finite, is therefore a unique time in history not only for biodiversity but also for humankind.

8.1 Sustainable intensification, ecosystem services and biodiversity

A key argument of this Report is that the global food supply will need to increase without the use of substantially more land and with diminishing impact on the environment: sustainable intensification is a necessity. Pursuit of this agenda requires a much better understanding of how different options for policy, both within and outside the food system, have impact on biodiversity and ecosystem services.

394 This chapter is based upon a more detailed Project Report C13 (Annex E refers).
395 MEA (2005); See UK National Ecosystem Assessment http://uknea.unep-wcmc.org/; SR39 (Annex E refers).
396 Lawton and May (1995)
397 Annex E refers

Box 8.1 Definitions:

Biodiversity: a term used to denote the variety of life on earth at all levels, from the genetic diversity within a species, the variety of species within a community or ecosystem, to the diversity of ecosystems themselves. Within the literature on food production, it is sometimes used in a more specialist sense to describe the genetic diversity within a crop or livestock species that may be valuable in breeding programmes.

Ecosystem: the plants, animals and micro-organisms at a particular locality linked by different biophysical processes constitute an ecosystem. Ecosystems may be highly influenced by man (for example, urban ecosystems and agro-ecosystems), may be relatively natural (rainforests, coral reefs), or at some point in between.

Ecosystem services: the benefits people obtain from ecosystems[398]. They can be classified as:

- *Provisioning services* are direct goods such as food, fibre or timbers.
- *Regulating services* help enable the provision of direct goods, for example by providing pollinators, natural enemies of pests, pure water, and a conducive local climate.
- *Supporting services* are more fundamental processes, such as those producing fertile soils and recycling water or nutrients, as well as the maintenance of genetic diversity that may be of future value to agriculture.
- *Cultural services* are generally less tangible public goods, such as landscapes that people cherish, and the preservation of biodiversity, that in most value systems are considered beneficial.

Ecosystem services can also be classified as *final,* those that directly benefit mankind; as opposed to *primary* and *intermediate,* which are typically ecological functions such as soil formation which act at an earlier stage. Concentrating on final ecosystem services avoids the risk of double-counting environmental benefits. The value of a final ecosystem service has two components: that provided without cost by the environment, and that ascribable to human input. Thus, the value of food produced by an agro-ecosystem is in part due to human investment, inputs and labour, but also to services provided without cost by the environment, which might include the supply of pure water, fertile soils, pollinators and natural enemies of pests. Different policy decisions can have positive or negative effects on ecosystem services and their explicit consideration is critical in setting priorities and maximising benefits. The capacity of an ecosystem to provide beneficial services is called its *natural capital*.

The concept of sustainability used in this Report is defined in Box 3.5. From a perspective of ecosystem services, a food system that is sustainable would not erode the natural capital of agro-ecosystems, for example the quality of the soil, the value of farmland in flood protection, or the capacity to purify water. Similarly, marine and freshwater capture fisheries would be exploited at renewable rates. A sustainable food system would limit the release of substances such as nitrates, greenhouse gases and other pollutants into the environment so that ecosystem services from other habitats would not compromised. A sustainable food system would also prevent the further loss of biodiversity.

It is crucial that policy makers appreciate the range of trade-offs affecting decisions involving food supply and ecosystem services. Important trade-offs include:

- **Yield versus ecosystem services:** Raising yield has often in the past come at the expense of different ecosystem services[399]. For example, optimising productivity in arable fields may involve the elimination of all non-crop species and hence a reduction of biodiversity. It may also involve an increase in the application of nitrogen fertiliser, and hence lead to both a reduction in the ability of the agro-ecosystem to provide pure water (an ecosystem service) and a rise in nitrogen run-off and greenhouse gas emissions (which harm ecosystem services).

398 Fisher and Turner (2008)
399 Donald (2004); Green et al. (2005a,b)

- **Trade-offs between ecosystem services:** Different ecosystem services are favoured by different management strategies. For example, positive ecosystem services, such as pollination and pest control provided by natural habitats, can be maximised by a landscape configured as a mosaic of farmed and non-farmed patches. However, such a landscape would not help conserve species that require large contiguous areas of habitat[400]. One goal of modern land use planning is the development of multifunctional landscapes[401], and its implementation will require the identification and understanding of multiple trade-offs amongst ecosystem services and other land-use objectives[402].
- **Land sparing versus wildlife-friendly agriculture:** A major debate concerns the relative advantages of adopting agricultural practices that stimulate on-farm biodiversity at the expense of yield, and raising yield on farmland to allow other land to be set aside for the protection of biodiversity. The relative advantages of these two alternatives depend critically on how yield increases and biodiversity decreases along the dimension of increasing intensification[403]. Complications also arise if the intensification of production in farmed areas produces negative externalities, such as pollutants, that reduce the functional value of land set aside for biodiversity[404], or if the political and institutional structures do not exist to realise the biodiversity-related benefits of 'land sparing'. This term is used to describe the strategy of increasing yields at the cost of biodiversity in some areas to allow land to be spared for conservation elsewhere.
- **Biodiversity and the needs of the poor:** Some of the most threatened and diverse habitats on earth exist in very low-income countries, and interventions that make farming more wildlife-friendly, fishing less damaging, or that set land aside as reserves, may impact on the livelihoods of the very poorest people. Some have argued that there is seldom a trade-off between protecting biodiversity and rural livelihoods and that, for example, low-input, labour-intensive agriculture in low-income countries is both pro-poor and pro-biodiversity[405]. Undoubtedly, this can sometimes be the case, but in other circumstances the needs of low-income societies will be better met by adopting more intensive forms of agriculture, in which case setting land aside as reserves may be essential to protect biodiversity. Whatever strategies are adopted, it is important to understand and quantify possible impacts on the livelihoods and wellbeing of communities as there are strong ethical arguments against imposing the costs of protecting biodiversity on those least able to pay them.

8.2 Linking food system and environmental policy at different geographical scales

The political reality that sustainability cannot be pursued in the absence of food security, and the fact that food production requires ecosystem services provided by both farmed and non-farmed land, means that policy in these two areas needs to be developed and properly connected at global, national and landscape scales.

At the global scale, there is a need to:

- **Recognise that food security and environmental protection are interdependent**. No government can pursue meaningful policies to protect the environment unless its citizens enjoy food security, which requires a properly functioning global food system. While it may be possible to increase food production in the short term without concern for the environment, over time unsustainable practices will undermine both agricultural productivity and fisheries catches. Because environmental feedbacks operate with a time lag, there is a danger of a negative spiral unless sustainability is emphasised from the outset.
- **Develop mechanisms to reward countries that produce supra-national environmental goods.** A particularly important example of the production of a supra-national environmental good is reduction in greenhouse gas emissions (see Chapter 7), but there are many other cases where both negative and positive environmental externalities of food production cross national boundaries. In addition, protection of biodiversity is a global good, as well as something to which individual nations accord a

400 SR36 (Annex E refers)
401 Foresight (2010)
402 Rodríguez et al. (2006)
403 Green et al. (2005a)
404 Daly et al. (2007)
405 Perfecto et al. (2009)

value. International policy needs to ensure that countries obtain benefits from providing global goods, especially when costs are borne by low-income countries.

- **Avoid policies that negatively impact the environment in other countries.** Measures to protect the environment in one country may have negative consequences if they provide a stimulus for environmental degradation in another country. Preventing such outcomes requires a good understanding of the direct and indirect environmental impacts of different actions, as well as consistency in environmental protection across countries (and avoidance of arguments for environmental protection being co-opted to protect national interests).
- **Coordinate the protection of biodiversity across administrative or national borders.** Much significant biodiversity can only be protected with coordinated regional or international action. Examples include species that require large contiguous habitats that can only be provided in reserves which cross borders, and the protection of migratory birds and other species that require suitable habitats, often in agro-ecosystems, in multiple countries.

At the national and 'landscape' scales, there is a need to:

- **Make land sparing work.** Land sparing may be the best strategy to maintain threatened non-food producing habitats, which provide very critical ecosystem services. It may also be the best approach for protecting biodiversity that cannot survive on land where the primary function is food production. Similar options might arise, for example, in using aquaculture to compensate for the creation of aquatic protected areas. However, the success of land sparing requires, first, institutions that can make decisions at the landscape level, and, secondly, mechanisms to ensure that the economic benefits of higher yields in some areas are shared by groups that suffer disadvantages from the creation of reserves.
- **Develop new infrastructure sensitively.** In Chapters 4 and 6, the importance of better infrastructure in low-income countries was stressed as a critical development strategy contributing to tackling hunger amongst poor people. Different options for infrastructure may vary in their impact on biodiversity. One example is the development of roads, often essential to achieving growth in rural incomes. Roads built through areas of protected biodiversity can have disproportionate effects, both through edge effects (for example the impact of a disturbance can penetrate deep into a forest) and through enabling illegal settlement and timber extraction. Similarly, the construction of ports can affect mangrove, coral reef and other coastal and marine ecosystems. It is therefore essential that impacts on biodiversity should be part of decision-making processes in the selection of options for infrastructure.
- **Consider biodiversity in planning at the landscape-scale.** Interventions at the landscape-scale can offer different ways of mitigating the effects of agriculture and food production on biodiversity and other ecosystem services. For example, in a highly modified landscape, areas of terrestrial or aquatic habitat with high biodiversity value may be restricted to isolated patches, and individual species may become at risk of local extinction due to small population size. Corridors linking habitats can help mitigate such threats.
- **Implement realistic minimum environmental flows.** The requirement to maintain minimum environmental flows in rivers is the single most important competing demand for water that agriculture faces[406]. Minimum flows are needed both to maintain aquatic ecosystem services and to preserve biodiversity. Often they are set at only a small percentage of the original natural flow (and may involve periods of no or very little flow). Many scientists argue that they need to be raised, often significantly so, hence increasing the need for water efficiency in agriculture. The development of integrated water management with sustainable aquaculture and freshwater fisheries can provide multiple benefits for food production, rural incomes and biodiversity.
- **Consider setting aside marine and freshwater protected areas.** The setting aside of marine areas, coastal habitats (including reefs, seagrass beds etc.), river or lake zones as reserves where no fishing is allowed can halt specific habitat damage and improve biodiversity. It has been argued that protected zones have the potential to benefit adjacent fisheries through enhancing stock recruitment, although more evidence of this effect is needed. The design and management of such zoning systems requires careful assessment but has considerable potential. The value of protected areas varies with their size, the type of ecosystem protected, and the effectiveness of controls on external fishing pressures.

406 DR12 (Annex E refers)

However, on balance, if well designed and effectively supported, it is likely that protected areas will have an increasingly valuable role in sustaining aquatic biodiversity.

- **Recognise the importance of 'wild foods' in low-income countries.** There is not a simple dichotomy between land used for food production and unmanaged areas. The provision of food to poor communities by natural habitats is an ecosystem service that has been consistently underestimated[407] and which needs to be better incorporated into both biodiversity and food policy. Non-cultivated plants and animals that persist in predominantly cultivated terrestrial and aquatic systems may also provide important supplementary food, particularly for the very poor at times of food stress. These sources of food should be considered in debates about the intensification of production in low-income countries.

Box 8.2 The crucial need to preserve tropical rainforests

Much of the land around the globe that could be brought into agriculture is currently covered by tropical rainforest. Pressure from expanding agriculture has been a major factor leading to recent tropical deforestation, especially in South America (where conversion to soybean and cattle ranching is the greatest pressure) and South East Asia (due to oil palm conversion). This form of deforestation has a number of very adverse effects:

- The conversion of tropical forests to agriculture releases large one-off amounts of greenhouse gases (GHG), and this is one of the most serious contributions of the food system to global warming. It also reduces the land's subsequent ability to take up GHGs.
- Tropical deforestation may have direct and damaging effects on local climate.
- Much of the associated biodiversity can only exist in rainforest, and is lost immediately when the land is converted to other uses.
- Tropical rainforests are home to many indigenous groups of people.

The Report concludes that there will hardly ever be a case to convert forests, especially tropical rainforests, to food production.

The importance of tropical forests to climate change was underlined by the launch in September 2008 of the United Nations Collaborative initiative on Reducing Emissions from Deforestation and forest Degradation (REDD), which offers incentives, through externally financed strategies, for low-income countries to reduce emissions from forested lands and invest in low-carbon paths to sustainable development. REDD+ (a commitment at COP 15 Copenhagen and reinforced at COP16 Cancun) goes beyond deforestation and forest degradation, and includes the role of conservation, sustainable management of forests and enhancement of forest carbon stocks and helps to enhance biodiversity and improve other ecosystem services such as watershed control. To achieve these multiple benefits, REDD+ will require the full engagement and respect for the rights of Indigenous Peoples and other forest-dependent communities, and will need to establish monitoring protocols to ensure the fair distribution of benefits and avoid the creation of perverse incentives. A new initiative that calls for agriculture to be part of the solution to climate change was announced at the COP16 climate negotiations in Cancun, Mexico, and proposes key actions to be taken to link agriculture-related investments and policies with the transition to 'climate-smart' growth. An increased focus on aligning REDD+ with agriculture and food security in low-income countries will be essential for its success.

8.3 Improving biodiversity and ecosystem services on farmed land, and through fisheries management

Terrestrial and aquatic ecosystems used in food production need to be managed so that they achieve multiple goals. As noted throughout this Report, where high productivity is important, then sustainable intensification should be the key principle. But as explored in a recent Foresight report[408],

407 DR21 (Annex E refers)
408 Foresight (2010)

land will also need to be managed for multiple functions: for example, food production, supporting rural economies, flood management and protection of biodiversity. Aquatic zones, particularly inland and coastal areas, require similar approaches. The challenges and opportunities of multifunctional uses, including integrating land and water food production systems are critical for policy formulation.

Some ecosystems used primarily for food production have particularly high biodiversity value. Examples include:

- Many agro-ecosystems in the Mediterranean basin that have high biodiversity adapted to agricultural practices that have persisted for several thousand years.
- Cork oak forests in Iberia.
- Grassland ecosystems such as the steppes, where cattle, sheep and other livestock have replaced natural grazers, some of which are now extinct.
- Wetlands used for rice growing, aquaculture and fishing.
- Coral reef marine ecosystems subject to capture fisheries.

For these special agro-ecosystems a strong policy imperative to protect biodiversity, even at the cost of reduced yields, is essential. But, even when such considerations do not apply, it may be possible to improve the provision of ecosystem services or protect biodiversity with relatively modest costs to yields.

Evidence-based, wildlife-friendly farming. There is a very large literature on wildlife-friendly farming and the numerous ways that biodiversity can be encouraged on productive land. Many high-income countries have schemes that reward or incentivise food producers for practices that encourage wildlife, although there have also been debates about the effectiveness of some of these interventions. Such schemes can potentially be of great benefit to wildlife, but there needs to be a more analytical and evidence-based approach to establish what works best. For example, in investing to support biodiversity, a full range of management options (including setting land aside in reserves) should be considered. When alternative interventions are compared, the appropriate spatial and temporal scales should be employed[409].

Biodiversity-sensitive fisheries. The development of ecosystem approaches for fisheries (EAF) management has potential benefits for both biodiversity and production, and although comprehensive approaches require considerable resources, elements can be adopted in many fisheries. In the absence of fully developed EAFs, the immediate prospects for protecting or building biodiversity are based on strategic measures such as controlling illegal fishing, reducing by-catch by improving fishing gear, as well as more specific actions such as creating protected zones, defining and protecting endangered species, controlling stock movements, banning destructive fishing methods, and restricting predator culls. For aquaculture, measures to avoid the use or release of non-native species, contamination of wild-species gene pools, and the culling of endangered bird, reptile or mammal predator species are important to protect biodiversity[410].

8.4 Strategic implications for policy

This Report has stressed the close connection between the development of policy for the environment, and for food supply and security. Although there has been a considerable coming together of the two domains in recent years, there are still areas of food system-related policy that pay insufficient attention to ecosystem services and biodiversity. For example, policy-makers in the agricultural sector sometimes use narrowly value-laden descriptions of non-agricultural land, describing it, for example, as wasteland or wilderness. This is both inappropriate and inaccurate, because all land has some value in providing ecosystem services, and this fact needs to be widely recognised. In contrast, some environmentalists attack modern agriculture without providing a viable alternative for how the global population can be adequately fed.

409 C13 (Annex E refers)
410 DR8 (Annex E refers)

The arguments in this chapter and the Report illustrate the benefits of making environmental issues an integral part of food system planning, and provide the basis for some strategic implications for policy makers:

- **Major knowledge gaps that urgently require further research**.
  - The ecological basis of many ecosystem services and their resilience to perturbation.
  - The economic assessment and evaluation of ecosystem services and biodiversity, building on international and national ecosystem assessments as well as initiatives such as *The Economics of Ecosystems and Biodiversity*[411] and the recently announced World Bank programme on the *Global Partnership for Ecosystems and Ecosystem Services Valuation and Wealth Accounting*[412]. The development of metrics and methodologies to assist the monitoring and scrutiny of programmes intended to enhance ecosystem services and biodiversity.
  - The development of a more analytical evidence base to judge between different management alternatives.
- **National and supranational governance.** Many of the most critical decisions in this area require decisions at national scale (for example, land use policy) or at international scale (governance of factors affecting global goods). Environmental issues at all scales are being brought much more into policy making as a whole than in the past, but this must be continued and strengthened.
- **Negative environmental externalities.** There needs to be a greater realisation that market failures exist in the food system that, if not corrected, will lead to irreversible environmental damage and long-term threats to the viability of the food system. Moves to internalise the costs of these negative environmental externalities are critical to provide incentives for their reduction.
- **Aligning environmental and market incentives.** Progress on achieving desirable environmental goals will be most easily achieved when they are congruent with market incentives. In addition to internalising the negative costs of environmental damages, the consumer (both individual and institutional) can play an important role by choosing to purchase food produced in environmentally sustainable ways. As discussed in Chapter 4, this approach requires clear metrics of sustainability or trusted certification schemes, and informed consumers who are given the requisite information.
- **Environmental protection and stewardship.** Payments for environmental stewardship are a means of both supporting rural incomes and protecting the environment without distorting agricultural markets. Such schemes should be designed so that they support the long-term maintenance of on-farm biodiversity, and are robust to changes in the food system and economic conditions. Stewardship schemes are less frequent in low-income countries, including those with centres of biodiversity, and should be encouraged.

