UNEP

International Resource Panel

FOOD SYSTEMS AND NATURAL RESOURCES

UNITED NATIONS ENVIRONMENT PROGRAMME

Acknowledgements

Editor
The International Resource Panel (IRP)
Working Group on Food Systems and Natural Resources chaired by Maarten Hajer

Lead Authors
Henk Westhoek (lead coordinating author, PBL Netherlands Environmental Assessment Agency), John Ingram (University of Oxford), Siemen van Berkum (LEI –Wageningen UR), Leyla Özay (PBL Netherlands Environmental Assessment Agency) and Maarten Hajer (Professor at Utrecht University and former Director General of PBL Netherlands Environmental Assessment Agency).

Contributions were received from: Maurits van den Berg (PBL), Martha van Eerdt (PBL), Maria Amélia Enríquez (Brazilian Society for Ecological Economy), Len R. Garces Braz (WorldFish – Philipines), Jeff Herrick (USDA-ARS), Lotte Huisman (PBL), Ma Lin, James Lomax (UNEP), Llorenç Mila-I-Canals (UNEP), Kazunobu Onogawa (IGES, Japan), Maripaz Perez (WorldFish – Philipines); Martijn Vink (PBL), Guus de Hollander (PBL) and Gete Zeleke (WLRC- Ethiopia).

The authors would like to thank PBL Netherlands Environmental Assessment Agency for its support in the preparation of this report. They would also like to thank participants of the workshops organized by the IRP in Paris (5-6 September 2012); Nairobi (8-9 November 2013); Jakarta (30 April–1 May 2014); and The Hague (17-18 September 2014) for the inputs provided during the preparation of this report.

The report went through a peer review process coordinated by Elias Ayuk with the support of the IRP Secretariat. The authors thank the anonymous peer reviewers for their constructive comments.

Special thanks go to Janez Potočnik and Ashok Khosla, Co-Chairs of the IRP during the preparation of this report, for their dedication and commitment, as well as to all members of the IRP and its Steering Committee for their constructive comments.

The Secretariat of the IRP coordinated the preparation of this report with the technical support of María José Baptista.

The main responsibility for errors remains with the authors.

Copyright © United Nations Environment Programme, 2016
This publication may be reproduced in whole or in part and in any form for educational or nonprofit purposes without special permission from the copyright holder, provided acknowledgement of the source is made.

UNEP would appreciate receiving a copy of any publication that uses this publication as a source. No use of this publication may be made for resale or for any other commercial purpose whatsoever without prior permission in writing from the United Nations Environment Programme.

Design/layout: Marie Moncet, SOURIBLE

Printed by: UNESCO

Cover photos@: 1. Byjeng, Shutterstock.com; 2. Kumpol Chuansakul, Shutterstock.com; 3. CRSHELARE, Shutterstock.com; 4. Aleksandar Todorovic, Shutterstock.com.

Graphics: Filip de Bois and Arie den Boer (PBL)

Disclaimer
The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of the United Nations Environment Programme concerning the legal status of any country, territory, city or area or of its authorities, or concerning delimitation of its frontiers or boundaries. Moreover, the views expressed do not necessarily represent the decision or the stated policy of the United Nations Environment Programme, nor does citing of trade names or commercial processes constitute endorsement

The full report should be referenced as follows
UNEP (2016) Food Systems and Natural Resources. A Report of the Working Group on Food Systems of the International Resource Panel. Westhoek, H, Ingram J., Van Berkum, S., Özay, L., and Hajer M.

Job Number: DTI/1982/PA

ISBN: 978-92-807-3560-4

UNEP promotes environmentally sound practices globally and in its own activities. This publication is printed on 100% recycled paper, using vegetable -based inks and other eco-friendly practices. Our distribution policy aims to reduce UNEP's carbon footprint.

About the International Resource Panel

This report was prepared by the Working Group on Food Systems of the International Resource Panel (IRP). The IRP was established to provide independent, coherent and authoritative scientific assessments on the use of natural resources and its environmental impacts over the full life cycle and contribute to a better understanding of how to decouple economic growth from environmental degradation. Benefiting from the broad support of governments and scientific communities, the Panel is constituted of eminent scientists and experts from all parts of the world, bringing their multidisciplinary expertise to address resource management issues. The information contained in the International Resource Panel's reports is intended to be evidence based and policy relevant, informing policy framing and development and supporting evaluation and monitoring of policy effectiveness.

The Secretariat is hosted by the United Nations Environment Programme (UNEP). Since the International Resource Panel's launch in 2007, fourteen assessments have been published. Earlier reports covered biofuels; sustainable land management; priority economic sectors and materials for sustainable resource management; benefits, risks and trade-offs of Low-Carbon Technologies for electricity production; metals stocks in society, their environmental risks and challenges, their rates of recycling and recycling opportunities; water accounting and decoupling; city-level decoupling; REDD+ to support Green Economy; and the untapped potential for decoupling resource use and related environmental impacts from economic growth.

The assessments of the IRP to date demonstrate the numerous opportunities for governments and businesses to work together to create and implement policies to encourage sustainable resource management, including through better planning, more investment, technological innovation and strategic incentives.

Following its establishment, the Panel first devoted much of its research to issues related to the use, stocks and scarcities of individual resources, as well as to the development and application of the perspective of 'decoupling' economic growth from natural resource use and environmental degradation. Building upon this knowledge base, the Panel has now begun to examine systematic approaches to resource use. These include the direct and indirect (or embedded) impacts of trade on natural resource use and flows, and the city as a societal 'node' in which much of the current unsustainable usage of natural resources is socially and institutionally embedded. In a similar vein it has become apparent that the resource use and requirements of the global food consumption call for a better understanding of the food system as a whole, and in particular its role as a node for resources such as water, land, and biotic resources on the one hand and the varied range of social practices that drive the consumption of food on the other. The years to come will therefore focus on and further deepening these work streams. Upcoming work by the IRP will focus on integrated scenarios of future resource demand, material flow database and analysis, resource implications of future urbanization, global resource efficiency prospects and economic implications, and remanufacturing.

FOOD SYSTEMS AND NATURAL RESOURCES

UNEP

International Resource Panel

Preface

Dr. Janez Potočnik Dr. Alicia Bárcena

Co-Chairs, International Resource Panel

We are what we eat, they say. Our existence and, therefore, any of the aspirations we might have as a society depend on the availability of, and access to, food. At the same time, our food depends directly on the state of our natural resources. The food we grow, harvest, trade, transport, store, sell and consume is therefore one of the essential connecting threads between people, their culture and wellbeing, and the health of our planet.

Concerns from population growth, climate change, changing patterns of resource consumption, food price volatility, and malnutrition, among others, have raised the profile of the food security debate within the international science and policy communities. Goal number 2 of the recently adopted Sustainable Development Goals, crystallizes the outcome of this debate and puts it at the top of policy agendas worldwide. It is well acknowledged that without eliminating hunger, achieving food security and improving health and nutrition of the world population, the 2030 Agenda for Sustainable Development cannot be effectively implemented.

Understanding the fundamental role of natural resources in the sound functioning of our global food systems is at the heart of this new report developed by the Food Systems Working Group of the International Resource Panel (IRP). With this report, the IRP is changing the conversation. We are no longer talking about the consequences of unsustainable agriculture and fisheries only. We are talking about the natural resource use and environmental impacts of all food related activities, their governance structures, socio-economic outcomes, and the complex interlinkages between all of these.

The report finds that many of our food systems are currently unsustainable from a natural resources perspective. The way in which these food systems currently operate are responsible for land degradation, depletion of fish stocks, nutrient losses, impacts on terrestrial and aquatic biodiversity, impacts on air, soil and water quality, and greenhouse gas emissions contributing to climate change. The expected population growth, expansion of cities, dietary shifts to unhealthy and unsustainable consumption will increase the pressures even more.

There are, however, significant opportunities to decouple food system activities from environmental degradation, specifically by both increasing efficiencies and improving the management of the natural resource base. Some options include increasing efficiencies of livestock feed (farmed animals consume around 35% of the total crop production), nutrients (the global average nutrient efficiency for nitrogen and phosphorus is only around 20%), genetics and water. New farming technologies (e.g. drip irrigation, 'low till and precision agriculture') and improved varieties (e.g. more resilient to water and heath stresses) have the potential to increase the efficiency at multiple levels (lower nitrogen losses, lower water use, and higher productivity), allowing to produce more food with less resources New farm- and decision-making related innovations (e.g. use of mobile technology to provide price and weather related information to farmers, remote sensing monitoring) can help reduce on-farm food loses and improve transparency in food markets thus reducing price volatility. More energy and water efficient food processing (e.g. dry extraction of plant-sourced protein) is also possible. A reduction in food loss and waste across food systems, and a levelling off of meat and dairy consumption in developed countries could reduce the global cereal demand by 15%; while the reduction by 50% of meat and dairy consumption in these countries could lead to up to 40% lower nutrient losses and greenhouse gas emissions.

The assessment shows that there is still much more to do if we want to identify effective points of intervention along the system. While there is a large amount of literature covering natural resource use and impacts from agriculture, there are still important data gaps on other food system activities, their outcomes and their connections (e.g. cultural and health dimensions). Defining the right framework is a necessary starting point.

We are very grateful to Maarten Hajer, John Ingram, Henk Westhoek, and the rest of the team for what we believe is a valuable contribution to advance systems thinking in a topic that requires the fullest attention. Their remarkable work gives us hope that with new practices and engaged actors, it is possible to feed the global population with sufficient nutritious food while nurturing our planet, to ensure continuity of supply for future generations.

Foreword

For thousands of years, nature has gracefully provided the necessary inputs to feed us, and we have in many occasions taken these precious gifts for granted. This report, "Food Systems and Natural Resources" developed by the International Resource Panel (IRP) is an effort to account for these inputs, looking at how we are using and managing them, the consequences of that management and the options to improve the efficiency with which they are managed.

The 2030 Agenda for Sustainable Development, a historic global commitment to a world free of poverty and hunger, will require science-based decisions that balance and integrate the social, environmental and economic pillars of sustainable development. In this report, the IRP proposes a new way of looking at food, one that moves from a compartmentalized vision to a more comprehensive, complex yet realistic approach. A 'food systems lens' goes beyond the classic production-centered discussions to connect all activities concerned with the food we eat (growing, harvesting, processing, packaging, transporting, marketing, consuming, and disposing of food and food-related items) and the various socio-economic and environmental outcomes of these activities.

The authors provide solid evidence on the need to transition to more 'resource-smart food systems', an imperative for the achievement of at least 12 out of the 17 Sustainable Development Goals (SDGs).

Globally, food systems are responsible for 60% of global terrestrial biodiversity loss, around 24% of the global greenhouse gas emissions, 33% of degraded soils, the depletion of 61% of 'commercial' fish populations, and the overexploitation of 20% of the world's aquifers. These pressures on our natural resource base are expected to significantly increase with population, urbanization and supermarketization trends, as well as dietary shifts to more resource-intensive food. By 2050, an expected 40% of the world population will be living in severely water-stressed river basins and greenhouse gas emissions from agriculture may increase from 24% to 30%.

There are also a number of alarming disparities worldwide that reveal the impacts of current food systems on our health. Nearly 800 million people are hungry, over 2 billion suffer from micronutrient deficiencies, while over 2 billion people are obese. Ensuring access to nutritious food will often depend on the way markets function at the local, national, regional and global levels, on the social safety nets created for vulnerable groups of the population (e.g. smallholder farmers), and on their access to infrastructure, finance, knowledge and technology. In countries suffering from overconsumption, lifestyle choices and consumer information play a fundamental role.

The IRP tells us that combined action at different points of intervention and by a diversity of actors throughout the system could lead to resource efficiency gains of up to 30% for certain resources and impacts. Governments, private sector actors, civil society and consumers all have a critical role to play.

The International Resource Panel, under the leadership of the Co-Chairs Alicia Bárcena and Janez Potočnik, has produced a state of the art analysis which reveals some of the greatest complexities we are living with in the anthropocene. I wish to congratulate and thank the authors for this important piece of scientific literature, which sheds some light on the magnitude of challenges we must face and opportunities we must seize to ensure access by all people to safe, nutritious and sufficient food, all year round.

Achim Steiner
UN Under-Secretary-General
UNEP Executive Director

Table of Contents

Acknowledgements ii

About the International Resource Panel 1

Preface 4

Foreword 5

Table of Contents 7

Executive Summary 12

Chapter 1 – Introduction 20

Chapter 2 – A Food Systems Approach to Natural Resource Use 26
- 2.1 Introduction 27
- 2.2 Why 'food systems'? 27
  - 2.2.1 Background to the food security debate 27
  - 2.2.2 Linking the food system concept to actors and natural resources 28
  - 2.2.3 Emergence of the food system concept 29
  - 2.2.4 Benefits of a food systems approach for natural resource management 30
- 2.3 Natural resources and environmental impacts 32
  - 2.3.1 Overview of natural resources and environmental impacts 32
  - 2.3.2 Natural resources needed for food system activities 33
  - 2.3.3 Environmental impacts related to food system activities 34
- 2.4 Measuring an efficient and sustainable use of natural resources in food systems 35
  - 2.4.1 Sustainable use of renewable resources 35
  - 2.4.2 Measuring resource efficiency in food systems 35
- 2.5 Overview of interactions between food system activities, natural resources and food security 37
- 2.6 Summary and conclusions 37

Chapter 3 – Food system types, governance dynamics and their implications for resource use 40
- 3.1 Introduction 41
- 3.2 Types of food systems 41
  - 3.2.1 Variety captured in stylized typology 41
  - 3.2.2. Traditional food systems 41
  - 3.2.3 Modern food systems 42
  - 3.2.4 Intermediate food systems 42
  - 3.2.5 Key features of food systems summarized 43

3.3 Main features of coordination mechanisms in food systems 45
3.4 Governance of food systems 46
3.4.1 Change in role of government 46
3.4.2 Food systems increasingly governed by downstream actors 47
3.4.3 Implications of 'supermarketization' for food market structures and resource use 49
3.5 Summary and conclusions 50

Chapter 4 – Socio-economic drivers impacting on food demand, production and food system outcomes 52
4.1 Introduction 53
4.2 Population growth and urbanization 53
4.3 Implications for food demand 55
4.4 Trends in global food production and trade in response to changing consumption patterns 58
4.4.1 Developments in crop production and trade 58
4.4.2 Increase in yields is expected to remain the main driver of production growth59
4.4.3 Large increase in livestock production 60
4.4.4 Fisheries and aquaculture 61
4.5 Food system outcomes for food security 62
4.5.1 Number of people undernourished 62
4.5.2 Food price development 63
4.5.3 Rural livelihoods in the context of rapidly changing and consolidating food systems 65
4.5.4 Food losses and food waste 65
4.5.5 Food consumption trends and health 66
4.6 Summary and Conclusions 69

Chapter 5 – Natural resources and environmental impacts of food systems 70
5.1 Introduction 71
5.2 Land, landscape and soils 71
5.2.1 Land use and food systems 71
5.2.2 Are current and future land use efficient and sustainable? 72
5.2.3 Consequences of unsustainable or inefficient land use 75
5.3 Water 75
5.3.1 Water and food systems 75
5.3.2 Is current and projected water use efficient and sustainable? 76
5.3.3 Consequences of inefficient or unsustainable water use 77
5.4 Minerals (nutrients) 78
5.4.1 Nutrients and food systems 78
5.4.2 Is the current and projected use of minerals efficient? 80
5.4.3 What are the consequences of an inefficient use of minerals? 81
5.5 Biodiversity and ecosystem services 83
5.5.1 The relevance of biodiversity and ecosystem services for food systems 83
5.5.2. Is the current and projected use of biodiversity and ecosystem services sustainable and efficient? 84
5.5.3 What are the consequences of inefficient and unsustainable use? 86
5.6 Genetic resources 86
5.7 Marine and inland aquatic resources 87
5.7.1 Marine resources and food systems 87
5.7.2 Are marine resources used efficiently and sustainably? 88
5.7.3 What are the consequences of the inefficient and unsustainable use of marine resources? 90
5.8 Fossil fuels 90

5.9 Environmental impacts 91
5.9.1 Water quality 91
5.9.2 Soil quality 92
5.9.3 Air quality 92
5.9.4 Greenhouse gas emissions 92
5.10 Food categories, resource use and human health 93
5.11 Summary and Conclusions 96

Chapter 6 – Understanding food systems in context: actors, behaviors and institutions 98
6.1 Introduction 99
6.2 Food system actors and their behavior 99
6.3 Farmers and fishermen 100
6.3.1 Institutional and regulatory environment 100
6.3.2 Physical environment 102
6.3.3 Social, cultural and economic environment 102
6.4 Consumers and citizens 103
6.5 Food companies, food service and retail 104
6.6 Governments 105
6.7 Non-governmental and other civil society actors 105
6.8 Summary and conclusions 106

Chapter 7 – Options towards environmentally-sustainable food systems 108
7.1 Introduction 109
7.2 What do sustainable food systems look like from a natural resource perspective? 109
7.3 Overview of options 111
7.4 Brief description of options 115
7.4.1 Options to increase resource efficiency in primary food production 115
7.4.2 Options to increase resource efficiency along food systems 117
7.4.3 Options outside the food system 120
7.5 Potential effects of options 120
7.6 Summary and conclusions 121

Chapter 8 – Opportunities for a transition towards sustainable food systems 124
8.1 Introduction 125
8.2 Limitations and the need for realism 125
8.3 'Principles' and importance of the 'food system lens' 126
8.4 Analysis of national or regional food systems and impact on national resources 126
8.5 Three pathways towards environmentally-sustainable food systems 128
8.5.1 Reforms by governments and international institutions 128
8.5.2 Private actors 131
8.5.3 Alternative (niche) innovators and NGOs 131
8.5.4 Co-evolution of three pathways for an upward spiral movement 133
8.5.5. Flexible, participative governance and co-opting with private actors that integrate sustainability as the core of their business 133
8.6 Nodes of action 135
8.6.1 Cities and reconnecting urban – rural relationships 135
8.6.2 Changing food consumption patterns, using health as a point of entry to improve natural resource management 136
8.6.3 Nutrients flows as indicator for food system functioning 137
8.7 Summary and conclusions 138

References 140

Annex 1 Resource specific options for a more sustainable and efficient use of natural resources in food systems 153

Annex 2 Glossary 158

List of figures

Figure 1 Relation between resource use, environmental impacts and food system activities 30
Figure 2 Relation between resource use and environmental impacts related to food system activities 33
Figure 3 Conceptual Framework of Food System Activities and Natural Resources 38
Figure 4 Population growth and urbanization per region 54
Figure 5 Urbanization and megacities by 2025 54
Figure 6 Per capita consumption of meat in selected countries or regions 56
Figure 7 Past and projected wheat import in five selected tropical countries (in 1000 t per year) 57
Figure 8 Per capita consumption of cereals in selected countries or regions 57
Figure 9 Current and projected production of cereals and oilseeds in a number of selected regions 58
Figure 10 Evolution of cereal utilisation shares (wheat and coarse cereals) in developed and developing countries between the base year (2011/13) and 2023 59
Figure 11 Increase in yield and harvested areas for main crops 60
Figure 12 Livestock production in various regions 61
Figure 13 Fishery production in live weight equivalent 61
Figure 14 Prevalence of undernourishment 62
Figure 15 Food affordability 63
Figure 16 Food price developments 1961–2014 64
Figure 17 Per capita food losses and waste in different regions (kg/year) 66
Figure 18 Prevalence of obesity 67
Figure 19 Yield gaps for wheat, maize and rice combined for the year 2000 73
Figure 20 Trends in total harvested area of staple crops and three major cereal crops 73
Figure 21 Regions vulnerable to crop production losses due to irrigation water shortages 76
Figure 22 Nutrient flows in food systems and various impacts 80
Figure 23 Trends and projections in global consumption of nitrogen and phosphorus fertilizer 81
Figure 24 Status of fish stocks 1974–2011 89
Figure 25 Land use (left) and greenhouse gas emissions (right) per kilogram of protein 95
Figure 26 Options for sustainable and efficient use of natural resources and reduced environmental impacts in food systems 112
Figure 27 Effect of various scenarios on cereal demand 121
Figure 28 Schematic representation of a national (or regional) food system, disaggregated into a food production and consumption system 128
Figure 29 Spiral movements created by the co-evolution of different pathways 133

Figure B.1 Geographical distribution of aquaculture production 2013 68
Figure B.2 Evolution of canal, tank and well irrigation in India 1950-2000 78
Figure B.3 Flows of N and P in the food pyramid in China at national level in 1980 and 2005 82
Figure B.4 Changes in environmental services and goods of watershed treated by MERET Project 119
Figure B.5 Changes in asset at HH level due to integrated homestead development in Ana Belesa watershed, Lemu, Ethiopia 119
Figure B.6 Fish consumption in the Netherlands 132

List of Tables

Table 1.	Indicative functions of natural resources needed for food system activities	34
Table 2.	Causes of negative impacts of food system activities on the environment	35
Table 3.	Definition of efficiency and sustainable use of natural resources needed for food system activities	36
Table 4.	Comparing some features of 'traditional', 'intermediate', and 'modern' food systems	44
Table 5.	Concentration in the Food Supply Chain – A Global Perspective	48
Table 6.	Essential minerals (nutrients) needed in the food system, for crop and animal production as well as for humans	79
Table 7.	Benefits from ecosystem services on various food system activities and impacts of these activities on terrestrial and aquatic biodiversity	84
Table 8.	Estimates of GHG emissions (in or around the year 2010) of sources within the food system (Mt CO_2-eq/yr)	94
Table 9.	Status of natural resources as needed for food system activities	96
Table 10.	Property rights regimes and institutional arrangements	101
Table 11.	Principles and indicators for sustainable food systems from the natural resource perspective	111
Table 12.	Example of options to reduce the impact of food system activities on resources and the environment (including synergies and trade-offs)	114
Table 13.	Non-exhaustive overview of current policies influencing directly or indirectly food systems and the use of natural resources	130
Table 14.	List of illustrations of sustainability-encouraging initiatives by the private sector (non-exhaustive)	132

List of Boxes

Box 1	Combining resources: the great balancing act to reach good overall efficiency	37
Box 2	Rapid changes in Southeast Asia	56
Box 3	Case study aquaculture	68
Box 4	Rapid growth of groundwater irrigation in India	78
Box 5	Case study of China	82
Box 6	Genetically-modified (GM) crops	88
Box 7	'THINK EAT SAVE' – Global engagement for the zero hunger challenge	117
Box 8	Reducing waste in Surabaya through composting and multi-stakeholder collaboration	118
Box 9	Case Study: Impacts of MERET Project on environment and livelihoods	119
Box 10	Draft framework for analyzing national food systems, with focus on national resources	127
Box 11	MSC and the Netherlands	132
Box 12	The School Lunch Programme in Brazil: The case of Paragominas	134

Executive Summary

1. Environmentally-Sustainable Food Systems[1]: an Imperative for Sustainable Development

Food systems are at the heart of the 2030 Agenda for Sustainable Development, a historic global commitment to eradicate poverty and hunger while ensuring healthy, prosperous and fulfilling lives. The food we grow, produce, consume, trade, transport, store and sell is the essential connecting thread between people, prosperity, and planet. We therefore need 'resource-smart' food systems.

Food systems crucially depend on natural resources: land, soil, water, terrestrial and marine biodiversity, minerals (essential nutrients for crops and animals) and fossil fuels. The use of these natural resources goes beyond primary food production, e.g. fresh water for processing and biomass for packaging or cooking. If we want ensure all people have safe and nutritious food, in appropriate amounts, these natural resources need to be managed sustainably and used efficiently, while reducing environmental impacts.

The food sector is globally the dominant user of a number of natural resources, particularly land, biodiversity, fresh water, nitrogen and phosphorus. Food systems, and food production in particular, are also a major driver of a number of environmental impacts, such as the loss of biodiversity, soil degradation, water depletion and greenhouse gas emissions. Therefore, the people who directly or indirectly manage our food systems are also the largest group of natural resource managers in the world and could become critical agents of change in the transformation of current consumption and production systems.

2. Current food systems are unsustainable and/or inefficient. [cf. Chapter 5]

Key statistics show the crucial role of food systems in the degradation or depletion of natural resources and provide evidence of unsustainable and/or inefficient practices regarding the use of said resources. This data is necessarily indicative. Indeed, the considerable lack of reliable data on the current condition of natural resources is a concern in itself. Also, the current state of natural resources significantly varies across regions.

- 33% of soils is moderately to highly degraded due to erosion, nutrient depletion, acidification, salinization, compaction and chemical pollution2;
- 61% of 'commercial' fish populations are fully fished and 29% are fished at a biologically unsustainable level and therefore overfished[3].
- At least 20% of the world's aquifers are overexploited, including in important production areas such as the Upper Ganges (India) and California (US)[4];
- 60% of global terrestrial biodiversity loss is related to food production[5], while ecosystem services supporting food production are often under pressure;

1. A food system "gathers all the elements (environment, people, inputs, processes, infrastructures, institutions, etc.) and activities that relate to the production, processing, distribution, preparation and consumption of food, and the outputs of these activities, including socio-economic and environmental outcomes". (HLPE, 2014a)
2. http://www.fao.org/nr/lada/gladis/gladis/; FAO (2015) Soil is a non-renewable resource: Data for 2000-2005
3. FAO (2014) The state of world fisheries and aquaculture 2014, Rome. Data for 2011.
4. Gleeson T., Wada Y., Bierkens M.F., van Beek L.P. (2012) Water balance of global aquifers revealed by groundwater footprint. Nature 488:197-200.
5. PBL (2014) *How sectors can contribute to sustainable use and conservation of biodiversity,* The Hague, (eds Kok M, Alkemade R), PBL & CBD. Data for 2010

- Of the total input in the form of nitrogen- and phosphorus fertilizers, only 15-20% is actually embedded in the food that reaches the consumers' plates, implying very large nutrient losses to the environment[6]. Some regions have lower efficiency and higher losses (North America, East Asia), while in Sub-Saharan Africa soil nutrient depletion (where extraction is higher than input) is common.
- Globally, food systems account for around 24% (21-28%) of the global greenhouse gas emissions[7].

There are large regional differences in how food systems are managed, and hence the nature of their impacts on natural resources. In some regions, land degradation and biodiversity loss are the major issues, while in other regions high nutrient losses leading to declines in air and water quality are of greater concern. In many cases, progress has been made over recent decades on various aspects of resource use in their food systems leading to, for example, higher crop yields (meaning more efficient use of agricultural land), increased nutrient- and water-use efficiency, improved water quality and lower greenhouse gas emissions. In other cases, such progress has been slower, or trade-offs have occurred, for example the focus on higher crop yields has led to water pollution by nutrients or pesticides or to soil degradation.

3. Food, natural resources and health concerns interrelate: current food security, natural resource management practices and diet-related human health are far from satisfactory. [cf. Chapter 4]

Although much progress has been made in some aspects, current food systems are not delivering food security and healthy food for everyone nor are they sustainably using the limited natural resource inputs as explained above. Food production has more than doubled, diets have become more varied (and often more energy-intense) satisfying peoples' preferences in terms of form, taste and quality; numerous local, national and multi-national food-related enterprises have emerged providing livelihoods for millions. Nonetheless over 800 million people are hungry, over 2 billion suffer from micronutrient deficiencies, in particular vitamin A, iodine, iron and zinc, and over 2 billion people overweight or obese[8]. This situation, and particularly the unhealthy overconsumption by an increasing number of people, is unsustainable and needs to change.

Nutrition is the cornerstone of sustainable development. To achieve the international targets set by the United Nations Secretary-General Zero Hunger Challenge[9] and Sustainable Development Goal 2[10] we must re-think the way in which food system activities are structured and carried out. Ensuring access to nutritious food for all is at the core of this change and this will often depend on the way markets function at the local, national, regional and global levels, on the social safety nets created for vulnerable groups of the population (e.g. the urban poor and smallholder farmers), and on their access to infrastructure, finance, knowledge and technology. In societies suffering from overconsumption, lifestyle choices and consumer information play a fundamental role.