411 TEEB (2010)
412 World Bank (2010)

9 Empowering choices and actions: developing indicators and tools for policy makers

By considering five key challenges facing the global food system over the next 40 years, previous chapters have highlighted a range of deficiencies in the evidence and analysis available to policy makers. This chapter draws together those threads to suggest a number of areas where improvements should be made.

The development of a number of classes of 'indicator' is also advocated – these relate to drivers of change and particular aspects of the global food system. If developed and adopted, they would provide important tools for decision-making, and for assessing the outcomes of policy decisions.

9 Empowering choices and actions: developing indicators and management tools

9.1 Better metrics for drivers affecting the global food system and for monitoring and evaluating policies

Policy development in the global food system requires accurate data on the external factors driving change, as well as indicators of how the food system is functioning. Without this information, managing and monitoring the food system cannot be done effectively, and in particular, policy cannot adapt to an uncertain future. Although extensive information is already collected on some aspects of the food system[413], data are poor in other areas, and data resources are often scattered and inaccessible. Also, links are often not made with relevant activities between different areas of policy. Investment in a better and more accessible database and the development of indicators and management tools to improve monitoring and evaluation should be a high priority for policy makers and research funders.

Though large amounts of data are collected on some aspects of the food system, there are major gaps that hinder analysis and planning. This Project has highlighted gaps in, for example, the measurement and monitoring of hunger, and the extent of waste in all parts of the global supply chain. Some gaps reflect the difficulty of collecting data in low-income countries or in nations without a culture of openness. Others arise because it is only recently that the need for the information has been recognised, for example, on the different components of sustainability.

As well as providing the evidence base upon which to design, monitor and evaluate policy, the collection of data and the development of indicators have other important functions. For example, they enable a more informed discourse about the successes and failures of the global food system, and allow civil society to judge progress against targets. They also facilitate analysis, and help improve food system management.

The primary challenge in developing metrics and measures of the food system is to cope with its enormous complexity. Inevitably, no single indicator can hope to encapsulate more than a fraction of the information of importance to policy makers. Instead, a portfolio of measures is required, which is referred to here as the food system 'dashboard'.

Indicators and other metrics should be developed as far as possible using existing national, sectoral and international data collection exercises, but promoting, wherever possible, the development of common standards and data ontologies. A further challenge is the fact that the choice of indicators and the weighting given to their different components is inevitably strongly influenced by ethical values and political judgements. However, developing common metrics and methodologies can be valuable in revealing shared positions as well as identifying different underlying assumptions and goals.

Modern information and communication technology (ICT) offers vast scope for improving the quantity, quality and accessibility of information available about the global food system. Satellite and mobile telephony and the growing ubiquity of the web make the collection of data more straightforward, as well as its analysis and dissemination. Developments such as cloud computing and the more intelligent handling of data using semantic web technology will further enhance the value and importance of shared information and agreed indicators. Active steps will be required to ensure that low-income countries are not left behind and to avoid the creation of an international 'digital divide'.

This chapter first considers better indicators and monitoring for hunger. It then explores what might be included in a food system dashboard, before considering how to empower consumers through access to better data and food system metrics. It finishes by considering issues of marshalling evidence in areas of

413 The contribution of the FAO to this process has been particularly strong, through its FAOSTAT statistics.

high uncertainty – particularly those involved with modelling the food system's interaction with climate and global trade.

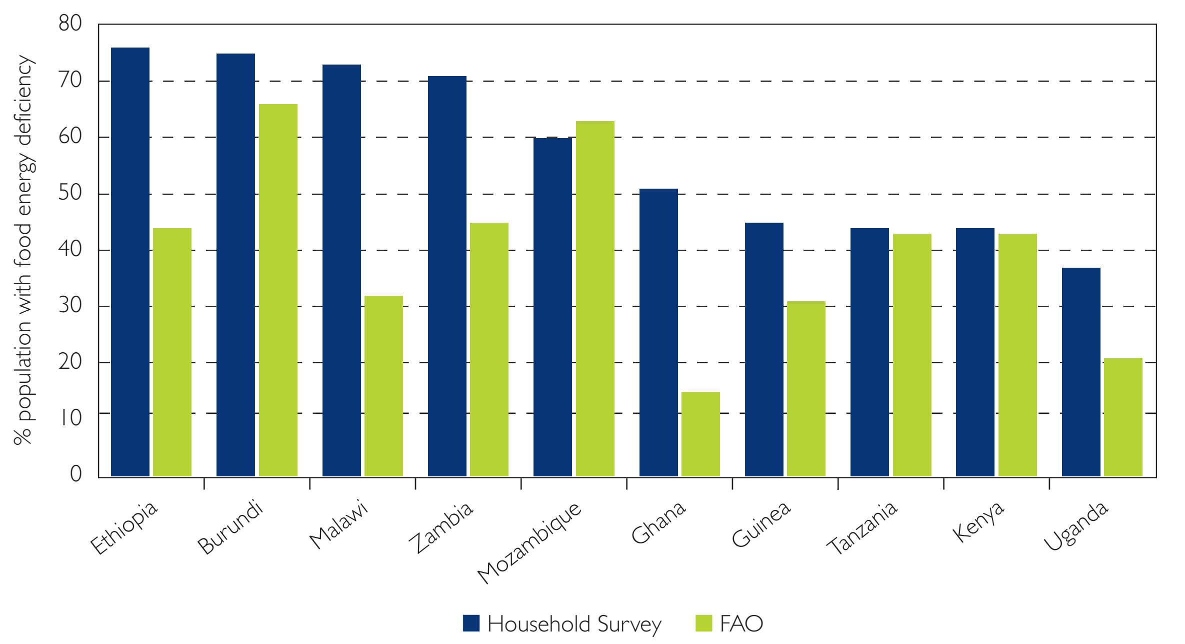
9.1 Better indicators and monitoring for hunger

Assessments of the extent of different types of hunger and malnutrition, and quantitative means of evaluating the outcomes of policies that address hunger need to be improved.

This was discussed in more detail in Chapter 6, where it was concluded that[414]:

- Current undernourishment data are anachronistic and need to be brought into line with modern understanding of human health and nutrition. There is a strong case for the FAO, WHO and World Bank to work together to develop much more accurate indicators of hunger. Evidence suggests that current indicators may be understating the magnitude and geographical distribution of the problem (see Figure 9.1).
- Governments need hunger data that are up to date and less than a year old to enable them to respond with agility to rapidly changing drivers and events. At present, and regardless of the particular hunger indicators employed, they are collected too infrequently. National agencies should explore developing novel real-time indicators that focus on bellwether sites using new information and communication technology.
- Indices describing different governments' commitments to hunger reduction can be powerful incentives for action. Civil society should work with their national governments to develop and publicise hunger commitment indices that are expressed in ways that facilitate monitoring and accountability.
- Similarly, there are few data and poor indices to assess the effectiveness of investment in agriculture to promote development to increase rural incomes, and to reduce hunger. Involving farmers in assessing the effectiveness of agricultural interventions has substantial promise in terms of empowering farmers, holding policy-makers to account, and, ultimately, making agriculture do more to reduce hunger. Working with farmers and other food producers to develop the information base will be important in rectifying the weak culture of monitoring and evaluation in agriculture, and so capitalising on the latest resurgence of interest from policy-makers[415].

Figure 9.1: Percentage of population with food energy deficiency: comparison of Household Survey and FAO estimates



Source: from data in IFPRI Research Report Smith et al. (2006)

414 See also Project Report C11 (Annex E refers).
415 Pinto et al. (2010)

9.2 A food system 'dashboard'

This section offers a first step in defining the information that would comprise a food system dashboard. Box 9.1 suggests some possible metrics to characterise important aspects of the food system. However, this is intended to be illustrative. A comprehensive and definitive set of indicators will need to be developed and agreed, working together with relevant policy-makers.

Box 9.1 Potential components of a food system dashboard

The following provides an indicative list of the type of metrics needed to allow the performance and state of the global food system to be assessed.

Demand metrics (global and by nation)

- Population size and age structure
- National GDP; employment; per capita income distribution
- Statistics on the income and education of women
- Rural and urban population distribution
- Consumption patterns (by major food types including meat, fish and dairy)
- Consumer and supply chain waste.

Supply metrics (global and by nation, fishery and agro-ecological zone)

- Production statistics (by all major crops, production systems and livestock species)
- Marine and terrestrial capture fishery yields, fishing fleet statistics
- Fraction and percentage of crop, animal, fish yields lost to disease
- Post-harvest waste in the food supply chain.

Economic and governance metrics

- Current and future commodity prices
- Patterns and volumes of trade by commodity
- Transaction and transport costs
- Yield, labour, capital and total factor productivity
- Producer and consumer support estimates[416], bound and applied agricultural trade tariffs
- Distribution of market share by company in agribusiness, supply chain and retail sectors
- Value added through the food chain
- Investment in food production infrastructure
- Investment in research by public, private and third sector.

Health and hunger metrics (see also previous section)

- Numbers of currently hungry, malnourished and overweight (including hidden hunger)
- Indices of maternal and child nutritional health
- Indices of commitment and action on hunger
- Measures of food poisoning
- Measures of food production safety (pesticide poisoning).

416 See the OECD's Producer and Consumer Support Estimates Database: http://www.oecd.org/document/59/0,3343,en_2649_33797_39551355_1_1_1_37401,00.html

Sustainability metrics

- Climate change
  - Climate and weather statistics
  - Global and regional CO_2 and other GHG emissions attributable to different parts of the food system
  - Carbon stored in different food-producing landscapes
  - Mitigation and adaptation measures by nation.
- Land use (displayed geographically)
  - Major land use types and recent crop history
  - Land conversion to agriculture
  - Land degradation (through erosion, desertification, salinisation, etc.)
  - Land under specific land management practice (e.g. zero-tillage, conservation agriculture, organic).
- Hydrology (displayed geographically)
  - Precipitation
  - Water types (blue, green, brown)
  - Actual river flows
  - Aquifer reserves
  - Flooding risk (through excess flow and raised sea level)
  - Water management: impoundment and regulation levels; hydrological balance characteristics, water productivity (output and value); water withdrawal by agriculture; reuse ratios
  - Water quality and pollutant levels.
- Energy
  - Energy intensity of food production
  - Sources of energy used in food production.
- Global aquatic ecosystems
  - Fisheries stocks
- Ecosystem services
  - Estimation of ecosystem services provided by food production systems

Whatever metrics are developed and used to aid the global governance of the food system, they will need to build upon existing national and international statistical systems where possible – for example, the FAO's Committee on World Food Security (CFS) 'National Food Security Indicators'[417] (see also Box 9.2 which provides an illustration of work on metrics being undertaken at national level – in this example, the UK).

The need to improve metrics has also been highlighted by the United Nations' High-Level Task Force on the Global Food Security Crisis, which has stressed the requirement for stronger systems of assessment, monitoring and surveillance as one of the aims of their Comprehensive Framework for Action[418]. However, while these focused on food, development and nutrition, it is suggested here that they should be strengthened to give greater emphasis to the whole food system, and include wider issues such as sustainability and the resource pressures facing the global food system.

Given the size, scale and expertise required to coordinate such a task, it would require the active involvement of UN organisations and especially the FAO. A partnership would be required that would

417 http://www.fao.org/unfao/govbodies/cfs/indicators_en.htm. These statistics cover: food deprivation and child malnutrition; food consumption and diet diversification; economic growth, poverty and employment; education and gender equality; health and sanitation; agricultural development; water, natural resources and infrastructure; trade, national debt and development assistance.

418 United Nations' High-Level Task Force on the Global Food Security Crisis; Comprehensive Framework for Action.

include, alongside the FAO, other UN and UN-associated bodies, such as the WHO, WFP, WHO and IPCC, as well as multilateral investment agencies and regional, sectoral and national data bodies. It would also require broad input and agreement from governments, the private sector, NGOs and individuals involved in the food system, from producers to consumers.

If properly designed, and if general agreement can be reached from the majority of participants in the food system, the central dashboard could provide coherence across the whole food system, and become a critical tool in designing, monitoring and evaluating the policy required to meet the challenges described in this Report.

Box 9.2 Illustrative work on indicators that could be drawn upon – UK example

The UK Food Security Assessment[419], led by the UK's Department for Environment, Food and Rural Affairs (Defra), aims to assess the sustainability and security of the UK's food supply within a global context, through establishing the most appropriate indicators from existing metrics. The assessment captures longer-term environmental challenges and global drivers that will influence a nation's food security with the following themes: Global Availability; Global Resource Sustainability; UK Availability and Access; UK Food Chain Resilience; Household Food Security; and Safety and Confidence in the food supply.

Each theme is associated with a headline indicator, and a number of supporting metrics. The UK Food Security Assessment acknowledges the need for a time frame and tracking assessment alongside the data, as well as supporting analysis and evidence for each metric. The UK's experience has shown that national metrics that go beyond the concept of self-sufficiency and which take a more nuanced view of access, availability and resilience of the food supply can be a helpful tool to policy makers. This has been used to inform the UK Government's Food Strategy[420].

9.3 Indicators to empower and influence consumers

Empowering individual choice in the global food system has great potential to create multiple benefits for individuals, communities, societies, and for the environment. The collective demand of a projected nine billion people in 2050 will exert enormous influence on what kind of food is produced, where it is sourced, and how it is grown or harvested. Here the challenge, and the opportunity, is to ensure the provision and use of adequate high-quality information, without overloading the consumer with complex and confusing figures. Clear data and agreed common indicators, possibly aided by the use of new information and communication technologies, could enable consumers to make more informed decisions and so incentivise a range of beneficial outcomes, for example improved sustainability, better protected biodiversity, and reduced GHG emissions.

There is a spectrum in the type of information that can be provided to consumers that is best illustrated by health-related labelling of food. Actual data can be provided (for example mg of fat per item) or the data can be processed to provide an indicator (a traffic light designation with green indicating a low-fat food). There is a considerable body of research on which types of information are most effective in empowering consumers to make decisions, although the conclusions are contested and different food industry companies have strongly divergent views on labelling.

Producing indicators to describe the sustainability of food production systems or their effects on poor people is complex because the component data are highly multidimensional. Inevitably, indicators or certification schemes rather than raw data are required. In some cases, indicators could build on data and indicators developed by food-related businesses for their own requirements. However, engendering confidence and ensuring impartiality will be critical, and this will almost certainly require the involvement of trusted third parties. A wide range of indicators have been developed to describe different forms of food production, involving private, public and third sector schemes as well as all different combinations. There is a need for rigorous research into which schemes work best and have the most desirable outcomes. As was discussed in Chapter 7, representatives of the commercial retail sector consulted

419 See http://www.defra.gov.uk/foodfarm/food/security/index.htm
420 Defra (2010)

during the Project indicated that they would welcome leadership by governments in helping to define and agree sustainability standards[421].

There is a danger that the complexity of the problem of developing sustainability and pro-development paralyses action. Enough is known now that it is possible to develop semi-quantitative measures of the impact of different production systems on the environment ('food footprints') or on people in low-income countries. Sustainability and pro-poor traffic light indicators, or new certification schemes, could be developed were there sufficient will and engagement across sectors. To incentivise desired responses in the food system these indicators or certification schemes would need to be based on transparent metrics, with care needed in their design to avoid perverse incentives. They would need to be in place long enough to justify private sector investment to improve performance, but subject to periodic revision in the light of monitoring, evaluation and new understanding.

The development of new indicators should also take into account the likely transformative role of new technology. For example, even with today's technology, it would be possible for a consumer to define a specific set of criteria for the food they want to purchase and then use a barcode- and web-enabled mobile phone to make real-time decisions about whether specific items in a retail outlet met their own personal standard. Individuals could, for example, choose the relative weights they accord to health, the environment (local or global) and to workers in low-income countries. Further ahead in the future, advanced devices in the home may be able to monitor food purchase and waste, and provide metrics and indicators of the efficiency of food use at the level of the individual household. These data could be aggregated at the level of the local community, or linked with data provided by food retailers, to develop novel metrics to incentivise behaviour at levels intermediate between the individual, company and government.

Public procurement and that by large institutions can also exert significant influence on markets to increase the sustainability of production systems or to have beneficial effects on low-income food producers. Indicators are essential for the organisations themselves to understand the consequences of their purchasing decisions, and for citizens and citizens' organisations to be able to hold them to account. Governments, particularly those in high-income countries and emerging economies, where food supply chains have the greatest impact, should look closely at the impact of government food procurement and set up clear frameworks and indicators designed to deliver wider public goods.