6. Sutton M.A., et al (2013) Our nutrient world: the challenge to produce more food and energy with less pollution NERC/Centre for Ecology & Hydrology, Edinburgh. Data for 2000 - 2011
7. FAO. (2014) Agriculture, Forestry and Other Land Use emissions by sources and removals by sinks, Rome; Vermeulen S.J., Campbell B.M., Ingram J.S.I. (2012) Climate Change and Food Systems. Annual Review of Environment and Resources 37:195-222. Data for 2010. See also chapter 5 of this report
8. Ng M., Fleming T., Robinson M., Thomson B., Graetz N., Margono C., Mullany E.C., Biryukov S., Abbafati C., Abera S.F. (2014) Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013: a systematic analysis for the Global Burden of Disease Study 2013. *The Lancet*.
9. The Zero Hunger Challenge sets five targets: 100% access to adequate food all year round; 0 stunted children under the age of 2; all food systems are sustainable; 100% increase in smallholder productivity and income; zero food loss or waste.
10. Sustainable Development Goal 2: *"End hunger, achieve food security and improved nutrition and promote sustainable agriculture"*.

4. Pressure on natural resources is expected to increase steadily over the coming decades. [cf. Chapters 4 and 5]

A number of developments will have important consequences for the use of natural resources in food systems:

1. The expected population growth, especially in Africa and Asia, implying a higher demand for food;
2. The increase in wealth in a large number of developing countries, typically leading to diets which are richer in resource-intensive products, such as (red) meats, fish, fruits and vegetables as well ultra-processed food and drink products. This process is intermingled with the effects of urbanization.
3. Climate change, which will impact both average weather conditions and extremes, which will have a large impact on the natural resources needed for food production.

5. There are significant opportunities to decouple food system activities from environmental degradation. [cf. Chapter 7]

The sustainable and efficient management of natural resources is now an imperative for the achievement of all United Nations Sustainable Development Goals (SDGs). Restoring and maintaining the health of the natural resource base is not only needed to adequately feed current and projected populations, but to provide a better quality of life in the years to come.

Sustainable resource management is about preventing degradation of resources (land, sea, ecosystem services), by reducing overexploitation (for example through regulation, pricing strategies or resource valuation) and adopting effective management practices of landscape elements such as wooded areas, hedges and wetlands.

Increasing the efficient use of all resources in all food system activities will help move towards a more sustainable use of renewable resources (e.g. fresh water reserves), lower environmental impacts (e.g. eutrophication from nutrient run-off and lower greenhouse gas emissions) and a lower depletion rate of non-renewable resources (e.g. fossil fuels and minerals).

Many options across the whole food system are already available to enable more efficient natural resource use and enhance decoupling of increasing food production from resource depletion. Although good integrated assessments of the combined potential of various options are lacking, findings from studies looking at individual options indicate that these could lead to an estimated 5–20% improvement in efficiency; when combined, the increase could be up to 20–30% for certain resources and impacts, assuming limited rebound effects. Options towards environmentally-sustainable food systems are very context and location dependent, but could include:

- 'Sustainable intensification' of crop production (e.g. higher yields without increasing environmental impacts);
- More effective use of ecosystems services (e.g. integrated pest management to reduce pesticide use);
- Better feed conversion (without reducing animal welfare) and higher productivity of pastoral systems;
- Higher nutrient efficiency along the food chain (e.g. better recycling of minerals in animal manure, use of by-products or food wastes as feed or compost, recycling of minerals from cities, etc.);
- More efficient aquaculture systems, with lower nutrient losses and less impact on coastal systems;
- More energy- and water-efficient food processing;
- Reduction of food losses in farms and fisheries, and reduction of food waste throughout food systems;

- Reduction of overconsumption and change of unhealthy dietary patterns (e.g. shift in affluent societies from animal-based to more plant-based diets).

If the above changes are not made, land degradation, the depletion of aquifers and fish stocks and contamination of the environment will lower future food production capacity. It will undermine the food systems upon which our food security depends, as well as cause further degradation of other ecosystem functions.

6. A 'food systems' lens is essential to improve resource efficiency, food and nutrition security. [cf. Chapter 2, 6 and 8]

One of the great strengths of the SDGs is the global recognition of the close links between human well-being, economic prosperity and a healthy environment. There is a growing amount of scientific information about the inter-linkages between the Earth's systems and human activities. A systems approach is needed to understand these complexities and identify effective responses to emerging human development challenges. This is certainly also applicable to the analysis of natural resource use and environmental impacts of food.

To effectively enhance resource efficiency in food systems the focus of attention should be expanded from farmers and fishermen, to include other actors further along ("downstream") the 'food chain', and ultimately to consumers. In our interconnected and complex world, acknowledging the important roles of food processors, packers, transporters, retailers and consumers, in addition to food producers, is an important step to identify pathways that address the challenges regarding natural resources, while simultaneously improving food and nutrition security. Using the food systems lens on local, national or regional levels allows for the analysis of underlying drivers and possible solutions in a more systematic and holistic manner.

A thorough analysis of existing food systems can assist in identifying the most important issues regarding natural resources, as well as the opportunities for effective policy, fiscal, social and/or technical interventions. In order to identify these opportunities, national or local food systems need to be properly analyzed (a multi-disciplinary exercise): Who are the main actors? How is the economic system functioning? What are the crucial institutional and governance arrangements? Which regulations are in place? What are the major developments of the last 10-20 years? What is the position of women in food systems?

An analysis from a systems perspective will reveal underlying causes of unsustainable production and consumption patterns. These underlying causes will vary substantially across world regions. Analysis through a food systems 'lens' helps identify where the greatest overall resource use efficiency gains can be achieved. Ambitions can be set to improve resource use efficiency as well as food security outcomes.

When analyzing food systems, it is important to note that on a local or national level, the food production system and the food consumption system rarely coincide: a part of the food produced might be exported, while a part of the food consumed is imported. This can reduce the capacity of governments to take action, for example because they cannot directly influence natural resource use of imported food products.

7. The convergence of some unsustainable trends in global food systems can lead to greater resource inefficiencies. [cf. Chapter 3 and 4]

Current food systems vary worldwide from 'modern' food systems in industrialized and emerging regions to more 'traditional' food systems in rural areas in developing countries. This variety in food systems, in combination with the social and natural environment in which they operate, has important implications on the possible pathways towards sustainable food systems and on the logic of intervention. In developing regions, there is a rapidly evolving replacement of traditional food systems by modern food systems. This trend is driven by macro-trends such as urbanization, increased wealth and other socio-economic and demographic developments. These intertwined trends also imply changes in dietary patterns and 'supermarketization' in many parts of the world. These developments significantly increase the pressure on our natural resources.

8. There are multiple pathways towards sustainable food systems. [cf. Chapter 8]

By using the food system lens, effective interventions can be identified towards sustainable food systems. These actions can be initiated by various actors from governments, companies and civil society. **Governments** have an important task in setting the institutional and regulatory framework. Especially in developing countries, poor tenure rights (of land and water) and access to natural capital, coupled with weak regulation, poor levels of education and limited access to input and output markets do not encourage sustainable resource use. The environmental costs (externalities) of the food system are hardly included in food prices (TEEB, 2015)[11]. The pricing of environmental externalities, reinforcement of legislation to prevent pollution and other forms of environmental degradation, and the removal of harmful subsidies (e.g. fossil fuels) could provide important incentives to improve resource efficiency. Governments play an important role in education, which is relevant both for food producers, as well as for food consumers. Children need to be taught how to prepare food from basic ingredients, and need to be aware of its nutritional aspects.

In all countries there is currently a large number of laws, financial and other regulations that are influencing directly or indirectly food systems and the use of natural resources. These can be policies at the international level (e.g. trade regulations), at the national level, but also at the local level (e.g. local farming extension services, location of restaurants, urban waste management, etc.). Aligning these policies in such a way that these contribute to sustainable food systems is thus an important mission for authorities at various levels of government. Governments have also a role in stimulating and facilitating innovations, new initiatives, collaboration and cooperation along the system. In general, special attention is needed for the role of women, as they are usually critical participants in food production and main managers of food consumption in their households. A number of concrete actions that governments could implement are:

1. Removal of subsidies that encourage unsustainable production or practices (e.g. fossil fuel subsidies);
2. Creation of adequate legal frameworks to secure property rights and land tenure and regulate access to and use of water, biodiversity, and ecosystems services;
3. Creation of adequate legal frameworks to regulate environmental impacts from food systems (e.g. regulation to prevent nutrient losses at all stages, but especially in the livestock sector);

11. TEEB (2015) TEEB for Agriculture & Food: an interim report, United Nations Environment Programme, Geneva, Switzerland

4. Investment in management practices and research development to enable a more effective use of biodiversity and ecosystem services in food production;
5. Investment in technology and research development for locally suitable seeds and breeds (with proper infrastructure, distribution system, quality assurance and certification schemes);
6. Creation of incentives for local or regional sourcing and investment in sustainable local supply chains;
7. Attraction of investments in rural infrastructure, small enterprise development (e.g. inputs, local storage and processing facilities, logistic and transport);
8. Facilitation of collaborative schemes between different food system actors (e.g. cooperation agreements among retailers to establish marketing codes of conduct);
9. Creation of incentives for cities to become innovation incubators where ideas on sustainable food systems are tested (urban farming, education campaigns, sustainable sourcing, food environment regulations, etc.);
10. Adoption of consumption-oriented policies (e.g. to promote consumption behavior research, stricter marketing rules for unhealthy food, create a food environment which stimulates healthy and sustainable diets);
11. Creation of adequate monitoring systems of the status of the natural resources needed in food systems, as well as their environmental impacts;
12. Creation of education programmes on the links between natural resources, consumption patterns and health.

The global community has called upon all businesses "*to apply their creativity and innovation to solving sustainable development*".[12] **Private actors** are crucially important players in food systems, as food systems are in effect a collation of enterprises. The current business logic of many food systems does not always give actors the right incentives to promote more sustainable practices. However, many companies are increasingly seeing it in their long term interest to invest in more sustainable supply chains. Private companies could undertake actions such as paying farmers and fishermen for better management of natural resources, helping smallholder farms and small agri-food businesses in developing countries invest in more sustainable activities including improving water and energy use-efficiency in food storage and processing, and in other post-farm-gate activities. Private actors have a key role in reducing food waste, especially in modern food systems, as well as in making healthy and sustainable food choices easier for consumers.

In many developing countries, smallholder farmers are not connected to modern food value chains that largely target urban consumers or export markets. Actors as retailers and food companies could invest in local supply chains, while assisting farmers to increase production in a sustainable way.

In affluent sections of society – both in 'developing' or 'developed' regions – the high consumption of animal based products, as well as of ultra-processed food (often containing 'empty calories') brings disproportionate environmental costs, and moreover undermines public health due to obesity-related diseases. This high consumption is partly driven by food companies influencing demand towards products with attractive profit margins.

Finally, actors from **civil society** can stimulate governments and private actors to take action, either in the form of constructive dialogue or by awareness raising and campaigning. They also can stimulate certain niche players, and thus challenge incumbent actors to act more swiftly.

12. General Assembly resolution 70/1, *Transforming our world: the 2030 Agenda for Sustainable Development*, A/RES/70/1 (21 October 2015), available from undocs.org/A/RES/70/1.

Twelve critical shifts towards environmentally-sustainable food systems

1. *Reduce* food loss and waste.
2. *Reorient* away from resource-intensive products such as meat, 'empty calories' and ultra-processed food; and *rethink* the 'food environment' (the physical and social surroundings that influence what people eat, especially relevant in urban areas) to facilitate consumers adopting more healthy and sustainable diets.
3. *Reframe* thinking by promoting 'resource-smart food systems' in which 'Climate-Smart Agriculture' (CSA) plays one part, and search for linkages to new dominant values such as 'wellbeing' and 'health'.
4. *Reconnect* rural and urban, especially in developing regions, where urban actors (e.g. supermarkets) could invest in regional supply chains and improve the position of smallholders.
5. *Revalue* the pricing of environmental externalities, *reinforce* legislation to prevent pollution and other forms of environmental degradation and *remove* subsidies that provide disincentives for better resource efficiency.
6. *Reconnect* urban consumers with how their food is produced and how it reaches their plates, and inform them about both the health and environmental consequences of dietary choices, protect peri-urban zones around cities and use them for local food production.
7. *Research* the current functioning of the local, national or regional food systems and their impact on national resources.
8. *Reconnect* mineral flows between urban areas and rural areas, as well as between crop and livestock production.
9. *Reform* policies on land and water rights, *develop and implement* policies at all levels of governments (multilateral, national and local) to enable better resource management and encourage synergistic 'adaptive governance' by the wide range of non-state actors (i.e. businesses and civil society) within the food system.
10. *Reinvigorate* investment in rural infrastructure, education, training, technology, knowledge transfer and payments of environmental services.
11. *Research and innovate,* to decouple food production from resource use and environmental impacts, and to replace certain inputs (such as pesticides) with ecosystem services.
12. *Rebuild* feedback loops by functional and informative monitoring and reporting, at various levels, such as countries, cities and companies.

Credit: Andrii Gorulko, Shutterstock.com

Chapter 1

Introduction

All people have the right to a healthy diet. This right has been unequivocally recognized by the international policy, scientific and civil society communities. It was reaffirmed by global leaders at the Conference on Sustainable Development (Rio+20) and integrated into the 2030 Agenda for Sustainable Development, a universally adopted document which establishes the goal to "end hunger, achieve food security and improved nutrition and promote sustainable agriculture".

This fundamental right and the goal set by the international community will only be protected and achieved if we change the way in which we manage our food system, that is the way in which we grow, produce, trade, transport, store, sell and, consume our food. In fact, the effective implementation of the entire agenda for sustainable development will depend on the way in which we manage the natural resources that allow the food system to function effectively.

The food system is critically dependent on a large array of natural resources. These include land, water, minerals, biodiversity and ecosystem services, including genetic resources and marine resources such as fish stocks. The sustainable and efficient use of these resources is thus essential for satisfying both current and future food demand. Due to increased wealth, globalization and urbanization, substantial changes in food systems and consumption patterns have taken place in many parts of the world. These changes are projected to continue, leading to an increase in total food demand and hence an increase in resource use.

The UNEP International Resource Panel (IRP) has identified food and its multiple resource interactions as an important 'node'. Rather than looking at each resource separately (such as land, water, minerals and biodiversity), the Panel has chosen a more integrated approach. In relation to food production in particular, this approach is based on its report on priority products and materials which states that agriculture "*is responsible for by far the most of the land and water use globally, leading to habitat loss and other negative impacts on ecosystems. The use of agrochemicals is related to ecotoxicity, eutrophication and depletion of phosphorus stocks. Intensive agriculture is related to substantial energy use. The loss of soil and biomass carbon can contribute to climate change. [.]. On the other hand, agriculture can also contribute to environmental solutions, e.g. by binding carbon in the soil, increase biodiversity through diverse habitats. The impacts of agriculture thus depend to a substantial degree on specific aspects of the activities and hence the resource management regime.*" The same report points at fisheries, stating that "*overexploitation of resources is clearly associated with this sector, as well as relatively high emissions from industrial fisheries.*"[13]

The Panel also aims to support the implementation of the UN Secretary-General's 'Zero Hunger Challenge' which aims for sustainable food systems and a 100% access to adequate food all year round. The UN Secretary-General states that the elimination of hunger by 2050 requires "*comprehensive efforts to ensure that every man, woman and child enjoy their right to food, […] investments in agriculture, rural development, decent work, social protection and equality of opportunity*" and he encourages a range of organizations and social movements to participate and invest in this vision[14].

For these reasons, and recognizing that food security involves more than just food production, the IRP decided to undertake a study on 'Food Systems and Natural Resources'. Before delving into the reasons for taking this focus, it is useful to define what is meant by 'food systems'. The High Level Panel of Experts on Food Security and Nutrition which report to the UN Committee on World Food Security (CFS), define a food system as:

> *"all the elements (environment, people, inputs, processes, infrastructures, institutions, etc.) and activities that relate to the production,*

13. UNEP (2010) *Assessing the environmental impacts of consumption and production: priority products and materials,* Nairobi / Paris, International Resource Panel United Nations Environmental Programme.
14. http://www.un.org/en/zerohunger/challenge.shtml

processing, distribution, preparation and consumption of food, and the outputs of these activities, including socio-economic and environmental outcomes" (HLPE, 2014a).

There are a number of reasons for looking at food *systems* rather than at food production alone:

- Recent decades have seen many initiatives and activities undertaken to increase the output of the agricultural and fisheries sectors. In parallel to this, much effort has been put into increasing the sustainable and efficient use of natural resources, with mixed results and major challenges. An approach which merely focuses on the *production* side does not consider opportunities within other food system activities (such as food processing, retailing and preparing) to attain more resource efficiency across the whole system. Reducing food losses and waste offers an especially important opportunity, and this has received more attention in recent years. Furthermore, a production-oriented approach cannot directly consider the socio-economic consequences of certain measures or choices, such as changes in demand or the effects of changes in trade regimes.
- A food systems approach addresses more directly the important food security issues of both undernutrition and overconsumption. A production-oriented approach fails to take into account the serious health implications that arise from current food consumption patterns. An increasing number of people are suffering from 'non-communicable diseases' such as diabetes, certain types of cancer or heart diseases related to the overconsumption of sugar and fat. Different dietary choices could lead to more resource-efficient food systems, resulting in both reduced pressures on natural resources and better health outcomes.
- A food systems approach also considers changes such as "supermarketization", referring to the increasing share of (in most cases) internationally-operated supermarkets in the total share of consumer food purchases, a trend that is particularly seen in Asia and South America. This supermarketization not only affects the power relations in the food supply chain, but very often also affects eating habits and product sourcing. A rapid consolidation process has taken place both in the input and the processing industries, resulting in dually structured food chains with a small number of companies dominating the market.
- Finally, a food systems approach considers food supply and demand in a balanced way, within the context of actors, institutions and governance. It is therefore better equipped to identify actual opportunities linked to food system actors (i.e. farmers/fishers, food companies, retailers and consumers). Although much of the resource use is at the farm or fisheries level, many opportunities to change practices exist 'upstream' in the food system. Many of the production activities are controlled by demand, and therefore are largely set by signals that come from the whole food chain.

With increasing globalization and concomitant demand for food, the food systems approach is now more relevant than ever. Most of the food consumed is no longer produced in self-sufficient families or communities, but travels (and often a long way) from producer to consumer. A globally increasing share of all consumed food is processed and arrives in packaged forms at the consumer. The global food system that makes this happen is not a neutral supply chain; actors such as food processing companies and retailers largely shape both supply and consumer demand (Lang *et al.*, 2009, Pinstrup-Andersen, 2002, Pinstrup-Andersen & Watson II, 2011). This is why in this study a 'food system lens' is used to identify biophysical, policy and other socioeconomic options and opportunities for these actors to arrive at more resource-efficient food systems with lower environmental impacts, while at the same time aiming to improve the societal outcomes (such as human health and rural livelihoods). Given the need to radically enhance both food security and environmental conditions, such an approach will also be helpful for policy development and implementation

by governments where the different aspects (nutrition, health, agriculture, fisheries, food industry, resources) are often treated separately.

There are two important points to bear in mind: (i) For specific issues (for example land degradation) the more traditional physical, resource-oriented approach and the more holistic food systems approach should be seen as complementary – the former can identify concrete options within the current context related to natural resource management *per se*, while the food systems approach offers opportunities from a broader perspective. It should be stressed that this report can only very limitedly capture the wealth of information available on the specific natural resources and environmental impacts of food systems. (ii) The food systems approach is relatively new and is still being developed and adopted. This report should be seen as an important step in this process, helping to further develop the approach and its application to the sustainable use of natural resources in food systems. The food systems analysis has to be concise, and more information is available in the current literature on some aspects related to the interactions between specific natural resources in given food systems, which are very largely region- and issue-specific.

It should also be noted that many regional and local food systems are connected to some degree, for example through trade or the exchange of technologies or resources. This study therefore includes a set of regional case studies for Sub-Saharan Africa, South East Asia and Europe. These have been selected to cover a wide range of contexts, from those in which food security is still mainly dependent on local subsistence/low-input farming, to 'modern' food systems connecting high-input production areas with consumers worldwide. Food systems therefore vary significantly across the globe in terms of actors, technology and type of resources used. Although very diverse, ultimately all of these food systems depend on natural resources.

Given the large and increasing reliance on natural resources of food production and consumption, as well as the significant environmental impacts of food systems, the IRP developed this report to:

1. Assess the current status and dynamics of natural resource use in food systems and the food system impacts on the environment (Chapters 4 and 5);
2. Determine opportunities for improving resource efficiency in food systems, responding to the following questions:
   - What do sustainable food systems look like from a natural resources perspective? (Chapter 7)
   - How can improvements in resource efficiency be made to enhance food security? (Chapter 7)
   - How can a transition towards sustainable food systems be stimulated? (Chapter 8)

In order to address these objectives, the report is structured as follows:

Chapter 2 introduces and explains the concept of a food systems approach and shows how this concept can help in developing ways to improve the efficient use of natural resources across the whole food system. It also provides background information on the use of natural resources in food production, processing, retail and consumption, as well the environmental impacts related to these activities.

Chapter 3 introduces and describes the characteristics of major types of food systems in terms of their natural resource use implications. It also describes the key characteristics in food systems governance and coordination mechanisms, and how these food systems have evolved over the past few decades, particularly driven by changing socio-economic and bio-physical circumstances.

Chapter 4 analyzes the projected socio-demographic changes and how these might affect food systems and the related natural resource and environmental issues. It also looks into the effects of current and projected

food consumption patterns on human health. Where does under-nutrition occur, now and in the near future? Where does over-nutrition and obesity occur and what are the trends? Where are diets expected to become more resource demanding?

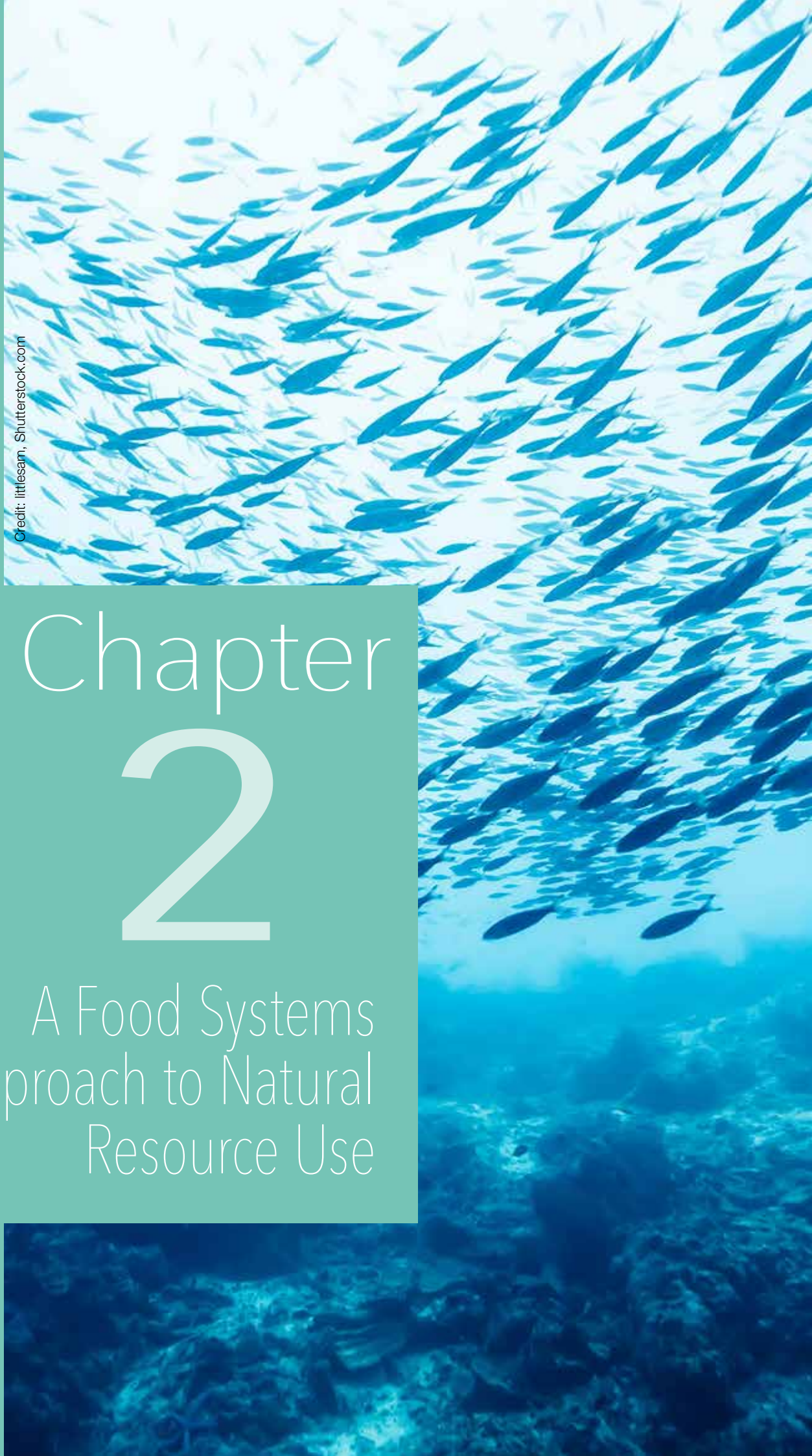
Chapter 5 focuses on the natural resource use and environmental impacts of current and projected food consumption and production in the context of food systems. The current and projected status and dynamics of natural resource use in regional food systems is reviewed, as well as a number of environmental pressures.

Chapter 6 looks at the behavior of food system actors and the context in which they operate, with a particular focus on property and tenure rights regimes. The chapter highlights issues around access, control and use of various resources and pinpoints to several institutional conditions that are relevant for moving towards more sustainable food systems.

Chapter 7 discusses the options for more sustainable food systems. It first describes the principles for sustainable food systems from a natural resources perspective. It then goes on to discuss a number of biophysical options to improve the overall resource efficiency of food systems while taking into account aspects such as food security, the contribution of food production to rural livelihoods and food sovereignty.

Chapter 8 suggests concrete actions that different actors could undertake to reduce the current environmental impacts of food system activities.

The urgency of the various issues covered in this report cannot be under-stressed. Many studies seem to focus on some decades ahead (e.g., 2050, 2100), many of the problems relate to aspects of the *current* food system, and many of the solutions already exist. Various natural resources that are critical for food production are under increasing pressure due, for example, to land degradation and the depletion of aquifers. The Green Revolution has boosted crop production in many areas, but some of these areas now show signs of stagnating increases in, or even declining, crop yields. This is caused by a combination of soil fertility decline, water shortages and changes in pest and disease dynamics. The environmental impacts of current food system activities often compound the situation locally, through, for instance, nutrient losses from intensive crop and livestock systems, and aquaculture, increasing resource demand, and effluents from other food system activities. Diets are changing rapidly worldwide, with dramatic consequences for both natural resources and human health. Now is the time to apply the many solutions already known to exist in order to move towards environmentally-sustainable food systems.



Credit: littlesam, Shutterstock.com

Chapter 2

A Food Systems Approach to Natural Resource Use

2.1 Introduction

This chapter provides background information on the use of natural resources as needed for food production, processing, retail and consumption, as well as the environmental impacts related to these activities. Food production is critically dependent on a large array of natural resources, such as land, fresh water, genetic resources and minerals. Many of these resources are in principle 'renewable' and, given proper management, can be used for centuries or more as they are naturally replenished or regenerated. When this is however not the case, the potential of these resources to provide a resilient basis for food systems, and notably food production, will be reduced, including lower crop yields, fish catches or livestock production. This intrinsically connects the issue of natural resource use to the food security challenge.