9.4 Improving food system modelling

In view of the complexity of the global food system, and the many interacting factors affecting it, interdisciplinary research is vital. Food system modelling in particular will continue to be an invaluable tool for informing policy-makers. Modelling is very far from a panacea and faces huge challenges – yet it is the only tool available for trying to understand the complex non-linear interactions of the numerous drivers affecting the food system.

There have been substantial achievements by the major groups throughout the world who have pioneered food system modelling. However, there is significant scope for the development of improved modelling capabilities and two specific proposals are described in Box 9.3: a forum for discussion and development of modelling methodologies, and an open-source database to provide better evidence, upon which models can be built and which avoids current duplication of effort.

Models of the food system have to cope with huge uncertainty, but are not alone in this. The field can benefit from expertise in cognate fields such as climate modelling in the physical sciences and the study of health provision in the social sciences. Food system models began as relatively narrow economic models but are continuing to expand to include hydrological, climate and plant physiological components. This needs to continue and expand even further.

For models to be useful for decision-makers, they must provide information in intelligible form that does not conceal their inherent uncertainties and imprecision. Advances in the analysis and presentation of climate models will also be useful. Finally, not only are good models needed but also intelligent customers, and decision-makers need to understand the strengths and weaknesses of the approach.

421 See Project Report W2 (Annex E refers).

Box 9.3 Improving data for modelling, and the linkages between models

Catalysing a forum for international food system modelling. The Project's international workshops have highlighted the need to bring together crop, agricultural trade and climate modellers to enable a more systematic comparison of different models, to share results and to integrate their work to meet better the needs of policy-makers. As a result, and following a call from both modellers and policy-makers, Foresight is in discussion with key participants on how to catalyse an international food system modelling forum, using the Energy Modelling Forum as an exemplar[422].

A proposed global, spatially-explicit, open-source database for analysis of agriculture, forestry and the environment[423]**.** Spatially explicit data hold the key to analysing issues of long run sustainability of the world's food system. While there are open-source global spatial databases on climate – motivated by the Intergovernmental Panel on Climate Change, there are no comparable databases for agriculture. Indeed, existing databases are either regional or national in scope, or they are incompatible and often not publicly available; when available, technical challenges preclude their widespread use. This has greatly inhibited the ability of researchers to address global issues adequately (i.e. issues ranging from climate change mitigation, to environmental impacts of biofuels, to offsite pollution from agriculture and the preservation of biodiversity). This proposal intends to create new infrastructure to support researchers working in these areas.

The proposed effort would: 1) gather national and sub-national statistics from various statistical agencies around the world to put together a consistent global data set, along with regional companion data sets, on agriculture and land use; 2) employ spatial disaggregation methods, including the use of satellite remote sensing technology and spatial statistics to develop geographically-explicit gridded data on a global scale; and 3) develop a data portal, including new tools for providing data in a variety of convenient formats to the global research community. A two-year pilot project will provide a limited set of data to the global community. This would involve a group of leading scientists who will champion this work – each one operating as an independent node, linked together, both bilaterally and through the administrative centre, which will be housed at Purdue University in the USA during this 'proof of concept' phase.

422 See http://emf.stanford.edu/

423 The authors of this proposal were Thomas Hertel (Purdue University), Wolfgang Britz (University of Bonn), Noah Diffenbaugh (Stanford University), Navin Ramankutty (McGill University) and Nelson Villoria (Purdue University), with additional contributions from Stanley Wood (IFPRI), Stefan Siebert (University of Bonn), Glenn Hyman (CIAT) and Andrew Nelson (IRRI).

10 Conclusions and next steps

This final chapter summarises the main conclusions of this Project. It argues for substantial change in the global food system and also in wider policy agendas.

It shows that inaction is not a viable option for policy makers, and argues the case for immediate steps to be taken. To be effective in the longer term, such action needs to be sustained and coherent, and championed at high level. Key actions for different classes of stakeholder are suggested.

10 Conclusions and next steps

This Foresight Project and other major studies[424] have shown that the global food system faces formidable challenges today that will increase markedly over the next 40 years. How the many different actors involved respond will affect the quality of life of everyone now living, as well as having major repercussions for future generations. Much can be achieved immediately with current technologies and knowledge, given sufficient will and investment. But coping with future challenges will require more radical changes to the food system and investment in research to provide new solutions to novel problems.

This Report has reviewed the major drivers that will affect the supply and demand for food over the coming decades[425]. It has highlighted the twin challenges of coping with the greater demand for food from a larger and on average wealthier global population, and producing food in a world increasingly experiencing climate change and ever-greater competition for land, water and energy. It has commissioned new economic modelling and reviewed existing studies[426] that attempt within the limitations of the analytical tools available to chart how food prices and availability may change between now and 2050. The consensus of these studies is that producing sufficient food to feed the global population will become increasingly difficult without major changes to the food system.

Identifying and implementing the changes to different components of the food system that will assure affordable and stable food supplies are two of the key challenges explored in this Report[427]. But the food system cannot be considered in isolation from other major global policy objectives. Producing enough food in the world so that everyone can potentially be fed is not the same thing as ensuring global access to food and ending hunger. The third key challenge discussed in this Report is to make changes to the food system and the broader development agenda to ensure the very poorest people enjoy food security[428]. Food production dominates much of the global land surface and water bodies, and has a major impact on all the earth's environmental systems. If the global food system continues to degrade the environment as it does presently, it will do major harm to the world's capacity to produce food in the future. It will also contribute further to climate change, and the destruction of biodiversity. The last two key challenges discussed in this Report are the critical issues of contributing to mitigation of climate change and making the food system sustainable[429].

Although this Report identifies five key challenges to the food system, it also stresses the importance of considering policy development in the round. In this chapter a number of key themes and conclusions that both summarise the Report and cut across the different challenges are highlighted, with an emphasis on what needs to be done immediately and who should do it.

10.1 Why action is needed now

There is urgency in taking what may be very difficult policy decisions today relating to diverse challenges facing the global food system, and also to address present levels of hunger – 925 million people suffer from hunger and perhaps a further billion lack sufficient micronutrients. It is imperative that the need for rapid action is realised by all concerned. However, this task is difficult because, notwithstanding recent volatility in food prices, the food system is working for the majority of people. Also, those suffering or at risk from hunger have the least influence on decision-making in the food system.

424 Annex C
425 Chapter 2
426 Chapter 3
427 Chapters 4 and 5
428 Chapter 6
429 Chapters 7 and 8

Besides the unacceptability of the present levels of hunger, some of the main arguments for immediate action are:

- The lack of sustainability in the global food system is already causing significant environmental harm, for example, through nitrogen pollution, food production's contribution to greenhouse gas emissions, and the drying up of rivers and lakes. Many marine ecosystems are damaged by unsustainable fishing.
- There is increased competition for, and scarcity of, inputs into food production. Of these, as discussed above, water is the most pressing, with significant effects on regional productivity likely to occur by 2030. Competition for land has also emerged as a significant factor in many countries.
- Some effects of climate change are now inevitable and the food system must prepare for them and adapt.
- The food system is a significant producer of greenhouse gases and must contribute to global mitigation efforts; immediate action on climate avoids the necessity of more radical measures in the future.
- There is the risk of negative irreversible events if action is not taken; this includes the loss of biodiversity, the collapse of fisheries, and the loss of some ecosystem services (for example, the destruction of soils).
- There is substantial evidence for increasing global demand for food (which probably contributed to the recent food price spike).
- Food security in 2030 and out to 2050 will require new knowledge and technology, and the basic and applied research underlying this needs to be funded now; there is evidence of a slowdown in productivity gains today correlated with a reduction in R&D investment in many countries over the last two decades.
- The absence of food security will also make it much harder or impossible to pursue a broad range of other policy goals. It may also contribute to civil unrest or to failed states; it may stimulate economic migration or fuel international tensions.
- Actions taken in the near future can address problems that if allowed to develop will require much more difficult and expensive measures later on.

10.2 High-level conclusions

A major conclusion of this Report is the critical importance of interconnected policy making. Other studies have stated that policy in all areas of the food system should consider the implications for volatility, sustainability, climate change and hunger, but here it is argued that policy in other sectors outside the food system also need to be developed in much closer conjunction with that for food. These areas include energy, water, land use, the sea, ecosystem services and biodiversity. Achieving much closer coordination with all of these wider areas is a major challenge for policy makers.

There are three reasons why broad coordination is needed. First, these other areas will crucially affect the food system and therefore food security. Secondly, food is such a critical necessity for human existence with broad implications for poverty, physical and mental development, wellbeing, economic migration, and conflict, that if supply is threatened, it will come to dominate policy agendas and prevent progress in other areas. And thirdly, as the food system grows, it will place increasing demands on areas such as energy, water supply and land – which in turn are closely linked with economic development and global sustainability. Progress in such areas would be made much more difficult or impossible if food security were threatened. The following highlight a number of key themes and conclusions:

1) Substantial changes will be required throughout the different elements of the food system and beyond if food security is to be provided for a predicted nine billion people by 2050. Action has to occur on all of the following four fronts simultaneously:

- More food must be produced sustainably through the spread and implementation of existing knowledge, technology and best practice, and by investment in new science and innovation, and the social infrastructure that enables food producers to benefit from all of these.
- Demand for the most resource-intensive types of food must be contained.

- Waste in all areas of the food system must be minimised.
- The political and economic governance of the food system must be improved to increase food-system productivity and sustainability.

The solution is not *just* to produce more food, or change diets, or eliminate waste. The potential threats are so great that they cannot be met by making changes piecemeal to parts of the food system. It is essential that policy-makers address all areas at the same time.

2) Addressing climate change and achieving sustainability in the global food system need to be recognised as dual imperatives. Nothing less is required than a redesign of the whole food system to bring sustainability to the fore.

The food system makes extensive use of non-renewable resources and consumes many renewable resources at rates far exceeding replenishment without investing in their eventual replacement. It releases greenhouse gases, nitrates and other contaminants into the environment. Directly, and indirectly through land conversion, it contributes to the destruction of biodiversity. Unless the footprint of the food system on the environment is reduced, the capacity of the earth to produce food for humankind will be compromised with grave implications for future food security. Consideration of sustainability must be introduced to all sectors of the food system, from production to consumption, and in education, governance and research.

3) It is necessary to revitalise moves to end hunger. Greater priority should be given to rural development and agriculture as a driver of broad-based income growth, and more incentives provided to the agricultural sector to address issues such as malnutrition and gender inequalities. It is also important to reduce subsidies and trade barriers that disadvantage low-income countries. Leadership in hunger reduction must be fostered in both high-, middle- and low-income countries.

Though the proportion of the world's population suffering from hunger has declined over the last 50 years, there are worrying signs that progress is stalling and it is very unlikely that the Millennium Development Goals for hunger in 2015 will be achieved. Ending hunger requires a well-functioning global food system that is sensitive to the needs of low-income countries, although it also requires concerted actions that come from within low-income countries.

4) Policy options should not be closed off. Throughout, the Project's Final Report has argued the importance of, within reason, excluding as few as possible different policy options on a *priori* grounds. Instead, it is important to develop a strong evidence base upon which to make informed decisions.

Food is so integral to human wellbeing that discussions of policy options frequently involve issues of ethics, values and politics. For example, there are very different views on the acceptability of certain new technologies, or on how best to help people out of hunger in low-income countries. Box 10.1 both illustrates the need to keep policy options open, and gathers together the Report's conclusions about the application of new technologies, such as the genetic modification of living organisms, the use of cloned livestock, and nanotechnology. Achieving a strong evidence base in controversial areas is not enough to obtain public acceptance and approval – genuine public engagement and discussion needs to play a critical role.

5) This Report rejects food self-sufficiency as a viable option for nations to contribute to global food security but stresses the importance of crafting food system governance to maximise the benefits of globalisation and to ensure that they are distributed fairly. For example, it is important to avoid the introduction of export bans at times of food stress, something that almost certainly exacerbated the 2007-2008 food price spike[430].

The food system is globalised and interconnected. This has both advantages and disadvantages. For example, economic disruptions in one geographical region can quickly be transmitted to others, but supply shocks in one region can be compensated for by producers elsewhere. A globalised food system also improves the global efficiency of food production by allowing bread-basket regions to export food to less-favoured regions.

430 HMG (2010)

Box 10.1 Appraising new technologies in the food system

- New technologies (such as the genetic modification of living organisms and the use of cloned livestock and nanotechnology) should not be excluded *a priori* on ethical or moral grounds, though there is a need to respect the opinions of people who take a contrary view.
- Investment in research on modern technologies is essential in the light of the magnitude of the challenges for food security in the coming decades.
- The human and environmental safety of any new technology needs to be rigorously established before its deployment, with open and transparent decision-making.
- Decisions about the acceptability of new technologies need to be made in the context of competing risks (rather than by simplistic versions of the precautionary principle); the potential costs of *not* utilising new technology must be taken into account.
- New technologies may alter the relationship between commercial interests and food producers, and this should be taken into account when designing governance of the food system.
- There are multiple approaches to addressing food security, and much can be done today with existing knowledge. Research portfolios need to include all areas of science and technology that can make a valuable impact – any claims that a single or particular new technology is a panacea are foolish.
- Appropriate new technology has the potential to be very valuable for the poorest people in low-income countries. It is important to involve possible beneficiaries in decision-making at all stages of the development process.

10.3 Addressing the five future challenges

Challenge A: Balancing future demand and supply sustainably

Concerted action across several policy domains is essential to address the challenge of balancing supply and demand sustainably over the next 40 years. Five approaches discussed in Chapter 4 are:

Improving productivity sustainably using existing knowledge. Four classes of intervention aimed at raising agricultural productivity are proposed, mostly for middle- and low-income countries:

- The revitalisation of extension services to increase the skills and knowledge base of food producers (often women).
- Improving the functioning of markets and providing market access, particularly in low-income countries.
- Strengthening the rights to land and natural resources, such as water, fisheries and forest as a high priority.
- Improving physical infrastructure in middle- and low-income countries to facilitate access to markets and investment in rural economies.

New science and technology to raise the limits of sustainable production and address new threats. Strategic conclusions on research and development set out in detail in Chapter 4 highlight:

- The importance of animal and plant breeding using conventional and new techniques to improve yields but also to increase water, nutrient and other input efficiencies.
- The need for research in agronomy, agro-ecology, soil science and other areas that have been comparatively neglected in recent years and are critical for sustainable intensification.
- Prioritising research on climate change adaptation and mitigation in the food system.
- The need for research in engineering, information and communication technology, and social science in support of sustainable food production.

Reducing waste. Halving the total amount of food waste by 2050 is considered a realistic target and ways of doing this are given in Chapter 4. If the current global figure of 30% waste is assumed, this could reduce the food required by 2050 by an amount approximately equal to 25% of today's production[431].

Improving governance of the food system. Food security is best served by fair and fully functioning markets and by liberalised global trade arrangements, not by policies to promote self-sufficiency.

Influencing demand. This approach is important since different foods vary considerably in the resources required for their production. Also, the very large number of consumers who can exercise choice in their food purchases could incentivise desirable behaviour, for example, to promote sustainability, further the interests of the poor, and reduce greenhouse gas emissions.

Challenge B: Addressing the threat of future volatility in the food system

High levels of volatility in global food markets are an issue because of the adverse effects they have on consumers and producers, because of the disruption they cause to the global food system, and, when particularly severe, because of the general economic and political instability that can occur. These effects will be most severe for low-income countries and the poor, and spikes in food price can be a major cause of increased hunger.

Although predicting future volatility is complex, there are several arguments suggesting that volatility may well increase in the future. Moreover, at least some food price spikes are inevitable with the following implications for policy:

- Protection of the most vulnerable groups from the worst effects of food price volatility should be a priority, especially those in low-income countries where market and insurance institutions are weak. This can be done indirectly through intervention to try to influence market prices, but is likely to be more effective through the provision of safety nets for poor consumers or producers to stabilise real incomes.
- The promotion of liberalised international trade in food will help to dampen volatility, because a production shock in one region can be compensated for by output and trade adjustments in others.
- The poorest food producers need specific assistance to obtain insurance against risk and volatility.
- There have been calls for a global system of virtual or actual international grain reserves to help dampen price fluctuations on global markets. This proposal risks addressing the wrong issue and is likely to be expensive, and it is far from clear that it would have a positive impact. However, targeted food reserves for vulnerable (typically low-income) countries should be considered.

Challenge C: Ending hunger[432]

Ending hunger is one of the greatest challenges to be considered by this Project. A range of actions is required, both inside and outside the global food system, to reduce levels of hunger and malnutrition. Investment in the agricultural and other food production sectors can be a powerful force for the reduction of hunger and poverty, particularly if explicitly designed to be pro-poor and anti-hunger. Strong levels of political courage and leadership in countries from low- to high-income status are essential to carry this agenda through.

This Report outlines a range of principles and priorities that should guide the choices and actions of policy makers. For example:

- It is important for policy makers to take a broad view of the nature and causes of hunger and its many impacts, including the severe and long-lasting nature of the effects that hunger and undernutrition can cause, particularly in children.
- Interventions will require the deliberate generation of a more robust and consistent consensus on tackling hunger.

431 The actual saving will depend upon a number of uncertain factors, not least the size of demand in 2050. However, the figure of 25% is considered a broad estimate of the magnitude of savings that could be achieved.

432 The emphasis here is on ending chronic hunger.

- The role of food production in rural development needs to be given higher priority and agricultural investment more specifically targeted at hunger reduction.
- Better metrics and indices of hunger, collected more frequently, need to be developed and citizens empowered to monitor progress against clearly identified targets.

Challenge D: Meeting the challenges of a low emissions world

Greenhouse gas (GHG) emissions from the food system constitute a substantial fraction of all emissions and need to be a key component of efforts to mitigate climate change. However, policy in this area is complex and must consider; in addition to carbon dioxide (CO_2), the powerful GHGs methane (CH_4) and nitrous oxide (N_2O), and also the wide range of production and distribution practices that have very different emission profiles. Much of the food system has so far been omitted from negotiations on GHG emission reductions and there are substantial challenges in designing incentives and regulation that avoid disrupting food supply. It will also be important to develop and implement effective monitoring and evaluation of policy outcomes.

- A wide range of measures discussed in Chapter 7 have the potential to reduce emissions. Significant reductions in GHG emissions could be achieved by incentivising and spreading current best practice, while new scientific, engineering and social science research offers the prospect of novel ways to reduce emissions.
- Policies to reduce GHG emissions in the food system should also consider how they affect the amount of food produced, the quantity of the inputs required, and other externalities of the food system, from effects on ecosystem services to animal welfare.
- Developing better and more comprehensive metrics of GHG emissions in the food system should continue to be a priority.
- Significant climate change is already inevitable, and the worst-affected areas will probably be in low-income tropical countries; investment in food system adaptation to climate change is a priority.

Challenge E: Maintaining biodiversity and ecosystem services while feeding the world

A key argument of this Report is that food supply will need to increase without the use of substantially more land and with diminishing impact on the environment: sustainable intensification is a necessity.

- The fact that food production requires ecosystem services provided by both farmed and non-farmed land, and has a major influence on ecosystems and biodiversity in all habitats, means that policy in these two areas needs to be developed and properly connected at global and landscape levels.
- The environmental consequences of different food production practices need to be better understood, their positive and negative economic effects internalised, and economic incentives developed to help sustain ecosystem services.
- Many of the most critical issues affecting biodiversity require decisions at landscape and even international scales, and should consider the options of maintaining on-farm biodiversity or increasing yields to allow land to be spared for conservation.

10.4 Cross-cutting priorities

Wider analysis of the Project suggests the following 12 cross-cutting actions (which are not in any order of importance) as priorities for policy makers.

Box 10.2 Key priorities for action for policy makers

1. Spread best practice.
2. Invest in new knowledge.
3. Make sustainable food production central in development.
4. Work on the assumption there is little new land for agriculture.
5. Ensure long-term sustainability of fish stocks.
6. Promote sustainable intensification.
7. Include the environment in food system economics.
8. Reduce waste – particularly in high- and low-income countries.
9. Improve the evidence base upon which decisions are made and develop metrics to assess progress.
10. Anticipate major issues with water availability for food production.
11. Work to change consumption patterns.
12. Empower citizens.

1) Spread best practice

There are major advances to be made using existing knowledge and technologies to raise yields, increase input efficiency, and improve sustainability[433]. However, this will require significant investment of both financial and political capital to ensure that food producers have the right incentives and are equipped with the necessary skills to meet current and future challenges. This Report has highlighted improvements in extension and advisory services, in high-, middle- and low-income countries, and in low-income countries, the strengthening of rights to land and natural resources, as priorities to achieve these ends[434]. Adopting proven models of extension and knowledge exchange to build human and social capital is critical to addressing all aspects of food production, from sustainable agronomy to business skills.

2) Invest in new knowledge

There is a consensus amongst the results of food system models that one of the most critical drivers of future food supply is the rate of growth of yields due to new science and technology[435]. New knowledge is also required for the food system to become more sustainable, to mitigate and adapt to climate change, and to address the needs of the world's poorest. These challenges will require solutions at the limits of human ingenuity and at the forefront of scientific understanding. No single technology or intervention is a panacea, but there are real sustainable gains to be made combining bio-technological, agronomic and agro-ecological approaches[436]. Because of the significant time lags in reaping the benefits of research, investment in new knowledge needs to be made now to solve problems in the coming decades. Investment needs to occur not only in the important field of biotechnological research, but across all the areas of the natural and social sciences involved in the food system.

433 IAASTD (2009); Chapter 4
434 Chapter 4
435 Chapter 3
436 The Royal Society (2009)

3) Make sustainable food production central in development

The 'Cinderella status' of primary food production in international development financing has for too long ignored the crucial role it plays in rural and urban livelihoods[437]. There is evidence from a series of recent initiatives that this neglect is now changing[438]. Such investment is not only about food production but also the web of people, communities and physical infrastructure that surrounds it. Investment in the sector offers a pro-poor model of economic growth with much wider positive impacts on low- and middle-income economies[439] and a means of producing a broader range of public goods[440]. Development trajectories should be chosen to help food producers in low-income countries to adapt to the effects of climate change to which they are likely to be disproportionately exposed. Development of sustainable production systems that avoid the mistakes made by previously low-income countries is required. Investment in infrastructure and capacity is needed at a scale that will be only realised by innovative new partnerships between governments, multilateral bodies and the private sector[441].

4) Work on the assumption there is little new land for agriculture

Relatively little new land on a global scale has been brought into food production in the last 40 years. Whilst modest amounts may in future be converted to agriculture, this Report concludes that major expansion is unwise. In particular, it is now understood that one of the major ways that food production contributes to greenhouse gas emissions is through land conversion, particularly of forests. Only in exceptional circumstances can conversion of forests (especially tropical rainforests), natural grasslands and wetlands to agricultural land be justified. This Report also recognises that while some biodiversity can be maintained on land used for food production, a very significant fraction, especially in the tropics, requires relatively undisturbed non-agricultural habitats. In contrast to land conversion, the restoration of degraded agricultural land can be an important means of increasing the food supply and a good use of international development monies.

5) Ensure long-term sustainability of fish stocks

Very few of the world's wild fish stocks are not currently exploited, with many over-exploited and subject to poor fisheries management. This is exacerbated by illegal fishing which thrives where controls are weak, and by the continued provision of capacity-enhancing subsidies. There is an urgent need to reform fisheries governance at national and international levels to ensure the long-term sustainability of this natural resource and enable it to meet the challenges identified in this report. The status quo is not an option, as many fish stocks will be more open to over-exploitation to meet increasing demand, be less resilient to climate change, and at greater risk of collapse. More effective management needs to be put in place building on examples of best practice around the world, and based on long-term allocation of clearer entitlements to fish to incentivise more sustainable use of the resource, and linked with clear market accountability in the supply chain. At the same time aquaculture, which will have a major role to play in meeting the supply and resource challenges ahead, will need to produce more with increased sustainability.

6) Promote sustainable intensification

It follows that if: (i) there is relatively little new land for agriculture; (ii) more food needs to be produced; and (iii) achieving sustainability is critical, then sustainable intensification is a priority. Sustainable intensification means simultaneously raising yields, increasing the efficiency with which inputs are used, and reducing the negative environmental effects of food production. It requires economic and social changes to recognise the multiple outputs required of land managers, farmers and other food producers, and a redirection of research to address a more complex set of goals than just increasing yield.

437 All Party Parliamentary Group (2010)
438 HLTF on food; AU & CADAAP; L'Aquila Food Security Initiative; FAO World Food Summit
439 World Bank (2008)
440 IAASTD (2009)
441 WEF

7) Include the environment in food system economics

The food system relies on a variety of services provided without cost by the environment – what are now called ecosystem services. The food system may negatively affect the environment and hence harm the same ecosystem services it relies upon, or affect those that benefit other sectors. Understanding the economics of ecosystem services is a very active area of current research and incorporating the true costs (or benefits) of different productions systems on ecosystem services is a powerful way of incentivising sustainability. It also helps identify situations where moves to increased sustainability impact upon the poorest people, who will require help and support.

8) Reduce waste – particularly in high- and low-income countries

Food is wasted at all stages of the food chain: in high-income countries waste tends to be concentrated at the consumer end, and in low-income countries more towards the producer end. Reducing food waste is an obvious priority and this Report supports earlier analyses in according it very high priority[442]. It is also an area where individual citizens and businesses, particularly in high-income countries, can make a clear contribution.

9) Improve the evidence base upon which decisions are made and develop metrics to assess progress

This Report makes specific recommendations for the creation of a global, spatially-explicit, open-source data base for the analysis of agriculture, the food system, and the environment, and the setting up of an 'International Food System Modelling Forum' to enable a more systematic comparison of different models, to share results, and to better integrate their work to meet the needs of policy-makers.

10) Anticipate major issues with water availability for food production

While this Report has highlighted a series of issues concerning competition for the inputs for food production, it is growing pressure on water supplies that is likely to be experienced first. The dangers come from higher demand for water from other sectors, the exhaustion of aquifers, changes in precipitation patterns, higher sea levels, and altered river flows caused by climate change. Incentives to encourage greater efficiency of water use and the development of integrated water management plans need to be given high priority.

11) Work to change consumption patterns

The informed consumer can effect change in the food system by choosing to purchase items that promote sustainability, equitability or other desirable goals. Clear labelling and information is essential for this to happen. Governments are likely to need to consider the full range of options to change consumption patterns, including raising citizen awareness, approaches based on behavioural psychology, voluntary agreements with the private sector, and regulatory and fiscal measures. Building a societal consensus for action will be key to modifying demand.

12) Empower citizens

Investment is needed in the tools to help citizens hold all other actors (and themselves) to account for their efforts to improve the global food system. Examples include the better provision and publication of information on the commitments of different groups, the extent to which they have acted on their commitments, and, through information on a food system 'dashboard', a measure of their effectiveness. Modern ITC needs to be mobilised to provide, for example, real-time hunger surveillance and to allow farmers and consumers to give feedback on what is working and not working in hunger reduction efforts.

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10.5 Priorities for action – who needs to act

There are a number of key actions that different classes of policy-maker and stakeholder need to take. Priorities are summarised in Table 10.1.

Table 10.1 Key priorities for different actors in the food system

UN and other international organisations
• Across all agencies, develop the institutional mechanisms to allow a more integrated approach to food supply and security (including both terrestrial and aquatic systems), making links with climate change, gender, poverty, biodiversity, ecosystem services, energy and other policy areas; bring food centre stage.
• Make a significant investment in a robust, comprehensive, integrated and accessible network of high-quality global, national and local food system and resource data, involving the FAO, UN economic and statistical bodies, multilateral investment agencies, regional, sectoral and national data bodies, and linking effectively with IPCC and other strategic climate change data systems, and with the WHO.
• Support the UN High Level Task Force and the FAO Committee on World Food Security in developing a coherent set of indicators (a food system dashboard) to understand and monitor drivers of change, their impacts on the global food system and on human nutrition, and their connections with climate change and related resource indicators.
• Instruct the FAO, working with international and national partners, to lead an integrated cross-sectoral approach to sustainable, climate-resilient food security including demand, supply, efficiency and waste, and the related human and institutional capacity building.
• With the WTO: implement genuinely pro-poor reforms of global trade, promote the removal of distorting and environmentally harmful subsidies, the avoidance of trade restrictions at times of food stress, and increase efforts across the trade and sustainability agendas.
• Further revitalise the CGIAR system and improve linkages with public and private sector development investment to create practical partnerships delivering clear positive outcomes for the world's poorest food producers and consumers.
• Implement the FAO Code of Conduct for Responsible Fisheries, with national governments, international NGOs and commercial partners, to bring about genuinely sustainable, productive and resilient fisheries in international, regional and national waters.
• Through UN agencies, the Convention on Biological Diversity, as well as multilateral investors and the private sector, ensure stronger and more effective actions to protect biodiversity and maintain ecosystem services on land and water both used and not used for food production.
• Support the new Commission on Sustainable Agriculture and Climate Change which will identify the policy changes and actions needed now to help the world achieve sustainable agriculture, and so inform the decisions of policy makers. This goal will contribute to food security and poverty reduction, and contribute to climate change adaptation and mitigation. It will also seek to build international consensus on actions relating to agriculture and climate change using existing evidence to inform key national and international policy makers.

National governments

- Move food further up policy agendas, taking a broad view of the whole food system and its links and influence on other policy areas.
- Develop and harmonise food system data and data standards.
- Develop and apply effective, climate-resilient land use and water resource strategies and policies for national food systems, to ensure rational, efficient and sustainable allocation and use.
- Increase the priority of research and capacity building in the food system, including biotechnology but also all other areas of agricultural, fisheries and the relevant environmental, economic and social sciences.
- Introduce modern extension systems to deliver innovation in technologies and practices to all actors in the food chain.
- Invest in agricultural training organisations to ensure the emergence of the next generation of researchers, extension workers and farmers.
- Remove subsidies and trade restrictions that distort global food markets, damage the environment and promote inefficiencies, where necessary finding other ways to support rural communities or other impacted groups.
- Increase food literacy amongst consumers, enabling individuals to make informed decisions on the health, environmental and pro-poor consequences of the food they purchase, and work with community organisations and the private sector, locally to internationally, to simplify and make transparent standards for sustainable and equitable food production.
- Implement sustainable fisheries management in national and trans-boundary waters, within effective catchment, coastal zone or shared resource frameworks.
- Develop informed and market-oriented strategies for waste reduction, energy efficiency, greenhouse gas mitigation, environmental services and biodiversity enhancement through the supply chain, service outlets and consumer action, to promote and build sustainable food systems.
- Substantially increase the proportion of international development aid focused on sustainable and resilient food production, markets and consumption, particularly for the poorest and most vulnerable households and communities; accelerate efforts to reduce hunger and malnutrition.
- Provide social protection and emergency food aid for the very poorest.

EU Member States and the EU Commission

- Reform the CAP and CFP to incentivise capital investments (including human capital) that will deliver both a competitive agricultural sector and a marked improvement in sustainable food production, trade access and equity for producers and consumers.
- Show global leadership on subsidy and trade reform.
- Increase the priority of food system research and development in the next EU Framework Programme, targeting both regional and international themes, and putting greater emphasis on hunger reduction in low-income countries.
- Implement rational approaches to strategic competition in food supplies and markets between the EU and other states or regional groupings.
- Strengthen the EU's presence and impact in international development support, food and resource data development, regional and international food security, poverty alleviation and climate mitigation and adaptation strategies.
- Ensure that governance and oversight of the food system and the introduction of new technologies is proportionate and evidence-based, and takes account of relevant considerations for ensuring future food security and sustainability.

Governments of low-income countries

- Prioritise strategies to meet or exceed MDG hunger targets, linking as required with broader poverty alleviation and climate change response themes, building rural incomes and ensuring the urban poor have access to healthy diets. Help civil society monitor government resource flows and other actions towards these goals.
- Give greater priority to the food production sector as an engine for both rural and urban development (for example, by meeting the African Union pledge of investing 10% of government expenditure in this area); invest in the economic, physical and social infrastructure to facilitate food production; promote entrepreneurship along supply and value chains.
- Help smallholders increase productivity through strengthening land and water rights, microfinance, insurance, market access, extension services etc, paying particular attention to the needs of women, and building local and community capacity for resilient and sustainable production; throughout use an evidence-based approach to choose most effective interventions.
- Work collaboratively and learn from best practice to develop scalable models of sustainable terrestrial and aquatic production across food systems.
- Support access for international food trade within broad strategies of national food supply and security, equity and sustainable resource use.

Private sector

- Work together and with governments, NGOs and other groups to assemble food and resource data and to simplify and make transparent standards for sustainable and equitable food production.
- In partnership with public and NGO sectors and with smaller-scale producers, develop sustainable food systems, communicating and marketing genuine achievements.
- Provide simple and clear food labelling to enable consumers to make informed choices.
- Collaborate in research and development in food sector climate change mitigation and adaptation, ecosystem services and biodiversity support, contributing to public goods and shared interest private returns.
- Build on best practice examples of long-term engagement and investment in food production and value development in low-income countries.
- Work to form and strengthen farmers' organisations to secure supply chains.

NGOs

- Form a global alliance to communicate forcibly the extent of hunger in the world.
- Work together across sectors recognising that problems of hunger, food supply, poverty, rights to land and natural resource assets, health, human and institutional capacity, economic and social development, climate change, biodiversity and ecosystem services are all interlinked.
- In addition to helping to protect the vulnerable in times of crisis, emphasise the importance of development through investment in the food system.
- Identify and plug gaps in research not supported by the private and public sectors alone (building, for example, on recent initiatives on biofortification and water-resistant crops for African smallholders); help bridge gaps in the research and extension chain between researchers and farmers.

The research community and research funders
● Increase the priority of natural and social science research in the sustainable food system, from the fundamental knowledge base to outcome-led interdisciplinary work. ● In addition to pursuing research in biotechnology, also target research investment in other relevant but currently neglected areas (for example, agronomy, agro-ecology and soil science), and ensure a coherent approach to discovering knowledge important to the food system at a time of global change. ● Pursue multiple scientific approaches to achieve growth in sustainable productivity and wider sustainability, and climate change adaptation; and rigorously assess the benefits and safety of novel technologies. ● Increase and develop new partnerships between public, private and third-sector funders. ● Recognising that most of the needs of the very poorest can be met using existing knowledge, engage with poor communities to explore where the development of new science and technology can be of value. ● Develop indicators of hunger and poverty that are reliable, accurate, can be calculated frequently and are not prohibitively expensive. ● Ensure the preservation of multiple varieties, land races, rare breeds and closely related wild relatives of domesticated species.
Citizens
● Develop an understanding of the magnitude of the challenges facing the global food system and the consequences of failing to plan ahead. ● Make strategic choices when purchasing food to help incentivise desirable behaviour in the food system. ● Minimise personal food waste. ● Support governments in making difficult choices to improve food system sustainability. ● Support charities and other NGOs working to stimulate poverty reduction and food production in low-income countries.