The food systems concept has proved its utility in helping to address this challenge (Ingram, 2011). In this report the same concept is extended to assess the current and projected use of natural resources within food systems. The concept is helpful as it integrates the notion of the full set of activities and actors (including the socio-economic environment in which they operate) in the 'food chain' (i.e. producing, processing, distributing, retailing and consuming food) with the outcomes of these activities for food security. It is increasingly being adopted by the food security community: *Healthy people depend on healthy food systems* (FAO, 2013a).

Using the food systems concept to structure the discussion, the chapter also considers the numerous two-way interactions between food systems and natural resources. This is important as food system activities (from producing to consuming food) are in many cases significantly degrading the natural resources upon which our food security depends, while also contributing to climate change, local and regional pollution. Tackling these problems now is of the utmost urgency considering one billion people will be added to the global population, mainly in cities where food insecurity is already a challenge. This population increase will be compounded by an increasing middle class, which in turn will result in a change towards more energy- and natural resource-intense diets. The combined impact of these trends on natural resources is likely to be substantial.

Finally, the chapter also includes a discussion on the benefits of a food systems approach for natural resource management. It concludes by presenting the concepts used in this report related to natural resource use and environmental impacts of food systems.

2.2 Why 'food systems'?

2.2.1 Background to the food security debate

Recent years have seen a heightened debate on 'food security' within science and policy communities, the food industry and the media. This has been largely driven by concerns about population growth, anticipated increases in food demand due to economic growth and climate change. Typical questions include: How will climate change affect food supplies? How will food price spikes affect the poor? How will the growing food demand be met without further undermining the natural resource base upon which our food security depends? Food security – and particularly its interactions with environmental concerns – now takes centre stage. Perhaps the most widely cited definition of food security is based on the 1996 Declaration on World Food Security definition (World Food Summit, 1996), but with the addition of the notion of 'social' access to food (CFS, 2009). According to this definition, food security is a condition whereby:

> *'all people, at all times, have physical, social and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life'.*

As well as highlighting 'access' to food, the definition of the Committee on World Food Security (CFS) – Food and Agriculture Organization of the United Nations (FAO) also integrates the notions of food availability and food utilization, moving beyond the productionist paradigm. There are several reasons for the debate on 'food security'. The central one is that, in spite of the fact that food production has significantly increased over the last 50 years, globally still around 850 million people are undernourished. The debate has also been driven by the food price spikes of 2008 and 2011 (which showed the vulnerability of major commodity prices to a number of interacting factors) (Martin & Anderson, 2011), and the fact that coming decades will likely show continued increases in overall demand (driven by the combination of population growth *per se* and changes in overall consumption patterns). Another important notion in the CFS-FAO definition above is 'sufficient'. While this was originally included to ensure 'not too little', its meaning of 'not too much' is now of growing importance, given the rising obesity epidemic. This therefore raises another major question: how can over-consumption by increasing affluent people be moderated? Apart from the health costs of the epidemic, there are also major environmental concerns related to supplying this additional food (i.e. in addition to the baseline increase due to population growth).

Discussions about a 'solution' within the debate on food security and how to make the food system more environmentally benign mostly remain focused on the food production aspects (e.g. 'climate smart agriculture'). These are certainly important as more food has to be produced over the coming decades. However, neither food security nor the sustainable management of natural resources are directly addressed when focusing on the production side of food only.

A food systems approach relates all the food system activities (growing, harvesting, processing, packaging, transporting, marketing, consuming, and disposing of food and food-related items) to the outcomes of these activities, not only for food security and other socio-economic issues, but also the environment. Food systems are therefore defined as both the food chain activities, and the food security and other outcomes of these activities (Ericksen, 2008, Ingram, 2011). The food systems approach thus allows the food chain activities to be linked to their social and environmental context. Moreover, actors in each section of the food chain have their own interests and affect each other's behavior. The food chain activities have implications for social and environmental welfare (Figure 1) but the latter also affect food chain activities; the systems approach implies the feedback and two-way linkages are taken into account.[15]

A food system therefore also encompasses the interdependent sets of enterprises, institutions, activities and relationships that collectively develop and deliver material inputs to the farming sector, produce primary commodities, and subsequently handle, process, transport, market and distribute food and other agro-based products to consumers. Food systems differ regionally in terms of actors involved and characteristics of their relationships and activities. In all cases they need to be 'sustainable', i.e: 'a sustainable food system (SFS) is a food system that delivers food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition for future generations are not compromised' (HLPE, 2014a).

2.2.2 Linking the food system concept to actors and natural resources

There are several ways to make the food system concept operational for analytical purposes. For instance, the agro-food system can be broken down into sub-sectors, generally by commodity or group of commodities (cereals, dairy industry, fruit and vegetables, etc.), each with their own specific features of structure, institutions and relationships. A disadvantage of a focus on sectors may be that the coordinating role of actors engaged in activities such as input,

15. The environmental context shows the natural resource endowment (including the quality of resources) which makes food production possible. The social context of a food system determines how resources are being used.

processing and logistics industries and retail in a food system are neglected. The transition from primarily subsistence farming to cash cropping and/or commercial livestock production and marketing entails the development of systems to coordinate the activities of input providers, producers and downstream agents, across both space and time. Moreover, a food system also has an institutional (rules and regulations) and a jurisdictional, administrative (provincial, national, intergovernmental) dimension (Ingram *et al.*, 2010). This implies that there are many aspects that should be taken into account when defining and describing a food system. For the purpose of this report, the objective is not to cover a very wide array of food systems, but rather to sketch the main characteristics of broadly-defined types of food systems to show their impacts on natural resource use and on the environment more generally.

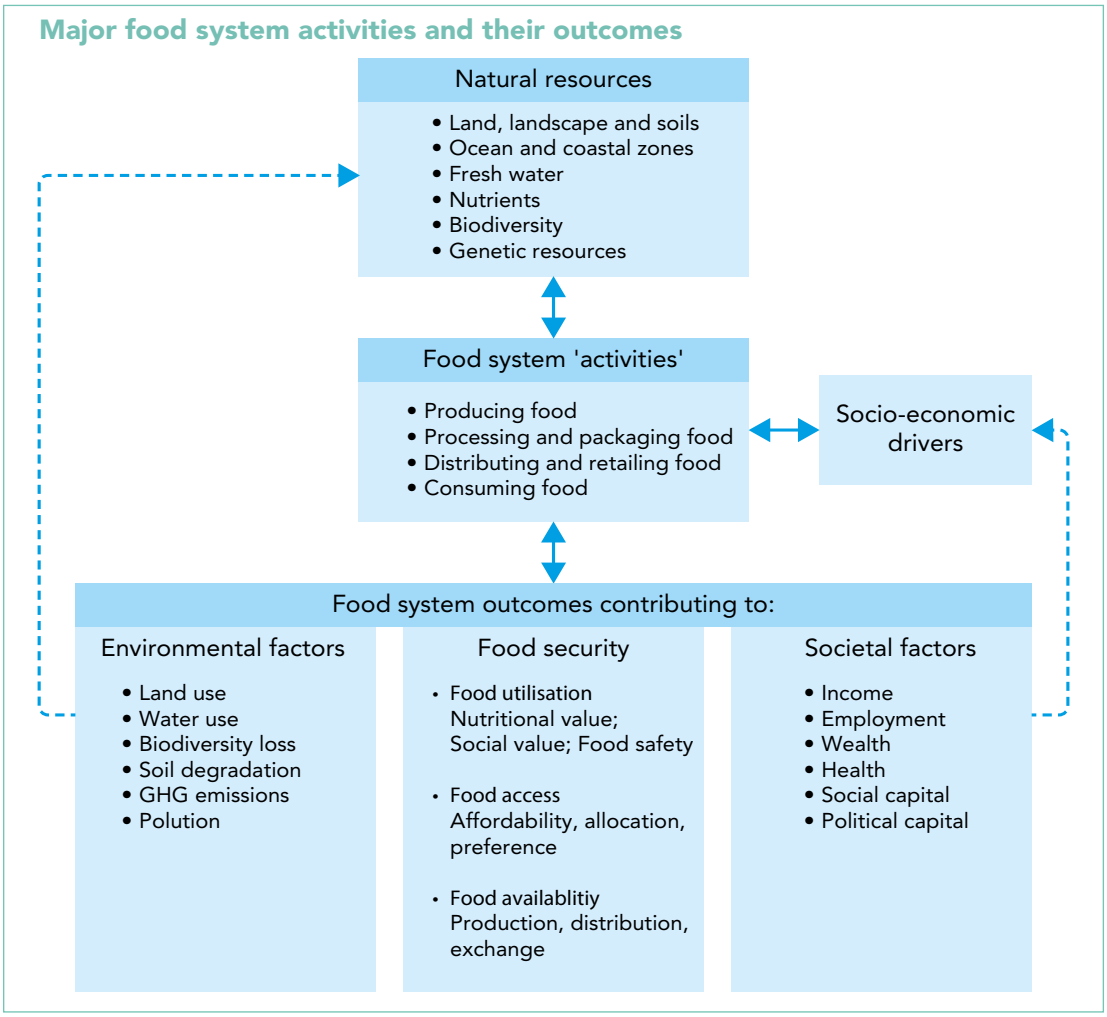
2.2.3 Emergence of the food system concept

The food system concept is not new; driven by social and political concerns, rural sociologists have promoted this approach for some years (McMicheal, 1994, Tovey, 1997). Several authors have since put forward frameworks for analyzing food systems, but (Sobal *et al.*, 1998) noted that few existing models broadly described the system and most focused on one disciplinary perspective or one segment of the system. They identified four major types of models: food chains, food cycles, food webs and food contexts, and developed a more integrated approach including nutrition. (Dixon, 1999), meanwhile, proposed a cultural economy model for understanding power in commodity systems, while (Fraser *et al.*, 2005) proposed a framework to assess the vulnerability of food systems to future shocks based on landscape ecology's 'Panarchy Framework'. Since then, food systems have been defined in a number of ways. Most focus on the 'food chain', which includes the whole array of "*activities"* ranging from the input of germplasm and agrichemicals, through harvesting, storing, processing, packaging, distributing and retailing food, to consuming food.

The suite of food system activities needs to be seen within the context of the overall food security objective and, despite these varied approaches, none was suitable for specifically analyzing the food security outcomes. One reason is that these analytical frames do not sufficiently recognize that food security outcomes have multiple causes and are the result of a complex set of activities, interactions and interdependencies among different aspects of food systems. This is therefore why the further extension of the inclusion of the '*outcomes*' of these activities has been helpful; they relate to food security *per se* (incorporating components of access to, and utilisation of food, in addition to food availability – all of which need to be stable over time). They also include outcomes relating to other socio-economic goals such as employment and wealth creation for those engaged in any of these activities. However, they also lead to a range of environmental outcomes that all impact natural resources. In summary, the food system concept can thus be thought of as a combination of the activities (the 'what we do') and the outcomes of these activities (the 'what we get'). The 'combined' food systems approach therefore clearly defines the full set of activities (not just the production aspects) and links these to a notion of food security 'unpacked' into its varied elements, in accordance with the FAO definition (Ericksen, 2008, Ingram, 2011). As all the activities have interactions with natural resources, this allows for a more thorough analysis of the links between food security and natural resources (Figure 1).

Figure 1 shows the four major sets of food system activities (all of which are dependent on natural resources) and their outcomes in relation to: (i) the three major components of food security and their respective elements (as derived from FAO's food security definition; in italics), all of which need to be satisfied for food security to be met; (ii) other societal factors; and (iii) environmental factors. Outcomes related to social factors feedback to social-economic drivers while the outcomes related to environmental factors feedback to natural resources

Figure 1 Relation between resource use, environmental impacts and food system activities



This depiction of food systems is generic and independent of spatial scale. How it manifests in a given situation is however highly context-dependent. Although all food systems have the same essential attributes, they vary significantly in different regions of the world, and hence have different interactions with natural resources: how natural resources underpin all system activities, and how these activities impact natural resources, vary considerably from case to case.

2.2.4 Benefits of a food systems approach for natural resource management

Many studies assess the impact of a given food system activity (e.g. producing or transporting food) on a given resource (e.g. land, water, minerals) or environmental outcome (e.g. GHG emissions), as discussed above. The food system concept provides a framework to integrate such studies to provide a more complete description of the 'food' interaction with both socio-economic and natural resource implications. However, its main value is in showing where the feedbacks to both socio-economic and environmental drivers lie, as these are often the ultimate cause for further natural resource degradation.

Using a 'food system lens' to look at multiple objectives

Food systems relate to multiple objectives. Attaining food security is of course central, but food systems are also instrumental in the livelihood strategies of all actors in the food system activities except 'consuming', and contribute to other socio-economic goals such as social capital and peace. While they can also address environmental objectives such as carbon sequestration in agricultural landscapes,

there is usually a trade-off between the social, economic and environmental goals.

As highlighted by the IRP "[T]he SDGs have been designed to address all of the dimensions of sustainable development – economic, social and environmental – in the recognition that progress will need to be made on all of them together, and that policies for implementing them need to be based on a systemic understanding of the different goals and be designed as an integrated, coherent package managing for co-benefits and mitigating the effects of trade-offs" (UNEP, 2015).

The food system approach helps both identify and 'map' these multiple goals, as well as organize and systematically structure the conversations needed to identify and work towards potential synergies between them.

Using a 'food system lens' to deal with complexity

(Ingram, 2011), summarizing (Ericksen, 2008), notes the food systems approach frames the food system activities as "dynamic and interacting processes embedded in social, political, economic, historical and environmental contexts". There are numerous food system 'actors' who undertake these 'activities' and they behave, act and influence each other in a certain way to attain their objectives. These are however no sets of linear acts and influences that follow each other in a predictable or sequential order. Food system actors decide and behave in response to what they perceive as incentives (opportunities, challenges and risks) and constraints (environmental, institutional and financial) in a particular context. These perceptions are continuously re-shaped by non-linear feedbacks that emerge from their interactions with other segments in the food system, but also from changes in the socio-economic context. This has two implications. The first is that the dynamics and feedbacks in food systems need to be analyzed as the result of a mix of factors, such as actors' relations, access to information, regulations, markets, market demand, and so on. The second is that the non-linearity of feedbacks means that even a small change may have unpredicted effects across different parts of the food system. These effects can be positive or negative and of varying significance. To understand food system outcomes, these changes need to be taken into account. The food system approach deals with these complexities and enables the identification of the mix of factors that clarify food system actors responses and behaviors and particular outcomes (Ericksen, 2008).