10.6 Conclusion

Despite inevitable uncertainties, the analysis of the food system presented in this Report makes clear that the global food system between now and 2050 will face enormous challenges, as great as any it has confronted in the past. The Report carries a stark warning for both current and future decision-makers on the consequences of inaction – food production and the food system must assume a much higher priority in political agendas across the world. To address the unprecedented challenges that lie ahead the food system needs to change more radically in the coming decades than ever before, including during the Industrial and Green Revolutions.

Although the challenges are enormous, there are real grounds for optimism. It is now possible to anticipate a time when global population numbers cease to rise; the natural and social sciences continue to provide new knowledge and understanding; and there is growing consensus that global poverty is unacceptable and has to be ended. But very difficult decisions lie ahead and it will require bold actions by politicians, business leaders, researchers and other key decision-makers, as well as engagement and support by individual citizens everywhere, to achieve the sustainable and fair food system the world so desperately needs.

Annex A: Acknowledgements

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Annex B: References

ABEROUMAND, A. 2009. Nutritional Evaluation of Edible Portulaca oleracia as Plant Food. *Food Analytical Methods,* 2, 204-207.

ACTIONAID. 2010. Who's really fighting hunger: Why the World is going backwards on the UN goal to halve hunger and what can be done. HungerFREE Scorecard. Johannesburg: ActionAid.

AHMED, A. & BOUIS, H. 2002. Weighing what's practical: proxy means tests for targeting food subsidies in Egypt. *Food Policy,* 27, 519–540.

ALEXANDRATOS, N. 2006. World Agriculture: towards 2030/50, interim report. An FAO perspective. Rome: FAO.

ALL PARTY PARLIAMENTARY GROUP 2010. Why No Thought For Food. London: The All Party Parliamentary Group on Agriculture and Food for Development.

ALSTON, J. M., CHAN-KANG, C., MARRA, M., PARDEY, P. & WYATT, J. 2000. Meta-analysis of Rates of Return to Agricultural R&D: Ex Pede Herculem? Washington, DC: IFPRI.

AUDSLEY, E., BRANDER, M., CHATTERTON, J., MURPHY-BOKERN, D., WEBSTER, C. & WILLIAMS, A. 2010. How low can we go? An assessment of greenhouse gas emissions from the UK food system and the scope for reducing them by 2050. Godalming, U.K.: FCRN and WWF-UK.

BAI, Z. G., DENT, D. L., OLSSON, L. & SCHAEPMAN, M. E. 2008. Global assessment of land degradation and improvement identification by remote sensing. Wageningen: ISRIC.

BARRETT, C. B. 2002. Food Security and Food Assistance Programs. *In:* GARDNER, B. & RAUSSER, G. (eds.) *Handbook of Agricultural Economics.* Amsterdam: Elsevier Science.

BATJES, N.H., 1999. Management Options for reducing CO_2-concentrations in the atmosphere by increasing carbon sequestration in soil. Report 401-200-031, Dutch National Research Programme on Global Air Pollution and Climate Change & Technical Paper 30 Wageningen, International Soil Reference and Information Centre.

BEINTEMA, N., BOSSIO, D., DREYFUS, F., FERNANDEZ, M., GURIB-FAKIM, A., HURNI, H., IZAC, A., JIGGINS, J., KRANJAC-BERISAVLJEVIC, G., LEAKEY, R., OCHOLA, W., OSMAN-ELASHA, B., PLENCOVICH, C., ROLING, N., ROSEGRANT, M., ROSENTHAL, E. & SMITH, L. 2008. Agriculture at a Crossroad. Global Summary for Decision Makers. IAASTD.

BELLARBY, J., FOEREID, B., HASTINGS, A. & SMITH, P. 2008. *Cool farming: climate impacts of agriculture and mitigation potential,* Amsterdam, Greenpeace.

BENNET, E. & ROBINSON, J. G. 2000. Hunting of wildlife in tropical forests, implications for biodiversity and forest peoples, Environment Dept Paper No. 76. Washington, DC: World Bank.

BHARUCHA, Z. & PRETTY, J. 2010. The roles and values of wild foods in agricultural systems. *Philosophical Transactions of the Royal Society B-Biological Sciences,* 365, 2913-2926.

BHUTTA, Z. A., AHMED, T., BLACK, R. E., COUSENS, S., DEWEY, K., GIUGLIANI, E., HAIDER, B. A., KIRKWOOD, B., MORRIS, S. S., SACHDEV, H. P. S. & SHEKAR, M. 2008. Maternal and Child Undernutrition 3 – What works? Interventions for maternal and child undernutrition and survival. *Lancet,* 371, 417-440.

BIGMAN, D. 2002. Intellectual Property Rights and the Commercialization of Public Agricultural Research in Developing Countries. *Globalization and the developing countries: Emerging strategies for rural developmentand poverty alleviation*.

BIRCHFIELD, L. & CORSI, J. 2010. Between starvation and globalization: realizing the right to food in India. *Michigan Journal of International Law,* 31.

BLOND, R. 1984. *The agricultural development systems project in Egypt,* Davis, University of California at Davis.

BOUET, A., DIMRANAN, B.V. & VALIN, H. 2010. Modelling the global trade and environmental impacts of trade policies. IFPRI Discussion Paper 01018. Washington, DC: IFPRI.

BOUET, A. & LABORDE, D. 2010. Assessing the potential cost of a failed Doha Round. *World Trade Review,* 9, 319-351.

BOUIS, H. E. & HADDAD, L. J. 1992. Are estimates of calorie income elasticities too high – a recalibration of the plausible range. *Journal of Development Economics,* 39, 333-364.

BRUCE, J.W. & ZONGMIN, L. 2009. Crossing the river while feeling the rocks. Land-tenure reform in China. *In:* SPIELMAN, D. & PANDYA-LORCH, E. (eds.) *Millions Fed. Proven successes in agricultural development.* Washington, DC: IFPRI.

BRUINSMA, J. 2003. World Agriculture: Towards 2015/2030. Summary Report. Rome: FAO.

BRUINSMA, J. 2009. The resource outlook to 2050: by how much do land, water and crop yields need to increase by 2050? *Expert Meeting on How to Feed the World in 2050.* Rome, FAO.

CABINET OFFICE 2008. Food Matters: A strategy for the 21st century. London: Cabinet Office.

CANNING, P., CHARLES, A., HUANG, S., POLENSKE, K. & WATERS, A. 2010. Energy Use in the U.S. Food System. Washington, DC: USDA Economic Research Service.

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.* Washington, DC.

CASTELLS, M. 1996. Rise of The Network Society. *Information Age,* 1.

CE DELFT 2008. Report to AEA for the RFA review indirect effects of biofuels. East Sussex: Renewable Fuels Agency.

CGIAR 2009. CGIAR Impact: The 2008 independent review of the CGIAR system find strong, cost-effective impact. CGIAR.

CHABER, A. L., ALLEBONE-WEBB, S., LIGNEREUX, Y., CUNNINGHAM, A. A. & ROWCLIFFE, J. M. 2010. The scale of illegal meat importation from Africa to Europe via Paris. *Conservation Letters,* 3, 317-323.

CHANG, H. J. 2009. Rethinking public policy in agriculture: lessons from history, distant and recent. *Journal of Peasant Studies,* 36, 477-515.

CHATRES, C. 2008. Invest in water for farming or the world will go hungry.

CHRISTIAENSEN, L., DEMERY, L. & KUHL, J. 2010. The (Evolving) Role of Agriculture in Poverty Reduction An Empirical Perspective. WIDER Working Paper No. 2010/36. Helsinki: UNU-WIDER.

CLAPP, J. & FUCHS, D. (eds.) 2009. *Corporate Power in Global Agrifood Governance.,* Cambridge, MA: MIT Press.

COLLIER, P. 2010. *The Plundered Planet,* UK, Allen Lane.

COLLIER, P. & DERCON, S. 2009. African Agriculture in 50 Years: Smallholders in A Rapidly Changing World? Food and Agriculture Organization Expert Meeting on 'How to Feed the World in 2050.'', 24-26 June 2009 Rome, FAO.

CONWAY, G. R. & WAAGE, J. 2010. *Science and Innovation for Development.,* London, UKCDS.

COTULA, L. & VERMEULEN, S. 2010. Making the most of agricultural investment: A survey of business models that provide opportunities for smallholders. . London: IIED.

COTULA, L. VERMEULEN, S., LEONARD, R & KEELEY, J., 2009, Land Grab or Development Opportunity? Agricultural investment and international land deals in Africa, IIED/FAO/IFAD, London/Rome.

DALY, G. L., LEI, Y., TEIXEIRA, C., MUIR, D., CASTILLO, L. E. & WANIA, F. 2007. Accumulation of current-use pesticides in neotropical montane forests. *Environmental Science & Technology* 41.

DANGOUR, A., DODHIA, S., HAYTER, A., AIKENHEAD, A., ALLEN, E., LOCK, K. & UAUY, R. 2009. Comparison of composition (nutrients and other substances) of organically and conventionally produced foodstuffs: a systematic review of the available literature. London: FSA.

DE SCHUTTER, O. 2009. Contribution of Mr. Olivier De Schutter, Special Rapporteur on the Right to Food to the 2nd Meeting of the Contact Group to Support the Committee on World Food Security (CFS).

DE SCHUTTER, O. 2010. Food Commodities Speculation and Food Price Crises. Briefing note by the Special Rapporteur on the right to food. Belgium: OHCHR.

DEFRA 2009. UK Food Security Assessment: Detailed Analysis. London: Department of Environment, Food and Rural Affairs.

DEFRA 2010a. Food 2030. London: Department for Environment, Food and Rural Affairs.

DEFRA 2010b. Food Statistics Pocketbook 2010. London: Department for Environment, Food and Rural Affairs.

DEININGER, K. 2003. Land policies for growth and poverty reduction. Washington, DC: World Bank.

DEININGER, K. & JIN, S. Q. 2006. Tenure security and land-related investment: Evidence from Ethiopia. *European Economic Review,* 50, 1245-1277.

DEMEKE, M., PANGRAZIO, G. & MAETZ, M. 2008. Country responses to the food security crisis: Nature and preliminary implications of the policies pursued. Rome: FAO.

DEUTSCHE BANK GROUP. 2009. Investing in Agriculture: Far-Reaching Challenge, Significant Opportunity. An Asset Management Perspective. Frankfurt: Deutsche Bank Group.

DFID 2009. Building Our Common Future in Sub-Saharan Africa. London: Department for International Development.

DONALD, P. 2004. Biodiversity impacts of some agricultural commodity production systems. *Conservation Biology* 18, 17-37.

DOSS, C. R. 2009. If women hold up half the sky, how much of the world's food do they produce? Paper prepared for 2010 FAO State of Food and Agriculture. Mimeo.

EASTERLING, W., AGGARWAL, P., ET AL. 2007. Food, fibre and forest products. *In:* PARRY, M., CANZIANI, O., PALUTIKOF, P., VAN DER LINDEN, P. & HANSON, C. (eds.) *Climate change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge: Cambridge University Press.

EEA 2007. Estimating the environmentally compatible bioenergy potential from agriculture. Copenhagen, Denmark: European Environment Agency.

ELLIS, F. Small-Farms, Livelihood Diversification and Rural-Urban Transitions: Strategic Issues in Sub-Saharan Africa. IFPRI Research Workshop on The Future of Small Farms, 2005 Wye, Kent, UK.

ENGSTROM, R. & CARLSSON-KANYAMA, A. 2004. Food losses in food service institutions – Examples from Sweden. *Food Policy,* 29, 203-213.

ENVIRONMENT FOOD AND RURAL AFFAIRS COMMITTEE 2009. Securing food supplies up to 2050: the challenges faced by the UK. London: House of Commons.

EUROPEAN COMMISSION 2006. Environmental impact of products (EIPRO): Analysis of the life cycle environmental impacts related to the total final consumption of the EU 25. European Commission Technical Report EUR 22284 EN. Brussels: European Commission.

EVANS, L. 1998. *Feeding the Ten Billion: Plants and Population Growth,* Cambridge, Cambridge University Press.

FAN, S., OMILOLA, B. & LAMBERT, M. 2009. Public Spending for Agriculture in Africa: Trends and Composition. ReSAKSS Working Paper No. 28. Regional Strategic Analysis and Knowledge Support System.

FAO 1981. Food loss prevention in perishable crops. *FAO Agricultural Service Bulletin.* Rome: FAO, FAO Statistics Division.

FAO 2001. State of Food Insecurity 2001. Rome: FAO.

FAO 2002. World Agriculture: towards 2015/2030. Rome: FAO.

FAO 2003. Ministerial round table on the role of water and infrastructure in ensuring sustainable food security. Rome: FAO.

FAO 2007a. Adaptation to climate change in agriculture, forestry and fisheries: Perspective, framework and priorities. Rome: FAO.

FAO 2007b. Gender and food security: Facts and figures. Rome: FAO.

FAO 2008. Information sheet—household metal silos: key allies in FAO's fight against hunger. Rome: FAO.

FAO 2009. How to Feed the World in 2050. Rome: FAO.

FAO 2010. The State of Food Insecurity in the World 2010. Rome: FAO.

FAO/IIASA 2000. Global Agro-ecological Zones.

FAONEWSROOM. 2008. Land degradation on the rise: One fourth of the world's population affected, says new study. Available: http://www.fao.org/newsroom/en/news/2008/1000874/index.html.

FAO/WHO/UNU 2001. Human energy requirements. Report of a Joint FAO/WHO/UNU Expert Consultation. Rome.

FAOSTAT. 2008. Rome: FAO. Available: http://faostat.fao.org/site/291/default.aspx.

FAOSTAT. 2010. Rome: FAO. Available: http://faostat.fao.org/site/291/default.aspx [Accessed November 2nd, 2010.

FISCHER, G. 2009. World Food and Agriculture to 2030/50: How do climate change and bioenergy alter the long-term outlook for food, agriculture and resource availability? *Expert Meeting on How to Feed the World in 2050.* Rome, FAO.

FISCHER, G., SHAH, M., TUBIELLO, F. N. & VAN VELHUIZEN, H. 2005. Socio-economic and climate change impacts on agriculture: an integrated assessment, 1990-2080. *Philosophical Transactions of the Royal Society B-Biological Sciences,* 360, 2067-2083.

FISCHER, G., VAN VELTHUIZEN, H., SHAH, M. & NACHTERGAELE, F. 2002. Global Agro-ecological Assessment for Agriculture in the 21st Century: Methodology and results. Laxenburg: IIASA.

FISHER, B., TURNER, R. K., ZYLSTRA, M., BROUWER, R., DE GROOT, R., FARBER, S., FERRARO, P., GREEN, R., HADLEY, D., HARLOW, J., JEFFERISS, P., KIRKBY, C., MORLING, P., MOWATT, S., NAIDOO, R., PAAVOLA, J., STRASSBURG, B., YU, D. & BALMFORD, A. 2008. Ecosystem services: classification for valuation *Biological Conservation* 141, 1167–1169.

FOOD ETHICS COUNCIL 2010. Food Justice: the report of the Food and Fairness Inquiry. Brighton, UK: Food Ethics Council.

FORESIGHT 2006. The Detection and Identification of Infectious Diseases. London: Government Office for Science. Department for Business, Skills and Innovation.

FORESIGHT 2007. Tackling Obesities: Future Choices – Project Report. London: Government Office for Science. Department for Business, Innovation and Skills.

FORESIGHT 2008. Mental Capital and Wellbeing: making the most of ourselves in the 21st century. London: Government Office for Science. Department of Business, Innovation and Skills.

FORESIGHT 2010. Land Use Futures: making the most of land in the 21st century. London: Government Office for Science. Department for Business, Innovation and Skills.

FUCHS, D., KALFAGIANNI, J. & ARTENSON, M. 2009. Retail Power, Private Standards, and Sustainability in the Global Food System. *In:* CLAPP, J. & FUCHS, D. (eds.) *Corporate Power in Global Agrifood Governance.* Cambridge, MA: MIT Press.

FUGLIE, K. O. 2008. Is a slowdown in agricultural productivity growth contributing to the rise in commodity prices ? *Agricultural Economics,* 39, 431-441.

FUGLIE, K. O. 2010. Accelerated productivity growth offsets decline in resource expansion in global agriculture. Washington, DC: Economic Research Service. USDA.

GARNETT, T. 2008. Cooking up a Storm: Food, greenhouse gas emissions and our changing climate. Guildford: Food Climate Research Network, Centre for Environmental Strategy, University of Surrey.

GAVENTA, J. & BARRETT, G. 2010. So What Difference Does it Make? Mapping the Outcomes of Citizen Engagement. Brighton, UK: Development Research Centre. Citizenship, Participation and Accountability. IDS.

GETLINGER, M. J., LAUGHLIN, C.V.T., BELL, E., AKRE, C. & ARJMANDI, B. H. 1996. Food waste is reduced when elementary-school children have recess before lunch. *Journal of the American Dietetic Association,* 96, 906-908.

GILLIGAN, D., HODDINOTT, J. & TAFFESSE, A. 2008. The impact of Ethiopia's Productive Safety Net Programme and its linkages. Washington, DC: IFPRI.

GLOBAL AUTHOR TEAM. Executive Summary for GAT Report. Global Conference on Agricultural Research for Development (GCARD), 2010 Montpellier, France.

GODFRAY, H. C. J., BEDDINGTON, J. R., CRUTE, I. R., HADDAD, L., LAWRENCE, D., MUIR, J. F., PRETTY, J., ROBINSON, S., THOMAS, S. M. & TOULMIN, C. 2010. Food Security: The Challenge of Feeding 9 Billion People. *Science,* 327, 812-818.

GOVERNMENT OFFICE FOR SCIENCE 2010. UK Cross-Government Food Research and Innovation Strategy. London: Department of Business, Innovation and Skills.

GRACE, C. 2010. DFID Product Development Partnerships (PDPs): Lessons from PDPs established to develop new health technologies for neglected diseases. DFID Human Development Resource Centre.

GREEN, R., CORNELL, S., SCHARLEMANN, J. & BALMFORD, A. 2005a. Farming and the fate of wild nature. *Science* 307, 550-555.

GREEN, R., CORNELL, S., SCHARLEMANN, J. & BALMFORD, A. 2005b. The future of farming and conservation: response. *Science* 308, 1257.

GRIFFIN, M., SOBAL, J. & LYSON, T. A. 2009. An analysis of a community food waste stream. *Agriculture and Human Values,* 26, 67-81.

GROLLEAUD, M. 2002. Post-Harvest Losses: Discovering the Full Story. Overview of the Phenomenon of Losses During the Post-Harvest System. Rome: FAO Agro Industries and Post-Harvest Management Service.

GUERRA, M., VIVAS, Z., QUINTERO, I. & ZAMBRANO DE VALERA, J. 1998. Estudio de las perdidas post-cosecha en nueve rubros horticolas. *Proc. Interamer. Soc. Trop. Hort.,* 42, 404-411.

HADDAD, L. & FRANKENBERGER, T. 2003. Integrating Relief and Development to Accelerate Reductions in Food Insecurity in Shock-Prone Areas. Occasional Paper No. 2. Washington, DC: USAID/ Office of Food for Peace.

HADDAD, L., LINDSTROM, J. & PINTO, Y. 2010. The Sorry State of M&E in Agriculture: Can People-centred Approaches Help? *IDS Bulletin 41.6.* Brighton, UK: IDS.

HAGGBLADE, S. & HAZELL, P. (eds.) 2009. *Successes in African Agriculture: Lessons for the Future.,* Baltimore: Johns Hopkins University Press.

HASLAM, D. W. & JAMES, W. P. T. 2005. Obesity. *Lancet,* 366, 1197-1209.

HAUSMAN, R., KLINGER, B. & WAGNER, R. 2008. Doing Growth Diagnostics in Practice: A 'Mindbook' CID Working Paper No. 177. Cambridge, Massachusetts: Harvard University.

HAZELL, P. & HADDAD, L. 2001. Agricultural Research and Poverty Reduction. Food, Agriculture, and the Environment. Discussion Paper 34. Washington, DC: IFPRI.

HAZELL, P. & WOOD, S. 2008. Drivers of change in global agriculture. *Philosophical Transactions of the Royal Society B-Biological Sciences,* 363, 495-515.

HERTEL, T. 2010. The Global Supply and Demand for Agricultural Land in 2050: A Perfect Storm in the Making? GTAP Working Paper No 63. West Lafayette, IN: Purdue University.

HMG 2010. The 2007/2008 Agricultural Price Spikes: Causes and Policy Implications. London: HM Government.

HMG 2009. The UK Low Carbon Transition Plan. London: HM Government.

HOEKSTRA, A. & CHAPAGAIN, A. 2008. The Global component of freshwater demand and supply: an assessment of virtual water flows between nations as a result of trade in agricultural products. *Water International,* 33, 19 – 32.

HOEKSTRA, A. & CHAPAGAIN, A. 2007. Water footprints of Nations: Water use by people as a function of their consumption pattern. *Water Resource Managment,* 21, 35 – 48.

HOLBEN, D. H. 2010. Position of the American Dietetic Association: food insecurity in the United States. *J Am Diet Assoc,* 110, 1368-77.

HOLMGREN, P. 2006. Global land use area change matrix. Forest Resources Assessment Working Paper 134. Rome: FAO.

HOUGHTON, R. A. 2005. Tropical deforestation as a source of greenhouse gas emissions. *Tropical Deforestation and Climate Change*.

HOUSE OF COMMONS ENVIRONMENTAL AUDIT COMMITTEE 2008. Are biofuels sustainable? First Report of Session 2007–08. London: House of Commons.

IAASTD 2009. Agriculture at a Crossroads. Global Report.: International Assessment of Agricultural Knowledge, Science and Technology for Development.

IEA 2008. World Energy Outlook 2008. Paris: International Energy Agency.

IFPRI 2004. Ending hunger in Africa: prospects for the small farmer. Policy Brief. . Washington, DC: IFPRI.

INTER ACADEMY COUNCIL 2004. Realising the Promise and Potential of African Agriculture. Amsterdam: Inter Academy Council.

INTERNATIONAL FUND FOR AGRICULTURAL DEVELOPMENT 2010. Rural Poverty Report 2011. Rome: IFAD.

IPCC 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, NY, US.

ISAAA 2010. Crop Biotech Update – Special Edition 23.

IVANIC, M. & MARTIN, W. 2010. Promoting global agricultural growth and poverty reduction. Lafayette, IN: Purdue University.

IWMI 2007. *Water for Food, Water for Life: Comprehensive Assesment of Water Managment in Agriculture,* London and Colombo,Sri Lanka, Earthscan and IWMI.

JAMES, C. 2008. Global status of commercialized biotech/GM crops: 2008. *ISAAA Briefs 39.* Ithaca, NY: International Service for the Acquisition of Agri-Biotech Applications.

JAMES, C. 2009. Global status of commercialized biotech/GM crops. *ISAAA Briefs 41.* Ithaca, NY: International Service for the Acquisition of Agri-Biotech Applications.

JAYNE, T., MATHER, D. & MGHENYI, E. 2010. Principal Challenges Confronting Smallholder Agriculture in Sub-Saharan Africa. *World Development,* 38, 1384-1398.

JONES, T. 2003. Using Contemporary Archaeology and Anthropology to Understand Food Loss in the American Food System. Unpublished paper. *Bureau of Applied Research in Anthropology.* Tuscon: University of Arizona.

KADER, A. 2005. Increasing food availability by reducing postharvest losses of fresh produce. *Proceedings of the 5th International Postharvest Symposium, Vols 1-3*, 2169-2175.

KANJI, N., COTULA, L., HILHORST, T., TOULMIN, C. & WITTEN, W. 2006. Innovation in securing land rights in Africa: Lessons from experience. London, UK: IIED.

LAMPKIN, N. 2010. Organic farming myths and reality. *World Agriculture,* 1, 46-53.

LAWTON, J. H. & MAY, R. M. (eds.) 1995. *Extinction Rates,* Oxford: Oxford University Press.

LEAVER, D. 2010. Support for agricultural R&D is essential to deliver sustainable increases in UK food production. All-Party Parliamentary Group on Science and Technology in Agriculture.

LECERF, J. M. 2009. Fatty acids and cardiovascular disease. *Nutrition Reviews,* 67, 273-283.

LEROY, J. L., RUEL, M. & VERHOFSTADT, E. 2009. The impact of conditional cash transfer programmes on child nutrition: a review of evidence using a programme theory framework. *Journal of Development Effectiveness,* 1, 103-129.

LIGON, E. & SADOULET, E. 2007. Background Paper for the World Development Report 2008 -Estimating the Effects of Aggregate Agricultural Growth on the Distribution of Expenditures. Washington DC: World Bank.

LINDSTROM, J. 2009. What is the state of M&E in agriculture? Findings of the ALINe online consultation survey. UK: ALINe.

LUNDQVIST, J., DE FRAITURE, C. & MOLDEN, D. 2008. Saving Water: From Field to Fork – Curbing Losses and Wastage in the Food Chain. SIWI Policy Brief. Stockholm: SIWI.

LUTZ, W. & SCHERBOV, S. 2008. Exploratory Extension of IIASA's World Population Projections: Scenarios to 2300. International Institute for Applied Systems Analysis.

MACGREGOR, J. & VORLEY, B. 2006. Fair Miles? The concept of "food miles" through a sustainable development lens. *Sustainable Development Opinion.* London: IIED.

MANN, J., CUMMINGS, J. H., ENGLYST, H. N., KEY, T., LIU, S., RICCARDI, G., SUMMERBELL, C., UAUY, R., VAN DAM, R. M., VENN, B., VORSTER, H. H. & WISEMAN, M. 2007. FAO/WHO Scientific Update on carbohydrates in human nutrition: conclusions. *European Journal of Clinical Nutrition,* 61, S132-S137.

MATSUOKA, Y. 2005. A level of Dangerous Climate Change and Climate Stabilization Target for Developing Long-term Policies. *Environmental Research Quarterly,* 138, 7-16.

MCDONALD, S., THIERFELDER, K. & ROBINSON, S. 2007. Globe: A SAM Based Global CGE Model using GTAP Data. USNA Working Paper No.14. Annapolis: US Naval Academy.

MEA 2005. Millenium Ecosystem Assessment. Washington, DC: Island Press.

MEENAKSHI, J. V., JOHNSON, N. L., MANYONG, V. M., DEGROOTE, H., JAVELOSA, J., YANGGEN, D. R., NAHER, F., GONZALEZ, C., GARCIA, J. & MENG, E. 2010. How Cost-Effective is Biofortification in Combating Micronutrient Malnutrition? An Ex ante Assessment. *World Development,* 38, 64-75.

MEHROTRA, S. 2010. Introducing Conditional Cash Transfers in : A Proposal for Five CCTs. Delhi: Institute of Applied Manpower Research. Planning Commisson of India.

MEINZEN-DICK, R., QUISUMBING, A., BEHRMAN, J., BIERMAYR-JENZANO, P., WILDE, V., NOORDELOOS, M., RAGASA, C. & BEINTEMA, N. Engendering Agricultural Research. Global Conference on Agriculture and Rural Development, 28-31 March, 2010 2010 Montpellier, France.

MINAGRI 2009. Agriculture Sector Performance Report Fiscal Year 2008 Sector Evaluation Report for the Joint Agriculture Sector Review of 2008. Rwanda Ministry of Agriculture and Animal Resources.

MITCHELL, D. 2008. A Note on rising food prices. World Bank Policy Research Working paper Series No. 4682. New York, NY: World Bank.

MOLYNEUX, S. 2009. Conditional Cash Transfers: Pathways to women's Empowerment?, Research Paper, IDS Series on Social Policy in Developing Countries. Brighton: IDS.

MORAN, D., MACLEOD, M., MCVITTIE, A., REES, B., JONES, G., HARRIS, D., ANTONY, S., WALL, E., EORY, V., BARNES, A., TOPP, K., BALL, B., HOAD, S. & EORY, L. 2010. Review and update of UK marginal abatement cost curves for agriculture: Report prepared for The Committee on Climate Change. Edinburgh: SAC Commercial Ltd.

MORGAN, E. 2009. Fruit and vegetable consumption and waste in Australia. Victoria: State Government of Victoria, Victorian Health Promotion Foundation.

MSANGI, S. & ROSEGRANT, M. 2009. World agriculture in a dynamically-changing environment: IFPRI's long-term outlook for food and agriculture under additional demand and constraints. *Expert meeting on how to feed the world in 2050.* Rome.

NAKICENOVIC, N., ALCAMO, J., DAVIS, G., DE VRIES, B., FENHANN, J., GAFFIN, S., GREGORY, K. & GRÜBLER, A. E. A. 2000. Special Report on Emissions Scenarios (SRES). Intergovernmental Panel on Climate Change (IPCC).

NELSON, G. ET AL 2010. Food security and climate change challenges to 2050: scenarios, results and policy options. Washington, DC: IFPRI.

NICHOLLS, R., HANSON, S., HERWEIJER, C., PATMORE, N., HALLEGATTE, S., CORFEE-MORLOT, J., CHATEAU, J. & MUIR-WOOD, R. 2007. Ranking of the world's cities most exposed to coastal flooding today and in the future. Paris, France: OECD.

NOOREN, H. & CLARIDGE, G. 2001. Wildlife trade in Laos: the end of the game. Amsterdam: IUCN.

ODI 2010. Preparing for future shocks to international staple food prices. London: Overseas Development Institute.

OECD 2010. OECD-FAO Agricultural Outlook 2010-2019: Summary Report. Paris: OECD.

OXFAM 2009. 4-a-week: Changing food consumption in the UK to benefit people and planet. UK: Oxfam.

OXFAM 2010. Halving Hunger: Still Possible? Briefing Paper 139 Oxfam International.

PACFA 2009. Fisheries and Aquaculture in our Changing Climate.

PARRY, M., ROSENZWEIG, C., IGLESIAS, A., LIVERMORE, M. & FISCHER, G. 2004. Effects of climate change on global food production under SRES emissions and socio-economic scenarios. *Global Environmental Change,* 14, 53-67.

PERFECTO, I., VANDERMEER, J., MAS, A. & PINTO, L. S. 2005. Biodiversity, yield, and shade coffee certification. *Ecological Economics* 54, 435-446.

PERFECTO, I., VANDERMEER, J. & WRIGHT, A. 2009. *Nature's matrix: linking agriculture, conservation and food sovereignty,* London, Earthscan.

PHAN, H. H. & NGUYEN, L. H. 1995. Drying Research and Application in the Mekong Delta of Vietnam. *Proceedings of the 17th ASEAN Technical Seminar on Grain Postharvest Technology.*

PIESSE, J. & THIRTLE, C. 2009. Three bubbles and a panic: An explanatory reiew of recent food commodity price events. *Food Policy,* 34, 119 – 129.

PIMENTEL, D. & PIMENTEL, M. 2003. Sustainability of meat-based and plant-based diets and the environment. *American Journal of Clinical Nutrition,* 78, 660S-663S.

PINGALI, P. 2010a. The Future of Small Farms. Proceedings of a Research Workshop. Wye: Jointly organized by IFPRI/2020 Vision Initiative, Overseas Development Institute (ODI) and Imperial College.

PINGALI, P. 2010b. Agriculture Renaissance: Making "Agriculture for Development" Work in the 21st Century. *In:* GARDNER, B. & RAUSSER, G. (eds.) *Handbook of Agricultural Economics.*

PINSTRUP-ANDERSEN, P. & SHIMOKAWA, S. 2008. Do poverty and poor health and nutrition increase the risk of armed conflict onset? *Food Policy,* 33, 513-520.

PINTO, Y., HADDAD, L., BONBRIGHT, D. & LINDSTROM, J. 2010. People-centred M&E: Aligning Incentives So Agriculture Does More to Reduce Hunger. *IDS Bulletin 41.6.* Brighton: IDS.

PRETTY, J. ET AL. 2010. The Top 100 Questions of Importance to the Future of Global Agriculture. *International Journal of Agricultural Sustainability,* 8, 219-136.

PRETTY, J. 2003. Social capital and the collective management of resources. *Science,* 302, 1912-1914.

PRETTY, J., MASON, C., NEDWELL, D. & HINE, R. 2003. Environmental costs of freshwater eutrophication in England and Wales. *Environmental Science and Technology,* 37, 201-208.

PRETTY, J. 2008. Agricultural sustainability: concepts, principles and evidence. *Philosophical Transactions of the Royal Society B-Biological Sciences,* 363, 447-465.

QUAM, M. 2009. The Economics of Genetically modified Crops. *Annual Review of Resource Economics,* 1, 665-694.

QUISUMBING, A. R. 1996. Male-female differences in agricultural productivity: Methodological issues and empirical evidence. *World Development,* 24, 1579-1595.

RAVALLION, M. 2010. A Comparative Perspective on Poverty Reduction in Brazil, China, and India. *World Bank Research Observer.*

REIJ, C. P. & SMALING, E. M. A. 2008. Analyzing successes in agriculture and land management in Sub-Saharan Africa: Is macro-level gloom obscuring positive micro-level change? *Land Use Policy,* 25, 410-420.

ROBINSON, S. & WILLENBOCKEL, D. 2010. GLOBE CGE simulation scenarios for Foresight Global Food and Farming Futures project: summary of main results. Brighton: IDS.

ROBLES, M., TORERO, M. & VON BRAUN, J. 2009. When speculation matters. Washington, DC: IFPRI.

RODRÍGUEZ, J. P., BEARD JR, T. D., BENNETT, E. M., CUMMING, G. S., CORK, S., AGARD, J., DOBSON, A. P. & PETERSON, G. D. 2006. Trade-offs across space, time, and ecosystem services. *Ecology and Society* 11.

ROLLE, R. (ed.) 2006. *Improving Postharvest Management and Marketing in the Asia-Pacific Region: Issues and Challenges Trends in the Fruit and Vegetable Sector,* Rome: FAO, Asian Productivity Organisation (APO).