Using a 'food system lens' to look from a range of viewpoints

There is a need for improved food system management to address current and anticipated food security inequalities and population health – and natural resources. This need is exacerbated by anticipated changes in climate, water availability, biodiversity and other critically-important environmental factors, all of which affect food supply. Meanwhile, methods of food production and other activities along the 'food chain' (i.e. processing, packaging, distributing, retailing and consuming) need to be more resource efficient, as current methods are seriously degrading the natural resource base which underpins many of these activities. This is of keen interest to a wide range of institutions, businesses and policy goals, as well as research.

Look from a business viewpoint

Many businesses are now striving to improve the management of natural resources, both to ensure continuity of essential feedstock for their processes, and also to project a more sustainable message to their customer base. This is a very important development, as the opportunity to bring about positive change in managing natural resources often best falls to resource managers and other non-state actors 'on the ground', rather than to the formal policy process. The food system 'lens' helps these actors to understand better where certain policy and/or technical interventions can have the best impact, and also helps them to consider what might otherwise have been the unforeseen consequences of such interventions. Using a food systems lens therefore helps move towards both better food security outcomes and better management of the natural resources upon which food security ultimately depends.

2.3 Natural resources and environmental impacts

2.3.1 Overview of natural resources and environmental impacts

Food systems are fundamentally underpinned by natural resources. Producing food in the form of agriculture or fisheries clearly depends on land, biodiversity, fresh water and marine resources. Other food system activities also depend on natural resources: for instance food processing on water and packaging on paper, card and aluminium. Almost all food system activities depend on energy, which is currently mainly provided in the form of fossil fuels. In traditional food systems in particular, energy is provided as an ecosystem service in the form of fuel wood, or as animal traction and of course in the form of human labor.

Natural resources can be divided in renewable and non-renewable resources (UNEP, 2010). **Renewable resources** stem from renewable natural stocks that, after exploitation, can return to their previous stock levels by natural processes of growth or replenishment, provided they have not passed a critical threshold or 'tipping point' from which regeneration is very slow (e.g. soil degradation), or impossible (e.g. species extinction). Crucial renewable resources for food systems are land, water, biodiversity (including genetic and marine resources) and ecosystem goods and services. Both renewable (e.g. biodiversity) and non-renewable (e.g. minerals for fertilizers) natural resources are of most significance in activities relating to producing food (i.e. agriculture, aquaculture and fisheries), and they are used to some extent in all food system activities (Table 1). In order to guarantee a continued supply of food (either from agriculture and livestock, fisheries or hunting), it is important that renewable natural resources are managed sustainably.

"**Non-renewable resources** are exhaustible natural resources whose natural stocks cannot be regenerated after exploitation or that can only be regenerated or replenished by natural cycles that are relatively slow at human scales" (OECD, 2002). Crucial non-renewable resources being used in food systems are minerals (nutrients, metals and other mined resources such as lime) and fossil fuels. Although minerals (such as phosphorus) are not actually 'used' (other than fossil fuels), they often become ineffective for use in food systems, for example because they get diluted in water.

All food system activities have an impact on the environment. Many of these impacts are intrinsically related to the use of natural resources in food systems. For example, the use of fossil fuels leads to CO_2 emissions (and to air pollution, depending on the burning process), while the use of minerals typically leads to nutrient emissions to ground and surface water. The relations between the use of the various resources and the environmental impacts are shown in a more systematic way in Figure 2. The bad news is the fact that all food systems depend on the use of natural resources, and that this use is almost always related to certain environmental impacts: food production will always have a certain effect on the environment. This is intensified by the fact that primary food production such as crop and livestock production and aquaculture are open systems, based on natural processes, which are typically dependent on unpredictable factors such as weather, leading to certain unavoidable emissions and other impacts. The good news is however that a more efficient or sustainable use of natural resources usually leads to a reduction in environmental impacts, creating many synergies. Concrete examples are better targeted fertilization, leading to lower resource use (minerals) and lower nutrient losses, and higher fuel efficiency along the food chain, leading to lower CO_2 emissions.

The environmental impacts usually feedback on the renewable resources as needed for both food system and other, non-food system activities. An example of the first is the impact of food system activities on water quality, making water less suitable for irrigation purposes. An example of the latter is the effects of pollution from agricultural sources on drinking water quality. The feedbacks are sometimes very local and

can act within a short timeframe (for example water contamination), whereas in other cases the feedbacks are through global systems with a time horizon of decades (e.g. GHG emissions leading to climate change).

Not all environmental impacts of food system activities are directly related to the main natural resources: the use of man-made components like pesticides, antibiotics, hormones and plastics in particular can lead to contamination and consequent effects on air, water and soil quality.

2.3.2 Natural resources needed for food system activities

For the various food system activities a range of natural resources is needed (Table 1). The relative share of use of a certain resource varies strongly; land for example is mainly needed for agricultural activities, whereas the use of fossil fuels is much more divided over the whole food system. Other natural resources such as iron ore and other minerals are needed for the many tools and machines also used across the range of food system activities. Table 1 indicates many of the natural resources needed for food system activities. Due to data limitations, the use of minerals and synthetic products (such as plastics) for packaging are not further elaborated in this report, although this is certainly an important issue. Nonetheless, it is clear that paper, card, plastics, steel and aluminium used for food packaging all have a negative impact on a range of natural resources. For instance, about 17% of aluminium in Europe is used in packaging (WHO; UNDP, 2009). Marine litter (much of which is from food packaging) is a serious threat to biodiversity.

From a natural resource management perspective, however, and in particular concerning their degradation, it is important to identify the causes of impacts of food system activities on the environment.

Figure 2 Relation between resource use and environmental impacts related to food system activities

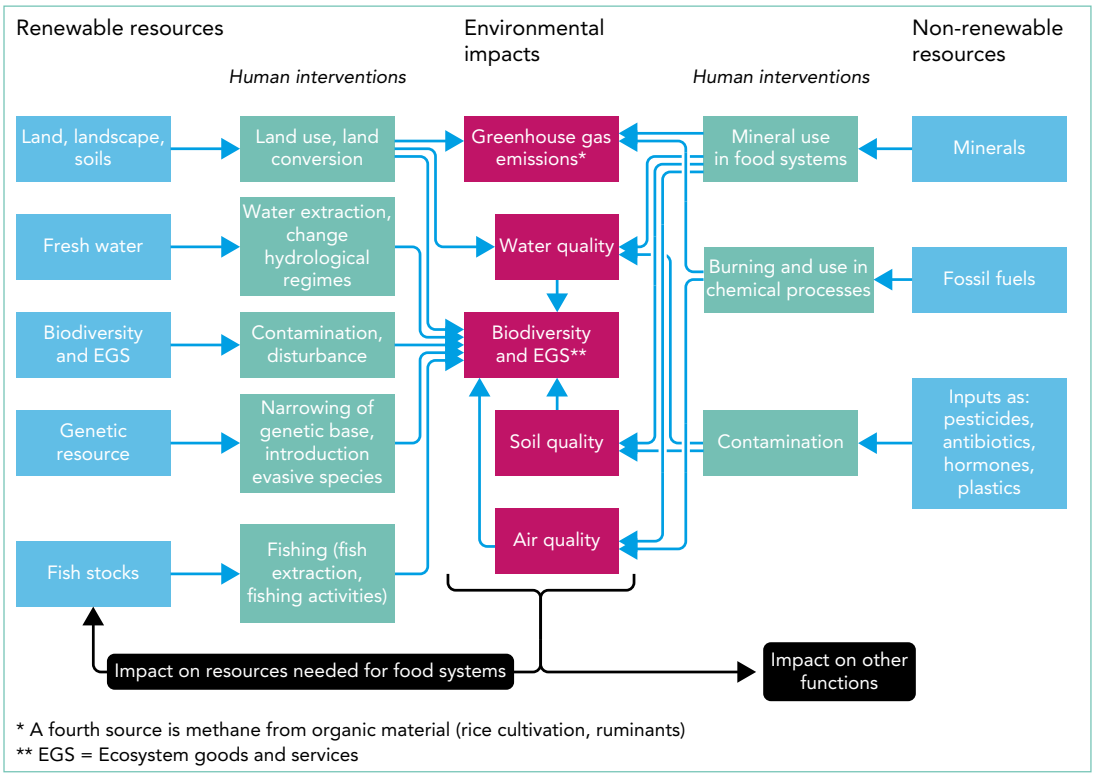


Table 1. Indicative functions of natural resources needed for food system activities[16]

Natural Resources	Producing food	Processing & Packaging food	Distributing & Retailing food	Consuming food	Managing waste
Renewable resources					
Land, soils and landscape	Cropping; grazing crop; hunting ●●●●●	Sites for factories ●	Sites for transport and storage, infrastructure and shops ●		Sites for landfill ●
Water	Irrigation; aquaculture ●●●●●	Washing; cooking ●		Cooking ●	Dumping and removing waste ●
Biodiversity and ecosystem services	Pollination; pest control; water and nutrient regulation ●●●●	Biomass for paper and card ●	Livestock for transport ●	Food variety; charcoal and wood for cooking ●●	Microbes to aid decomposition ●●
Genetic resources	●●●●●	●			
Non-renewable resources					
Minerals	P, K etc. for fertilizer and feed; chalk (liming) machinery ●●●●●	Iron, tin, bauxite (Al), kaolin and other resources for packaging ●●	Iron and other resources for transport, infrastructure ●●	Iron and other resources for cooking and storage, equipment ●	Iron and other resources for incinerators ●
Fossil fuel	Fertilizer and agrichemical production; machinery ●●●	For cleaning; drying; processing; packaging ●●	For transport and warehousing; freezing and cooling; heating and lighting shops ●●●	Cooking; cleaning ●	Collecting; re-cycling; purifying ●

2.3.3 Environmental impacts related to food system activities

As with many human activities, food system activities are leading to a number of – largely unintended – environmental effects. Examples of how food system activities impact on the environment are summarized in Table 2. Loss of both terrestrial and marine biodiversity is largely driven by food system activities. Satisfying future demand by increasing agricultural intensification through the use of more fertilizers, irrigation and pesticides increases production, but if not done properly can be environmentally deleterious. In addition to environmental concerns, intensification in this way is also increasingly expensive as energy prices rise and freshwater supplies diminish, so food affordability for many will decrease. Conscious of the negative impacts of most current food production methods on natural resources, it is clear that the necessary gains in production will have to be made in a more environmentally-benign manner (Foresight, 2011, Gregory & Ingram, 2000). To this end, research has increasingly focused on the production system (rather than just on the plant or animal component), seeking to increase the efficiency by which inputs (especially nitrogen and water) are used, and reducing negative externalities such as soil degradation, water pollution, loss of biodiversity and greenhouse gas emissions. The food systems approach has been further developed by the Global Environmental Change and Food Systems (GECAFS) project and in the international context such as (ICN2, 2014).

16. Dots indicate the estimated relative share of the use.

Table 2. Causes of negative impacts of food system activities on the environment

Environmental impact	Food System Activity				
	Producing food	Processing & packaging food	Distributing & retailing food	Consuming food	Managing waste
GHG emissions	fertilizer production and use; irrigation; tillage; machinery; livestock; rice, land conversion	cooking; cleaning; machinery	trucks; cold chain leakages; outlet heating & lighting	cooking; catering; restaurants	burning residues; landfill
Air quality	forest burning and pastures; dust; ammonia emissions (mainly from livestock)	factory exhausts	truck exhausts	cooking smoke	burning residues and waste
Biodiversity loss	land conversion; intensification; hunting & fishing; habitat fragmentation	biomass for paper and card		charcoal; fuel wood	pollution
Soil quality	erosion; nutrients; salinization; compaction; soil organic matter decline; biotic decline	pollution	pollution		pollution
Water quality	eutrophication; pesticide pollution; sediment load	pollution; litter	emissions from shipping, coastal degradation	detergents;	pollution, litter, esp. plastics

Source: adapted from Ingram, 2011

2.4 Measuring an efficient and sustainable use of natural resources in food systems

When assessing the current status and dynamics of natural resource use in food systems (Objective 1 of this study), as well as when determining opportunities for improving the resource efficiency of food systems (Objective 2 of this study), a good understanding and clear definition of the various terms is necessary.

2.4.1 Sustainable use of renewable resources

As pointed out before, in order to guarantee food supply for future generations, it is important that renewable resources are managed sustainably. Here we use the word sustainable in a strict sense, simply meaning that the use of the resource can continue, because the resource is not degraded or depleted beyond continued use and/or replenishment. This means that they return to their previous stock levels by natural processes of growth (for example in the case of marine fish stocks) or replenishment (rainfall to replenish aquifers), within human time scales (OECD, 2002).

2.4.2 Measuring resource efficiency in food systems

Table 3 provides an overview of how the efficiency of use of various natural resources can be defined, as well as (for renewable resources) the sustainable use. **Resource intensity** depicts the amount of natural resources used to produce a certain amount of value or physical output. It is calculated as resource costs per value added or resource use (in quantity) per physical output.

Table 3. Definition of efficiency and sustainable use of natural resources needed for food system activities

Resource	Renewable?	Measure of efficiency	Measure for sustainable use
Land, landscape, soils	Yes	Micro: yield per ha Macro: amount of land needed for food production	Degree of land degradation / land restoration
Water*	Largely; extraction of fossil water is the exception	Micro: volume of water used per unit of final product Macro: total amount of 'blue' and 'green' water1 in a food system	Regeneration (or depletion) of water in aquifers; disturbance of watersheds
Biodiversity and ecosystem services	Yes	Cannot be defined in terms of efficiency	Conservation of biodiversity; maintenance of ecosystem services
Including: *Genetic resources*	Yes	Cannot be defined in terms of efficiency	Genetic diversity. Including the conservation of old varieties
Marine resources	Yes	% by-catch	Regeneration of marine stocks
Nutrients (minerals)	No	Micro: input / output ratio at crop or animal level Macro: output / input ratio for a food system / region	-
Minerals (packaging, machinery)	No	Amount of materials used for whole food chain per product / consumer; For nutrients: whole food chain efficiency (output / input)	-
Fossil fuels	No	Amount of fossil fuels used for whole food chain per unit product	-

* Blue water is defined as fresh surface and groundwater, in other words, the water in freshwater lakes, rivers and aquifers; Green water is water which is stored in the soil or temporarily stays on top of the soil or vegetation.

A food system is considered **more resource efficient** when more food is produced and finally consumed with the same amount of resources, or when the same amount of food is produced with fewer resources (UNEP, 2011b). Higher resource-use efficiency can be realized in various ways: by more efficient production (also called **decoupling**[17]), as well as by reducing food demand and consumption in various ways (by reducing food waste, by dietary changes towards less resource-demanding products and by reducing overconsumption of resource-intensive calories). Resource efficiency is a key aspect of sustainable food systems, but 'sustainable food systems' is a broader concept that also includes economic and social dimensions.

In some cases, increasing resource-use efficiency can be achieved by addressing a single parameter, for example increasing water-use efficiency by reducing leakages from irrigation systems. In food systems, the situation is usually more complex as more resources have to be considered simultaneously. For example, increasing nitrogen fertilization can lead to a lower overall N-use efficiency (i.e. yield per unit N applied), but the increase in crop yields leads to higher efficiencies for other resources, such as for land, water and fossil fuels (for ploughing), as well as for human labor in the case of manual cultivation (see Box 1).

17. Resource decoupling means delinking the rate of use of primary resources from economic activity. Absolute resource decoupling would mean that the Total Material Requirement of a country decreases while the economy grows. It follows the same principle as dematerialization i.e. implying the use of less material, energy, water and land to achieve the same (or better) economic output (UNEP (2011b) *Draft Glossary of Terms Used by the International Resource Panel,* Nairobi / Paris, UNEP International Resource Panel.

Box 1 Combining resources: the great balancing act to reach good overall efficiency

Farmers (and, to varying degrees, other food system actors) have long had to deal with the question of how to optimize various inputs, including natural resources, labor and capital goods, in order to reach an optimal outcome of their hard work. Historically, important inputs which could be influenced were labor (with the possibility to switch to animal traction), type of crop, seeds (amount, variety), land, water and manure. Simultaneously, farmers had to cope with unknown variables such as weather and pests. Currently, new inputs such as fertilizers, fossil fuel and pesticides have become part of the equation. When assessing resource efficiency, notably in agriculture, it is essential to assess the efficiency of the total combination of natural resources. Judging the efficiency of one resource only, will lead to erroneous conclusions.

The following example might help to explain this: assume a soil with low inherent soil fertility (and most soils are indeed low in nitrogen). A dose of nitrogen fertilizer of 20 kg of nitrogen per ha will in most cases increase crop yield. If we would increase the dose to 40 kg, crop yields will increase again (but a little less). The nitrogen efficiency of the second dose will be lower than that of the first dose (defined for example as nitrogen in crop / nitrogen applied). Also the additional crop production of the second step will be lower compared to the first step. With each additional application, the nitrogen efficiency will further decline (and losses to the environment might increase).

When evaluated from the point of view of nitrogen fertilizer, no use or very limited use is the most efficient. When evaluated from the point of view of land, water, seed input or labor, higher inputs of nitrogen typically lead to **higher** efficiency. The crop yield might double from 0 to 40 kg N per ha, without additional input of land, water, or labor, so that all these resource are used more efficiently. The same is also true assuming a higher input of other resources: if phosphorus is limiting crop production, additional input of phosphorus might make the input of nitrogen more efficient. This is not a plea for the unlimited application of nitrogen fertilizer, but the crucial point is that (especially at the farming stage) the effect of the **combined inputs of the various natural resources** needs to be assessed.

2.5 Overview of interactions between food system activities, natural resources and food security

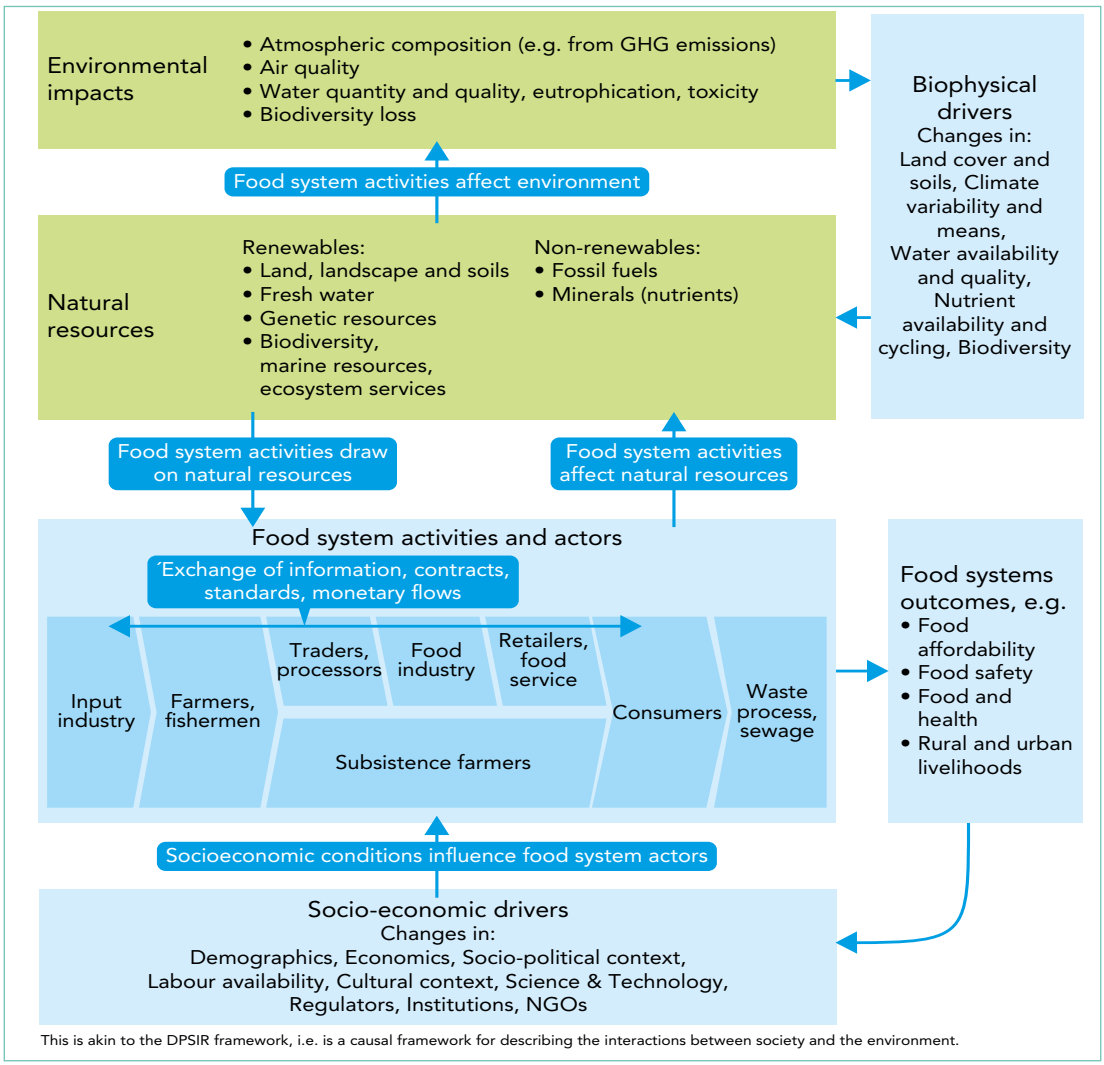
Building on Figure 1, a conceptual framework of the interactions between food system activities and natural resources has been developed by the authors (Figure 3). This identifies a number of socio-economic drivers which affect the socio-economic conditions within which the array of food system actors operate. Driven by a range of motives (e.g. food production, profit), the 'activities' of these actors draw on a range of natural resources. This impacts these resources directly (usually by depleting them) and indirectly by driving other environmental processes such as greenhouse gas emissions leading to climate change.

2.6 Summary and conclusions

In our interconnected and complex world, acknowledging the critical roles of food processors, packers, transporters, retailers and consumers, in addition to food producers, is an important step in identifying pathways to address the challenges regarding natural resources, while simultaneously improving food and nutrition security.

The food system concept relates all the food system activities (growing, harvesting, processing, packaging, transporting, marketing, consuming, and disposing of food and food-related items) to the outcomes of these activities, not only for food security and other socio-economic issues, but also for the environment.

Figure 3 Conceptual Framework of Food System Activities and Natural Resources



A food system therefore also encompasses the interdependent sets of enterprises, institutions, activities and relationships that collectively develop and deliver material inputs to the farming sector, produce primary commodities, and subsequently handle, process, transport, market and distribute food and other agro-based products to consumers. Food systems differ regionally in terms of actors involved and characteristics of their relationships and activities. In all cases they need to become 'sustainable', i.e: '*a sustainable food system (SFS) is a food system that delivers food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition for future generations are not compromised*' (HLPE, 2014a).

The food system concept provides a framework to integrate such studies to provide a more complete description of the 'food' interaction with both socio-economic and nature resource implications. However, its main value is in showing where the feedbacks to both socio-economic and environmental drivers lie, as these are often the ultimate cause for further natural resource degradation.

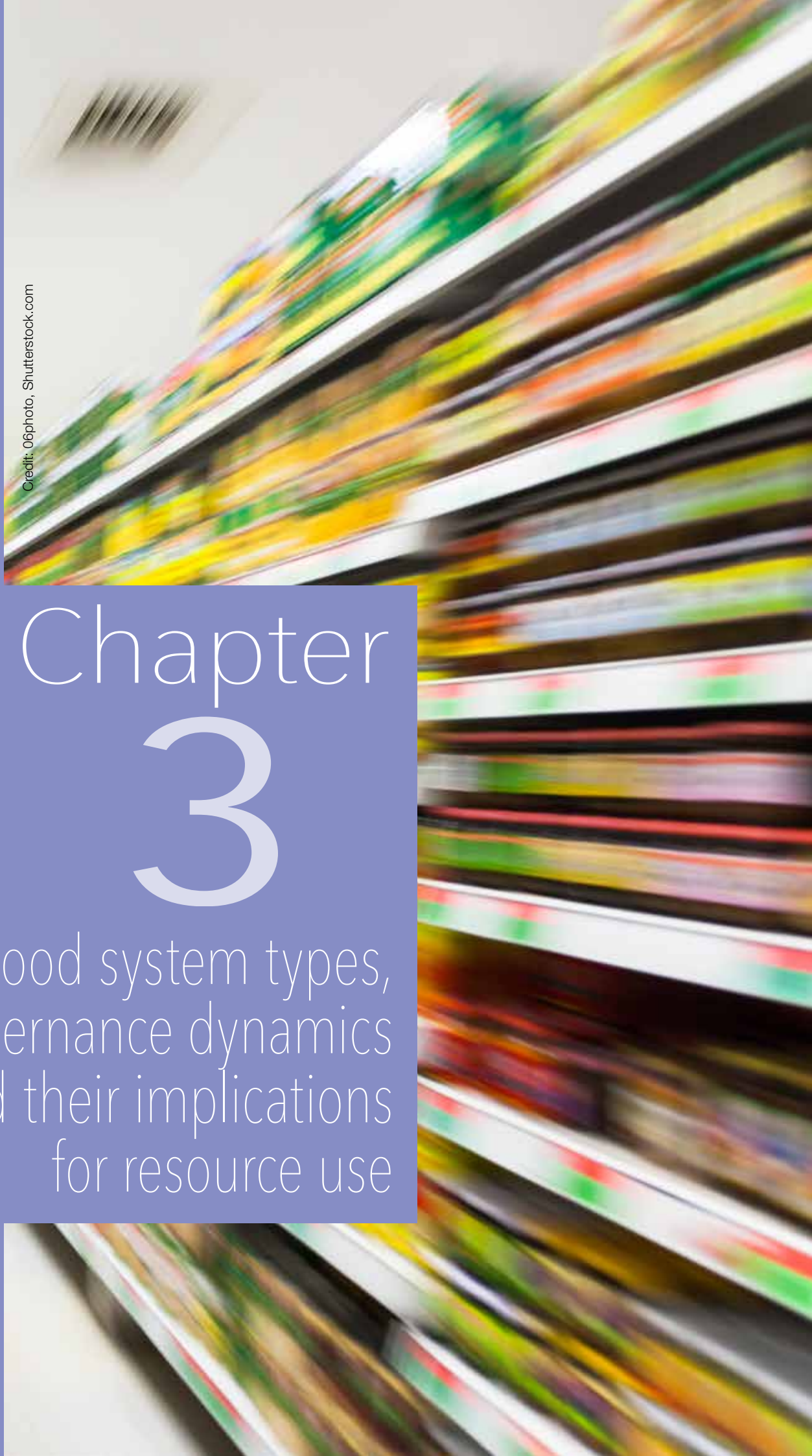
Food systems are fundamentally underpinned by natural resources. Producing food in the form of agriculture or fisheries clearly depends on renewable resources such as land, biodiversity, fresh water and marine resources, as well as on non-renewable resources such as fossil fuels and minerals. Other food system activities also

depend on natural resources: for instance food processing on water, packaging on paper, card and aluminium and distributing and cooling on fossil fuels.

Driven by a range of motives (e.g. food production, profit), the 'activities' of these actors draw on a range of natural resources. This impacts these resources directly (either by degrading or depleting them) and indirectly by driving other environmental processes such as greenhouse gas emissions leading to climate change. As with many human activities, food system activities are leading to a number of – largely unintended – environmental effects.

A food system is considered more resource efficient when more food is produced and finally consumed with the same amount of resources, or when the same amount of food is produced with fewer resources. Higher resource-use efficiency can be realised in various ways: by more efficient production (also called decoupling), as well as by reducing food demand and consumption in various ways (by reducing food waste, by dietary changes towards less resource-demanding products and by reducing overconsumption of resource-intensive calories). Food system actors will be confronted with difficult resource management decisions when seeking ways to improve the efficiency with which they are used. The combined effects of their activities in the environment must be taken into account to ensure effective and durable environmental and economic co-benefits.