SABATES-WHEELER, R. & DEVEREUX, S. 2009. Cash Transfers and High Food Prices: Explaining outcomes on Ethiopia's Productive Safety Net Programme. Future Agricultures Consortium Working Paper.: Future Agricultures Consortium.

SAITO, K., MEKONNEN, H. & SPURLING, D. 1994. Raising the productivity of women farmers in Sub-Saharan Africa. World Bank Discussion Paper 230. Washington, DC: World Bank.

SARRIS, A. 2009. Policies and institutions for assuring grain import supplies for net food importing countries. Presentation to the World Grain Forum, St Petersburg. Rome: FAO Trade and Markets Division.

SCHULZE, D., HEINZE, C., GASH, J.V., A. & FREIBAUER, A. K. 2009. Integrated assessment of the European and North Atlantic Carbon Balance: key results, policy implications for post 2012 and research needs. Brussels: European Commission.

SCIENTIFIC ADVISORY COMMITTEE ON NUTRITION 2007. Advice on fish consumption: benefits and risks. London: The Stationary Office.

SECKLER, D., MOLDEN, D. & BARKER, R. 1999. Water Scarcity in the Twenty-First Century. IWMI Water Brief 1. Colombo, Sri Lanka: IWMI.

SHEN, Y., OKI, T., UTSUMI, N., KANAE, S. & HANASAKI, N. 2008. Projection of future world water resources under SRES scenarios: water withdrawal. *Hydrological Sciences,* 53**,** 11-33.

SIM, S., BARRY, M., CLIFT, R. & COWELL, S. J. 2007. The Relative Importance of Transport in Determining an Appropriate Sustainability Strategy for Food Sourcing. *Int J LCA,* 12**,** 422-431.

SIWI, IFPRI, IUCN & IWMI 2005. Let it reign: The new water paradigm for global food security. Final report to CSD-13. Stockholm: Stockholm International Water Institute (SIWI).

SMAKHTIN, V. 2008. Basin closure and environmental flow requirements. *International Journal of Water Resources Development,* 24**,** 227-233.

SMITH, L., ALDERMAN, H. & ADUAYOM, D. 2006. Food insecurity in Sub-Saharan Africa: new estimates from household expenditure surveys. Washington, DC: IFPRI.

SMITH, L., RAMAKRISHNAN, U., NDIAYE, A., HADDAD, L. & MARTORELL, R. 2003. The Importance of Women's Status for Child Nutrition in Developing Countries. Research Report 131. Washington DC: IFPRI.

SMITH, P., MARTINO, D., CAI, Z., GWARY, D., JANZEN, H., KUMAR, P., MCCARL, B., OGLE, S., O'MARA, F., RICE, C., SCHOLES, B. & SIROTENKO, O. 2007. Agriculture *Climate Change (2007): Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*.

STEINFELD, H., GERBER, P., WASSENAAR, T., CASTEL, V., ROSALES, M. & DE HAAN, C. 2006. Livestock's Long Shadow. Environmental Issues and Options. Rome: FAO.

STERN, N. 2006. Review on the Economics of Climate Change. London: HM Treasury.

STUART, T. 2009. *Waste: Uncovering the Global Food Scandal,* London, Penguin.

SYNGENTA. 2010. *Syngenta and CIMMYT establish industry-leading partnership to advance wheat research* [Online]. Basel. Available: http://www.syngenta.com/global/corporate/en/news-center/news-releases/Pages/en-100406.aspx.

TEEB 2010. The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the approach, conclusions and recommendations of TEEB.

TEEGALA, S. M., WILLETT, W. C. & MOZAFFARIAN, D. 2009. Consumption and Health Effects of Trans Fatty Acids: A Review. *Journal of Aoac International,* 92**,** 1250-1257.

THE ROYAL ACADEMY OF ENGINEERING 2010. Global Water Security: an engineering perspective. London: The Royal Academy of Engineering.

THE ROYAL SOCIETY 2009. Reaping the Benefits: Science and the Sustainable Intensification of Global Agriculture. London: The Royal Society.

THE SOIL ASSOCIATION 2010. Telling porkies: The big fat lie about doubling food production. Bristol: The Soil Association.

THORBURN, P. J., BIGGS, J. S., COLLINS, K. & PROBERT, M. E. 2010. Estimation of nitrous oxide emission from ecosystems and its mitigation technologies. *Agriculture, Ecosystems & Environment,* 136, 343-350.

TOULMIN, C. 2009. *Climate Change in Africa.,* London, Zed Press.

UDRY, C. 1996. Gender, agricultural production, and the theory of the household. *Journal of Political Economy,* 104, 1010-1046.

UDRY, C., HODDINOTT, J., ALDERMAN, H. & HADDAD, L. 1995. Gender differentials in farm productivity – implications for household efficiency and agricultural policy. *Food Policy,* 20, 407-423.

UK COMMITTEE ON CLIMATE CHANGE 2010. The Fourth Carbon Budget Reducing emissions through the 2020s. London: Committee on Climate Change.

UK SUSTAINABLE DEVELOPMENT COMMISSION 2009. Setting the table: Advice to Government on priority elements of sustainable diets. London: UK Sustainable Development Commission.

UN STANDING COMMITTEE ON NUTRITION 2004. Fifth Report on the World Nutrition Situation. Nutrition for Improved Development Outcomes. Geneva: United Nations System Standing Committee on Nutrition.

UN STANDING COMMITTEE ON NUTRITION 2010. Sixth Report on the World Nutrition Situation. United Nations System Standing Committee on Nutrition.

UN-HABITAT 2008. State of the World's Cities 2008/2009. UN-HABITAT.

UNITED NATIONS 2002 COMTRADE: Commodity Trade Data Base. New York, NY: United Nations Statistical Division.

UNITED NATIONS . 2008. China's Progress Towards the Millenium Development Goals. Published jointly by the Ministry of Foreign Affairs of the People's Republic of China and United Nations System in China.

UNITED NATIONS 2009. The Millennium Development Goals Report. New York, NY: United Nations.

UNPD 2006. World population projections, the 2006 revision. New York, NY: United Nations Population Division.

UNPD 2007. World urbanisation prospects, the 2007 revision. New York, NY: United Nations Population Division.

UNPD 2008. World Population Prospects, The 2008 Revision. New York, NY: United Nations Population Division.

US CIA. *World Factbook* [Online]. Available: https://www.cia.gov/library/publications/the-world-factbook/.

US-EPA 2006. Global Anthropogenic non-CO2 Greenhouse Gas Emissions, 1990-2020. Washington, DC: United State Environment Protection Agency.

USDA. 2009a. Briefing Rooms. Brazil: Overview. Available: http://www.ers.usda.gov/Briefing/Brazil/ [Accessed November 1st, 2009].

USDA 2009b. USDA Agricultural Projections to 2018. Washington, DC: USDA.

VAN DAM, R. & SEIDELL, J. C. 2007. Carbohydrate intake and obesity. *European Journal of Clinical Nutrition,* 61, S75-S99.

VAN DER MENSBRUGGHE, D., OSORIO-RODARTE, I., BURNS, A. & BAFFES, J. 2009. Macroeconomic environment, commodity markets: a longer term outlook. *Rome.* FAO Expert Meeting on How to feed the World in 2050.

VON BRAUN, J. (ed.) 1995. *Employment for Poverty Reduction and Food Security,* Washington, DC: IFPRI.

VON BRAUN, J. & TORERO, M. 2009. Implementing physical and virtual food reserves to protect the poor and prevent market failure: Policy briefs 10. Washington, DC: IFPRI.

WHO/FAO 2003. Diet, Nutrition and the Prevention of Chronic Diseases. Geneva: WHO.

WIGGINS, S. 2009. Can the smallholder model deliver poverty reduction and food security for a rapidly growing population in Africa?' Paper for FAO Technical Meeting on How to feed the world in 2050. Rome: FAO.

WILLIAMS, A. G., AUDSLEY, E. & SANDARS, D. L. 2006. Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra.

WORLD BANK 2006a. Reengaging with agricultural water management. New York: World Bank.

WORLD BANK 2006b. Repositioning Nutrition as Central to Development: A Strategy for Large-Scale Action. Washington, DC: World Bank.

WORLD BANK 2008. World Development Report 2008: Agriculture for Development. Washington, DC: World Bank.

WORLD BANK. 2010. *World Bank Launches New Global Partnership to "Green" National Accounts. Press Release* [Online]. Available: http://web.worldbank.org/WBSITE/EXTERNAL/NEWS/0,,contentMDK:22746592~pagePK:64257043~piPK:437376~theSitePK:4607,00.html.

WRAP 2008. *The Food We Waste,* Banbury, Waste and Resources Action Programme.

WRAP 2009. Household Food and Drink Waste in the UK. Banbury: Waste and Resources Action Programme.

WRIGHT, J. 2010. Feeding Nine Billion in a Low Emissions Economy – Simple, Though Not Easy. London: A review for the Overseas Development Institute.

WTO/ITC/UNCTAD 2008. World Tariff Profiles 2008. Geneva: WTO.

ZIMMER, D. & RENAULT, D. 2003. Virtual Water in Food Production and Global Trade: Review of Methodological Issues and Preliminary results. *International Expert Meeting on Virtual Water Trade.* Delft: World Water Council.

ZOMMERS, Z. & MCDONALD, D. 2006. The wildlife trade and global disease emergence. London: Office for Science and Innovation.

Annex C: Examples of important research, futures projects and government initiatives drawn upon during the Project

The analysis in this report has taken account of a large number of past and present government and non-government initiatives, reviews, research programmes and strategies, as well as a number that are currently under way. The following list is not intended to be exhaustive but provides a flavour of the range of material that the analysis has drawn upon. (The following are in alphabetical order of organisation.)

1. Chatham House: Feeding the nine billion: global food security for the 21st century, 2009
2. Environment Agency: Agriculture and natural resources: benefits, costs and potential solutions, 2002
3. Food and Agriculture Organization (FAO): Global survey of agricultural mitigation projects, 2010
4. Food and Agriculture Organization (FAO): World agriculture towards 2030/2050. Interim report: prospects for food, nutrition, agriculture and major commodity groups, 2006
5. House of Commons Environment, Food and Rural Affairs Committee: Securing food supplies up to 2050: the challenges faced by the UK, volumes 1 and 2, 2009
6. IAASTD: Agriculture at a crossroads: international assessment of agricultural knowledge, science and technology for development, 2009
7. Imperial College London: The Montpellier Panel Report, Africa and Europe: partnerships for agricultural development, 2010
8. INRA (French National Institute for Agricultural Research): Agrimonde: scenarios and challenges for feeding the world in 2050, 2009
9. International Food Policy Research Institute (IFPRI): 2020 Vision for food, agriculture and the environment, 2010
10. International Food Policy Research Institute IFPRI: Millions fed: proven successes in agricultural development, 2009
11. International Fund for Agricultural Development (IFAD) Rural Poverty Report 2011, 2010
12. International Panel on Climate Change: Climate Change, 2007
13. The National Academies: Towards sustainable agricultural systems in the 21st century, National Research Council Committee on Twenty-First Century Systems Agriculture, 2010
14. OECD: Climate Change and Agriculture, 2010
15. OECD-FAO: Agricultural Outlook, 2010
16. Overseas Development Institute: Feeding nine billion in a low emissions economy: challenging, but possible: a review of the literature, Julia Wright, 2010
17. Oxfam: Halving world hunger: still possible, building a rescue package to set the MDGs back on track, 2010

18. Royal Society: Reaping the benefits: science and the sustainable intensification of global agriculture, 2009

19. The Smith Institute: Feeding Britain – what consumers want, 2010

20. UK Food Ethics Council: Food and Fairness Inquiry, 2010

21. United Nations: Access to land and the right to food, Report of the special rapporteur on the right to food, presented at the 65th General Assembly of the United Nations, 21 October 2010

22. United Nations: Trends in sustainable development – towards sustainable consumption and production 2010–2011, 2010

23. United Nations World Food Programme: Climate change and hunger: responding to the challenge, 2009

24. UK Government Department for Environment, Food and Rural Affairs: Food 2030 Strategy, 2010

25. UK Government Department for Environment, Food and Rural Affairs: Food: ensuring the UK's food security in a changing world – a discussion paper, 2008

26. UK Government Department for Environment, Food and Rural Affairs: Food Chain Analysis Group: food security and the UK – an evidence and analysis paper, 2006

27. UK Government Department for Environment, Food and Rural Affairs: The strategy for sustainable farming and food – facing the future, 2002

28. UK Parliamentary Inquiry into Global Food Security: why no thought for food? 2010

29. World Bank: World Development Report 2008: agriculture for development, 2008

30. World Resources Institute: Millennium Ecosystem Assessment: Living beyond our means, natural assets and human well being, 2005

Annex D: Glossary and acronyms

The terms and acronyms listed here cover the Project Final Report and Project Synthesis Reports.

Glossary

Agricultural parastatals: partially or wholly government-owned and -managed agricultural enterprises.

Agriculture: The managed production of crops and livestock for food, fibre, forage and fuel.

Agronomy: The application of scientific principles to land management and crop production.

Antimicrobial: The capacity of a substance to kill or inhibit the growth of microorganisms such as bacteria, fungi or protozoans.

Aquaculture: The managed production of marine or freshwater animals and aquatic plants, usually with controlled seed stocks, water management and feeding or nutrient input.

Aquaponic system: Integrated aquaculture (growing fish) and hydroponics (soil-less plant production).

Biochar: Another name for charcoal, which is a form of carbon produced when wood material is heated to a high temperature in the absence of oxygen. Biochar is not readily metabolised by microorganisms and therefore has a long resident time in soil. For this reason it is considered to be a useful means of sequestering carbon; there is also some evidence that biochar incorporation can increase soil fertility.

Biodiversity: The amount of biological variation within and between species of living organisms and whole ecosystems in terrestrial and aquatic environments.

Biofortification: Increasing the amount of a specific major or minor nutrient in a plant product by genetic improvement (breeding or genetic modification) or supplementation.

Biotechnology: Any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use, for example, such as the genetic modification of living organisms and cloned livestock..

Capture fisheries: The harvesting of fish or other aquatic organisms, using a variety of techniques, in inland, coastal or open sea areas.

Carbon credits: A tradable certificate or permit, with a monetary value, representing the right to emit one tonne of carbon dioxide or carbon dioxide equivalent.

Carbon negative: A process that removes carbon from the atmosphere.

Carbon sequestration: The process of removing carbon dioxide from the atmosphere and storing it for a prolonged period of time.

Carbon sink: A natural or artificial reservoir that absorbs and retains more carbon dioxide from the atmosphere than it emits.

Civil society: Organised, voluntary civic and social bodies including trade unions, non-governmental organisations, charities, religious organisations, community-based organisations or advocacy groups, but not government and commercial market-based institutions.

Climate change: The change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods (United Nations Convention on Climate Change definition).

Conservation farming: Agricultural practice that aims to conserve soil and water by ensuring continuous surface coverage with growing plants or a non-living mulch in order to minimise run-off and erosion as well as improve conditions for subsequent crop establishment and growth.

Corporate consolidation: A process by which two or more corporations join together into one corporation. It often refers to the mergers and acquisitions of smaller companies into larger ones.

Cover crop: A crop grown and ploughed into the soil specifically to increase organic matter and provide nutrients for subsequent crops. Cover crops are typically annuals and may be grazed during their growth.

Denitrification inhibitor: A substance capable of stopping or slowing the microbial reduction of nitrate to gaseous nitrous oxide and nitrogen.

Desertification: Degradation of land in arid and dry sub-humid areas resulting in loss of vegetation as a result of climatic factors and destructive human activities.

Drip irrigation: A method of irrigation whereby water is delivered directly and slowly to the roots of plants through a network of valves, pipes and tubing such that losses due to evaporation are minimised.

Ecosystem services: Any and all benefits that are delivered to human societies from natural or managed ecosystems such as food (a provisioning service), attractive landscapes (a cultural service), biological pest control (a regulating service) or fertile soil (a supporting service) (see Box 8.1).

Embodied energy: The total quantity of energy required to produce, deliver and dispose of a particular product, including during the processes of raw material extraction, transport, manufacture, assembly, installation, disassembly, deconstruction and/or decomposition.

Endogenous: Generated by internal factors, as opposed to outside (exogenous) factors. A variable is endogenous in a model if it is at least partly a function of other parameters and variables in a model.

Ethical trading: All types of business practices that promote more socially and/or environmentally responsible trade.

Exogenous: A variable is exogenous to a model if it is not a function of other parameters and variables in the model, but is set externally and any changes are a result of external forces.

(Agricultural) extension systems: The function of providing need- and demand-based knowledge, skills and technologies to farmers with the objective of improving their production and livelihoods; this encompasses a wide range of communication and learning activities delivered by professionals from different disciplines and institutions.

Failed state: A state perceived as having failed to provide the basic conditions and responsibilities of a sovereign government. This is often characterised by social, political and economic failure where a national or regional government has little practical control over much of its territory and there is non-provision of public services, widespread corruption, refugees and involuntary movement of populations, and economic stagnancy or decline.

Fair trade: An organised social movement and market-based system that focuses in particular on exports from developing countries to developed countries. The system promotes trading conditions that aim to help producers in developing countries to obtain prices above the conventional market rate and follow good social and environmental standards.

First-generation biofuel: Liquid fuel made from crop-derived carbohydrates such as sugar or starch (bio-ethanol) through the process of fermentation and distillation or from esterified vegetable oil or animal fats (biodiesel).

Food miles: The distance travelled and method of transport required for food to move from where it is produced to where it is consumed.

Food system: All processes involved in providing food and food-related items to a population, including growing, harvesting, processing, packaging, transporting, marketing, consumption and disposal. The system also includes the inputs required and outputs generated at each step where such steps may be connected to a more extensive regional or global system.

General circulation models: A mathematical model that simulates changes in climate as a result of slow changes in some boundary conditions or physical parameters, such as the greenhouse gas concentration. General circulation models and global climate models are widely applied for weather forecasting, understanding the climate, and projecting climate change. These computationally intensive numerical models are based on the integration of a variety of fluid dynamical, chemical and, sometimes, biological equations.

Global trade: The exchange of capital, goods and services across international borders.

Governance: The exercise of political, economic and administrative authority in the management of a country's affairs at all levels. Governance comprises the complex mechanisms, processes, relationships and institutions through which citizens and groups articulate their interests, exercise their rights and obligations and mediate their differences.

Greenhouse gas emissions: Emissions into the atmosphere of gases that absorb and emit radiation within the thermal infrared range.

Green Revolution: The enormous increase in the yields of rice and wheat that occurred in Asia in the 1960s was called the 'Green Revolution'. It was founded on the production of new high-yielding semi-dwarf, disease-resistant varieties where the genetic potential was achieved with investment in irrigation, application of synthetic fertilisers, chemical pest control and intensive land use practices.

Heterogeneity: Consisting of elements that are not of the same kind or nature; comprising unrelated or differing parts or elements.

Hydroponic systems: A method of growing crops using mineral nutrient solutions without soil. Terrestrial plants are grown with their roots in nutrient solution often absorbed into an inert medium such as perlite, gravel, mineral wool or coconut husk.

Ibrahim index: This index provides a comprehensive ranking of African countries according to quality of governance.

Infrastructure: The physical and organisational structures needed for the operation of a society or enterprise, or the services and facilities necessary for an economy to function. The term usually refers to the technical structures that support a society, such as roads, water supply, sewerage, power grids, telecommunications.

Integrated soil management: Management practices that make the best use of inherent soil nutrient stocks, locally available soil amendments and mineral fertilisers to increase land productivity while maintaining or enhancing soil fertility.

Intrauterine growth retardation: A condition in which fetal growth is inhibited and the fetus does not attain its growth potential.

Knowledge transfer/exchange: Effective sharing of ideas, knowledge or experience among researchers, policy-makers and end-users of research to enable the development and use of new beneficial products or practices. Knowledge transfer may involve the protection and licensing of intellectual property. Effective knowledge exchange results in mutual learning through the process of developing, identifying and disseminating best practices, and producing, disseminating and applying existing or new research in decision-making environments.

Law of the Sea: The international agreement that resulted from the third United Nations Conference on the Law of the Sea (UNCLOS III), which took place from 1973 to 1982. The Law of the Sea Convention defines the rights and responsibilities of nations in their use of the world's oceans, establishing guidelines for businesses, the environment and the management of marine natural resources.

Microfinance initiatives: Microfinance is the provision of financial services in the form of small, non-collateralised loans to clients with a low income, including consumers and the self-employed, who traditionally lack access to banking and related services.

Micronutrients: A mineral, vitamin or other substance that is essential, even in very small quantities, for normal growth and development of a plant or animal (including humans).

Minimum tillage: A method of soil cultivation that disturbs only the top few centimetres of the topsoil. The method avoids the need for inversion ploughing with the associated potential damage to soil structure and energy demand. There are claims that the method results in sequestration of more soil carbon but this is not universally accepted.

Modelling: A theoretical method that represents (economic) processes by a set of variables and a set of quantitative relationships between them. The model is a simplified framework designed to illustrate complex processes.

Montreal Protocol: An international treaty, signed in 1987, which established restrictions for the manufacture and use of ozone-depleting substances in an international effort to reduce ozone depletion. This treaty led to phasing out the production of numerous substances believed to be responsible for ozone depletion.

Precision agriculture: The delivery of essential farming operations in a highly precise way in terms of time and space. This is made possible by computer-based models and forecasting systems to optimise spray applications, for example. Global positioning systems (GPSs) and differential GPSs (DGPSs), sensors, satellites or aerial images, and information management tools (geographic information systems, GISs) can be used to assess and respond to variable conditions across short distances in a single field and to tailor such things as herbicide and fertiliser applications to particular requirements.

Right to food legislation: Legislative measures for the implementation of the human right to adequate food.

'Right to Food' movement: A movement that emphasises the right to food, and its variations, as a human right. The movement derived from the International Covenant on Economic, Social and Cultural Rights (ICESCR). It stresses the 'right to an adequate standard of living, including adequate food', as well as the 'fundamental right to be free from hunger'.

Right to work: Concept describing individuals' right to work, and their right to not be prevented from doing so. The right to work is included in the Universal Declaration of Human Rights and recognised in international human rights law through its inclusion in the International Covenant on Economic, Social and Cultural Rights.

Ruminants: Mammals that have a rumen, a large digestive vat in which fibrous plant material is partially broken down by microbial fermentation and regurgitated, prior to digestion in another stomach (the abomasum). There are also two other stomachs, the reticulum and the omasum. Typically ruminants are cattle, sheep and goats.

Safety net programme: Non-contributory transfer programmes seeking to prevent the poor or those vulnerable to shocks and poverty from falling below a certain poverty level. Safety net programs can be provided by the private or the public sector.

Sanitary and phytosanitary agreement: Sanitary and phytosanitary measures and agreements are measures to protect humans, animals and plants from diseases, pests or contaminants. This agreements covers all sanitary (relating to animals) and phytosanitary (relating to plants) (together – SPS) measures that may have a direct or indirect impact on international trade. Countries agree to base their SPS standards on science, and are encouraged to use standards set by international standard-setting organisations. Embodied in the agreement, countries maintain the sovereign right to provide the level of health protection they deem appropriate, but agree that this right will not be misused for protectionist purposes or result in unnecessary trade barriers.

Secondary metabolites: Chemicals that are produced by plants that are not directly involved in the plant's growth, photosynthesis, reproduction or other 'primary' functions.

Smallholder farmers: Farmers who have limited resource endowments relative to other farmers in the sector or geographic location.

Sovereign wealth fund: A state-owned investment fund composed of financial assets such as stocks, bonds, property, precious metals or other financial instruments intended to benefit the country's economy and citizens.

Supply chain: A system of organisations, people, technology, activities, information and resources that begins with the sourcing of raw material and extends through the delivery of end items to the final customer.

Sustainable/sustainability: A system or state where the needs of the present and local population can be met without diminishing the ability of future generations or populations in other locations to meet their needs and without causing harm to the environment and natural assets (see Box 3.5).

Sustainable intensification: The pursuit of the dual goals of higher yields with fewer negative consequences for the environment (see Box 3.5).

Sustainable production: A method of production using processes and systems that are non-polluting, conserve non-renewable energy and natural resources, are economically efficient, are safe for workers, communities and consumers, and do not compromise the needs of future generations.

Trade-related intellectual property rights: The Agreement on Trade-related Aspects of Intellectual Property establishes minimum global standards governing the scope, availability and use of intellectual property rights and patent protection of fellow World Trade Organization members.

Trade liberalisation: A process of complete or partial elimination of trade distorting government policies, including the elimination or reduction of trade barriers such as quotas and tariffs.

Transitional country: A country whose economy is changing from a centrally planned economy to a free market. Transition economies undergo economic liberalisation, whereby market forces set prices and trade barriers are removed.

Urbanisation: The rapid physical growth and migration to urban areas. Urbanisation is also defined by the United Nations as movement of people from rural to urban areas with population growth equating to urban migration.

Volatility (price volatility): The wide and frequent variation in average price over a period of measurement.

Wild foods: Food derived from non-domesticated plants and animals living in natural or semi-natural habitats.

Yield gap: The difference between realised productivity and the best that can be achieved using current genetic material and available technologies and management.

Acronyms

ALINE: Agriculture Learning and Impacts Network

BRAC: Bangladesh Rehabilitation Assistance Committee

BRIC: Brazil, Russia, India and China

CAADP: Comprehensive Africa Agriculture Development Programme

CAP: Common Agricultural Policy

ECOWAS: Economic Community of West African States

FAO: Food and Agriculture Organization

GAAT: General Agreement on Tariffs and Trade

GCARD: Global Conferences on Agricultural Research for Development

GFAR: Global Forum on Agricultural Research

GM: genetically modified/GMO genetically modified organism

LAC: Latin America and Caribbean

MDGs: Millennium Development Goals

MEA: Millennium Ecosystem Assessment

NCHS: National Center for Health Statistics

NREGA: National Rural Employment Guarantee Act

REDD: Reducing Emissions from Deforestation and Degradation (programme)

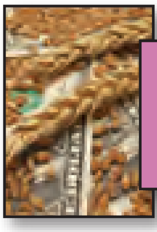
SADC: Southern African Development Community

STEPS: Social, Technological and Environmental Pathways to Sustainability (programme)

TNC: transnational corporation

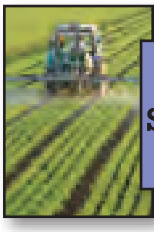
UNFCCC: United Nations Framework Convention on Climate Change

Annex E: Project reports and papers



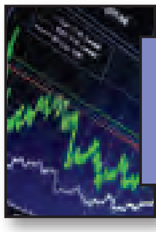
Assessment of Future Challenges

- **C1:** Demand, Production and Prices
- **C2:** External Pressures on the Food System
- **C3:** Governance
- **C4:** Modelling and Scenarios



Challenge A: Sustainable Supply and Demand

- **C5:** Better Use of Existing Technology
- **C6:** New Science and Technology
- **C7:** Addressing Waste
- **C8:** Modifying Demand
- **C9:** Sustainable Intensification in African Agriculture



Challenge B: Volatility

- **C10:** Addressing Future Volatility

Driver Reviews

- **DR1:** Population
- **DR2:** Climate change and its effect on agriculture
- **DR3:** Consumption and consumer attitudes
- **DR4:** Energy and agriculture
- **DR5a:** Production possibilities: crops
- **DR5b:** Production possibilities: livestock
- **DR7a:** Ecosystem services
- **DR7b:** Competition for land
- **DR8:** Agricultural investment, research, extension and development
- **DR10a:** Review of existing modelling and scenarios
- **DR10B:** Economics of globalisation, specialisation and trade
- **DR12:** Competition for water
- **DR13:** Urbanisation, megacities and de-urbanisation
- **DR14:** Marine fisheries
- **DR15:** Freshwater fisheries
- **DR16:** Aquaculture
- **DR17:** Production to plate
- **DR18:** Volatility
- **DR19:** Income distribution
- **DR20:** Waste
- **DR21:** Wild foods
- **DR22:** Health

Regional Reviews

- **R1:** U.K. – Sustainably increasing productivity
- **R2:** China – Investment in agricultural research and development
- **R3:** Africa Nile catchment – Trans-national water sharing
- **R4:** India – Determinants of demand for food
- **R5:** Brazil – Competition for land in the face of increasing food production
- **R6:** Mekong – Inland fisheries and aquaculture
- **R7:** Eastern Europe – Production possibilities

Additional Reviews

- **WP1:** The relationship between agriculture and health
- **WP2:** Moderating consumer behaviour and demand
- **WP5:** 100 questions – overview
- **WP6:** Food Security, Farming, and Climate Change to 2050
- **WP9:** Physical resources and commodities and climate change

Working Papers

- **WP10:** New pathways to innovation
- **WP8:** Governance
- **WP13:** International Aid for Agricultural Development

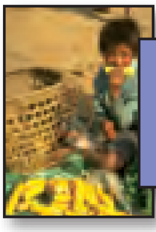
Sustainable Intensification in African Agriculture – case examples (see next page)

Project reports and papers can be found on the Project's CD and are freely available to download at http://www.bis.gov.uk/Foresight

Note: some report numbers were initially allocated but were not subsequently used.

Executive Summary

Final Report



Challenge C: Hunger

- **C11:** Addressing Hunger

Challenge D: Climate Change Mitigation

- **C12:** The Food System in a Low Emissions World

Challenge E: Maintaining Biodiversity

- **C13:** Maintaining Biodiversity and Eco-system Services

Workshop Reports

- **W2:** The global food supply chain
- **W3:** Difficult to imagine drivers
- **W4:** The reduction of food waste
- **W5:** Sustainable livestock production
- **W6:** Food system ethics
- **W7:** Modelling the food system

State of Science Reviews

- **SR1:** Biotechnology in crops
- **SR2:** Biotechnology in livestock
- **SR3:** Biotechnology in aquaculture
- **SR4:** Advances in plant disease and pest management
- **SR5:** Advances in weed management
- **SR6:** Advances in animal disease management
- **SR7:** Integrated soil management
- **SR8:** Modern aquaculture
- **SR9:** Management in capture fisheries
- **SR10:** Novel crop science to improve yield and resource use efficiency
- **SR12:** Societal attitudes to food production
- **SR13:** Climate change and trade in agriculture
- **SR14:** Modifying crops
- **SR15:** Postharvest losses and waste
- **SR16b:** Education, training and extension
- **SR17:** The social structure of food production
- **SR19:** Urban and periurban food production
- **SR20:** Long-range meteorological forecasting
- **SR21:** Alternative mechanisms to reduce food price volatility
- **SR22:** Latest developments in financial risk management
- **SR23:** Governance of international trade in food
- **SR24:** The sustainability and resilience of global water and food systems
- **SR25:** Helping the individual: education, extension services, and land rights
- **SR27:** Developing national food security strategies
- **SR30:** A review of hunger indices
- **SR31:** Fertiliser availability in a resource-limited world
- **SR32:** Opportunities for reducing greenhouse gas emissions in the food system
- **SR33:** Options of reducing greenhouse gas emissions from agricultural ecosystems
- **SR34a:** The new competition for land
- **SR34b:** Competition for land from biofuels
- **SR35:** Engineering advances for input reduction
- **SR36:** Minimising the harm to biodiversity
- **SR37:** Ecosystem services and sustainable agriculture/aquaculture
- **SR38:** Climate change and the loss and gain of marine fisheries
- **SR39:** Valuation of ecosystem services
- **SR45:** Recent developments in intellectual property
- **SR46:** Funding research on the food system
- **SR48:** Gender in the food system
- **SR49:** Children in the food system
- **SR55:** Arid agriculture in Australia
- **SR56:** Global food waste reduction

Sustainable Intensification in African Agriculture – case examples

- **AA1:** Agriculture service provision: Oxfam's strategic cotton programme: Mali
- **AA2:** Indigenous vegetable enterprises and market access: East Africa
- **AA3:** Fertiliser tree systems: Southern Africa
- **AA4:** Conservation agriculture: Zimbabwe
- **AA5:** CARBAP and innovation in plantain banana: West and Central Africa
- **AA6:** Livestock research for sustainable disease management: Mali and Burkina Faso
- **AA7:** Conservation agriculture: Tanzania
- **AA8:** Focal area approach: agricultural extension and market developments: Kenya
- **AA9:** Focal area approach: agricultural extension and market developments: Kenya
- **AA10:** Growing sustainable tea: Kenya
- **AA11:** Harnessing sustainability, resilience and productivity: Likoti in Lesotho
- **AA12:** Meru dairy goat and animal healthcare
- **AA13:** On-farm biological control of the pearl millet head miner: Mali, Burkina Faso and Niger
- **AA14:** Breeding and dissemination of improved sweet potato varieties
- **AA15:** Promoting smallholder seed enterprises (SSE): Cameroon
- **AA16:** Push-pull technology: a conservation agriculture approach
- **AA17:** Quncho: the first most popular tef variety in Ethiopia
- **AA18:** The adoption of fodder shrub innovations in East Africa
- **AA19:** Revival of cassava production: Nakasongola District, Uganda
- **AA20:** Sharing ideas between cultures with videos
- **AA21:** Soyabeans and sustainable agriculture: Southern Africa
- **AA22:** Sustainable crop production intensification: Senegal and Niger River Basins of Francophone West Africa
- **AA23:** The Ghana Grains Partnership
- **AA24:** The Malawi Agricultural Input Subsidy Programme: 2005/6 to 2008/9
- **AA25:** The Rakai Chicken Model: Uganda
- **AA26:** The rise of peri-urban aquaculture: Nigeria
- **AA27:** The System of Rice Intensification (SRI) as a sustainable agricultural innovation: Timbuktu region of Mali
- **AA28:** Trees, agroforestry and multifunctional agriculture: Cameroon
- **AA29:** Soil and water conservation techniques to rehabilitate degraded lands: North western Burkina Faso

Working Papers

- **AWP1:** Designing innovative: Small-scale organic agricultural technologies
- **AWP2:** Diffusion of tissue culture banana technology to smallholder farmers: Kisii District
- **AWP3:** Egyptian aquaculture sector overview
- **AWP4:** Orange-fleshed sweet potatoes for food, health and wealth: Uganda
- **AWP5:** Partnership in managing bean root rots: Eastern and Central Africa
- **AWP6:** Pigeonpeas for prosperity: East and Southern Africa
- **AWP7:** Institutional collaboration in the development of rice production: Kpong Irrigation Project, Ghana
- **AWP8:** Zooming-in Zooming-out: Videos to scale up sustainable technologies and build livelihood assets
- **AWP9:** Experience du Projet de Conservation des Eaux Et Des Sols

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