Besides an efficient use of resources, a sustainable use of renewable resources (such as soils and marine resources) is critical to ensure food security for future generations. The efficient use of natural resources is a key aspect of sustainable food systems, but 'sustainable food systems' is a broader concept that also includes economic and social dimensions.



Credit: 06photo, Shutterstock.com

Chapter 3

Food system types, governance dynamics and their implications for resource use

3.1 Introduction

Chapter 2 highlighted the relevance and value of a food systems approach. This chapter introduces the types of food systems used in this study. Food systems are defined in stylized forms, with various features such as length of the supply chain, food production system, nutrition and environmental concerns. The coordination of linkages between the actors in the supply chain is also a key and distinguishing characteristic of a food system. Coordination mechanisms, such as contracts and standards, are key in explaining the governance and power relations in a system. This chapter shows a historical pattern of changes in the governance structures of food systems in the Western world, which is also taking place in most of the emerging and developing countries as well. The implications of these governance dynamics in the food systems for natural resource use are briefly indicated in the concluding section of this chapter and further analyzed in the following chapters.

3.2 Types of food systems

3.2.1 Variety captured in stylized typology

Food systems vary highly across the world. They span a wide spectrum from those developed by communities dependent on hunter-gathering to satisfy local needs, to systems developed by globalized societies interacting within a global market. Even within major types of food systems there can be variations: in more 'traditional' food systems some modern elements might be present (e.g. some processed food such as cooking oil), while in modern food systems some degree of subsistence might occur (home gardens, etc.). Most food systems, even the most traditional ones, are linked to some extent, through the transfer of food commodities, genetic materials, technology and processed foodstuffs, and through food prices.

In sketching developments in food systems over the centuries, (Reardon & Timmer, 2012) follow earlier literature on the evolution of food systems (e.g. (Ericksen, 2008, FAO & UNEP, 2014, Malassis & Ghersi, 1996) in characterizing food systems as traditional and modern, while also noting an intermediate system. This report follows the authors in using this typology, but by no means does this represents a value judgement (e.g. modern would be better than traditional). It is simply a way of indicating the rapid pace of change in food systems from labor-intensive towards capital- and other external input-intensive systems, where traditional systems are defined as being on the spectrum where labor is dominant over capital, and the modern system the other way around. Also, in characterizing the systems in a condensed way, the authors are aware of running the risk of oversimplification as local or regional circumstances (both of natural resources and/or socioeconomic conditions) may add particularities to the two food systems highlighted in the sections below. The inclusion of an intermediate version (in section 3.2.4 and in Table 4) captures the existing variety in food systems only to some extent.

3.2.2. Traditional food systems

In this stylized dichotomy, 'traditional' food systems (or 'low external input-intensive food systems') involve farmers and fishers using mainly inputs available on the farm, applying growing and harvesting techniques established already for a long time and moving produce by foot, animal or cart to local markets, where they usually sell or trade their commodities relatively unprocessed. Crop yields and livestock productivity are usually low relative to high external-input systems and consumers tend to

process food at home. Agricultural production, commodity and food trading and processing takes place in small-scale operational units, which have little or no commercial linkages outside the local region. Part of the farming community may be of a subsistence type, not integrated in the market directly. Typically, market relations are spot exchange, in which commodities are traded for immediate delivery. Most food is sold raw to be milled, slaughtered and processed at home or by small local processors. The great majority of the food consumed comes from the local area and consumption patterns are often seasonally dictated. A typical food basket is dominated by plant-based products, although with exceptions (e.g. communities in coastal zones or pastoralists with livestock, and forest dwellers that gather [honey] and hunt [wild meat]).

As people in such systems mainly depend on locally-produced food, a failure in sufficient food production can lead to local food shortages. An additional demand for food in this situation, notably as a result of a growing population, will create a need to either exploit new natural resources (e.g. clear marginal land not previously used for agricultural purposes, or extend into new fisheries) or intensify production. This exploitation of often additional natural resources creates risks for natural resource degradation, while unsustainable forms of intensification will lead to higher environmental impacts.

3.2.3 Modern food systems

In contrast, 'modern' systems (alternatively referred to as 'high external-input food systems') depend on a range of inputs such as new crop varieties, fertilizers, pesticides, veterinary applications, machinery and other high-tech equipment for producing food, and high-tech systems for storing, transporting, processing and retailing activities. Productivity in terms of production per worked hour, per hectare and per animal is generally high compared to low external input systems. Especially in developed countries where labor is expensive, some inputs such as fertilizers, pesticides, seeds and fossil fuel are relatively cheap. Farmers in these countries therefore tend to avoid risks of lower crop yields by overusing the cheaper inputs, resulting in an 'efficiency gap' between actual and potential efficiency. Generally, many farmers are operating at small margins and often lack the capacity to invest in a sustainable use of resources. Chapter 5 further clarifies the impacts of food systems on natural resource use, underlining that there are marked differences between the two systems with regard to the use of natural resources and environmental impacts.

Consumers in modern food systems largely purchase processed, packaged food that originates from all over the world. Furthermore, the processing, transporting/trading and retailing activities are all activities that are a substantial factor in employment and value addition. These activities also use substantial amounts of energy (mainly derived from fossil fuels) contributing significantly to GHG emissions. A modern food system is also characterized by specialized farms, firms and traders, operating at a large scale and connected by linkages in both product and service flows and by institutional linkages (e.g. contracts and standards such as coordination arrangements).

Furthermore, a modern food system typically consolidates the processing and food retail segments of the supply chain, which has, or has had, significant effects on the organization and structure of other segments of the supply chain too (such as farm consolidation). Supply chain relations and activities are increasingly of a transnational nature. This transformation process in the food system mainly took place in the 20th century in Europe, the USA and other industrialized parts of the world.

3.2.4 Intermediate food systems

Since the 1980s, a 'modernization' of the food system has taken place in many developing countries in Latin America, Asia, Eastern

Europe and some African countries. In these countries, however, consolidation in the retail and processing segments occurs in a context of many small-scale actors on the supply side and persistent strata of poverty among both consumers and suppliers. The production is still largely dominated by small- and medium-sized farms. Here, empirical evidence shows that food processing and retail apply different sets of procurement methods, sourcing by spot market exchange and by contracts depending on the characteristics of the product and the suppliers (Berdegué *et al.*, 2005, Reardon & Timmer, 2012). The food system in these countries could be characterized as an intermediate traditional system, whereby regional food systems are in the process of becoming integrated into global food systems.

In most parts of the world, food systems are currently somewhere in between the two extremes of a traditional and modern food system. In large parts of Asia, for example, most people primarily buy unprocessed or partly processed food, generally not from supermarkets but grocery stores or street markets. At the same time, supermarkets are enhancing their market position, and modernization and rapid consolidation is taking place in the processing sector. Sections 3.4.2 and 3.4.3 address this trend of 'supermarketization' in more detail.

3.2.5 Key features of food systems summarized

Table 4 below shows some of the key features of traditional and modern types of food systems. Important in this context is that environmental concerns relating to the two systems are quite different. Traditional food systems typically face the risk of soil degradation (in particular when population grows) because there are no or too few options for applying an adequate amount of nutrients (in the form of manure or fertilizers). Consequently, crop yields remain low and in some regions farmers need to clear land previously not used for agricultural purposes. Farming in modern food and intermediate systems, on the other hand, sometimes uses too much fertilizer and pesticides, so that water quality and ecosystems are negatively affected. Another source of nutrient losses is crop-livestock interactions (i.e. specialization of regions), especially with confined animals. In addition, the processing, transport/trade and retail activities are fossil fuel and water use intensive and contribute substantially to GHG emissions (see also Section 2.2.3).

It is also important to note two further issues:

First, modern and traditional types of food systems can occur in a town, country or region alongside one another, although there are regions in which traditional food systems are found more often than modern systems (and the other way around). In regions where modern food systems dominate, exceptions to that trend such as regional product chains and organic agriculture may be found. It shows again that in a particular country or region, diverse food systems are possible.

Second, food systems do not operate in isolation from other key systems (e.g. energy, water and health) and other aspects of society (e.g. urbanization and political issues). Food systems interact strongly with all of these and the nature and intensity of such interactions affects the interaction of food systems with natural resources (Ingram, 2011).

Table 4. Comparing some features of 'traditional', 'intermediate', and 'modern' food systems

Food system feature	'Traditional' food systems	Intermediate food systems	'Modern' food systems
Estimated number of people in system	~1 billion	~4 billion	~2 billion
Principal employment in food sector	In food production	In food production	In food processing, packaging and retail
Supply chain	Short, local; small-scale structures	Short to longer, supply chain has typically more actors than in 'modern' food systems	Long with many food miles and nodes; consolidation in input, processing and food retail segment; transnational companies and chains
Supply chain coordination system	Ad-hoc, spot exchange	Mainly ad-hoc, spot exchange	Contracts, standards, vertical integration
Food production system	Diverse, mixed production system (crops and animal production), varied productivity; low-input farming systems. Food systems are the main source of energy	Combination of diverse, mixed production system and specialised operations with a certain degree of inputs, including fossil fuels	Few crops dominate (e.g. monoculture); specialisation and high productivity; high external input intensity, including fossil fuels. Food production consumes more energy than it delivers.
Typical farm	Family-based, small to moderate	Combination of small-holder farms and larger farms / fishery operations	Industrial, larger than in a traditional setting
Typical food consumed	Basic locally-produced staples	Combination of basic products and processed food	Larger share of processed food with a brand name, more animal products
Food bought from	Small, local shop or market	Small, local shop or market, share of supermarkets small but rapidly growing	Predominantly large supermarket chain, food service and catering (out of home)
Nutritional concern	Undernutrition	Both undernutrition and diet-related diseases	Diet-related diseases
Main source of national food shocks	Production shocks	International price and trade problems	International price and trade problems
Main source of household food shocks	Production shocks	International shocks leading to food poverty	International shocks leading to food poverty
Major environmental concerns	Soil degradation, land clearing, water shortage	Combination of concerns in traditional and modern systems	Emissions of nutrients and pesticides, water demand, greenhouse gas emissions, and others due to fossil fuel use
Influential scale	Local to national	Local to global	National to global

Source: adapted from (Ericksen, 2008).

3.3 Main features of coordination mechanisms in food systems

A key element in defining food systems is how the system's activities and actors are linked with each other. Typically, traditional food systems have a relatively short supply chain, with several activities concentrated at the farm: producing crops and animal products (in mixed farming systems), processing them in-house, and trading the raw and/or processed products. Commercial relationships largely take place on a spot or cash market, implying loose connections between the segments of the food chain. In fact, farmers and fishermen are simultaneously producer, processor and trader of their produce in a traditional food system, as there are relatively few processing and food retail actors in addition to the primary producers. Modern food systems, on the other hand, are characterized by specialization and subdivision of activities. At the farming stage, this often leads to highly specialized farms, implicating monocultures and segregation of crop and livestock production. This feature also increases the length of the supply chain, including specialized companies in delivering inputs such as seed, fertilizers, machinery and feed, and several stages of processing and trade (distribution, wholesale, retail).

Coordination of all the activities of the specialized actors in such a system is typically based on contracts and standards (of measurement, quality, etc.) to save time and transaction costs. The vertical integration of activities is also a way to reduce transaction costs and business risk. The latter effectively means a shortening of the supply chain as a company (partly) owns and controls a downstream (inputs) or upstream (distribution or retail) activity in the supply chain. Farmers/fishermen and other actors in the food supply chain have to comply with contract and standard requirements, otherwise they run the risk of being excluded from selling to a market that may be attractive to them. The coordination mechanism in the food system is key in explaining the governance and power relations in a system as those who set the conditions for contracts and/or the standard requirements determine the playing field for the various actors in the food system.

Modern food systems are characterized by institutional arrangements governing or coordinating economic relations between segments and transacting parties using procurement systems such as contracts and private standard requirements of quality and safety. Modern procurement systems also include the use of dedicated wholesalers and logistics firms (elements of a transformed wholesale and logistics sector) who contract with retail chains downstream and with farmers or traders upstream (Reardon & Timmer, 2012). Empirical evidence shows that the procurement system applied by the retail chain is conditioned by the characteristics of the product and the supplier. In general, the more perishable and niche-like the product and the more concentrated its suppliers, the greater likelihood the product is procured directly. In contrast, the more bulk commodity-like a product is and the more it is produced by many small producers, the more likely it is to be procured via the traditional wholesale market.[18] The intermediate method – procurement via a specialized/dedicated wholesaler – lies between these two poles as far as the range of product and supplier characteristics are concerned.

18. Governments in developing countries are trying to institutionalize redistributive mechanisms that serve both commercialization and regional food security (e.g. the rise of commodity exchanges and warehouse receipt systems in some countries in East Africa).

3.4 Governance of food systems

Governance can be defined as a system of rules, authority and institutions that coordinate, manage or steer society. Governance is more than the formal functions of government but also includes markets, traditions and networks and non-state actors such as firms and civil society. The governance of food systems has changed dramatically over the last 50–60 years due to the liberalization of agricultural and financial markets that started in the 1980s, the transformation and consolidation process in the food chain and the 'rolling back' of the state. 'Non-state' actors now dominate governance arrangements in many food systems.

3.4.1 Change in role of government

Many countries have a long tradition in protecting its agricultural sector, for strategic food security reasons. This policy received an impetus after World War II, to restore and increase agricultural and food production in the regions most affected. During the first decades after WWII agricultural commodity markets in North America and Western Europe were largely regulated through domestic price support, while high tariffs kept low cost products out. In communist countries, the agri-food chain was a state affair by default, while in many African countries, having gained independence in the 1960s, governments were heavily involved in agriculture through direct investments in (state) farms and enterprises, parastatals and marketing boards. Food production in several Asian countries (India, Philippines) increased through the Green Revolution, which refers to a series of research and technology transfers aiming at increasing the productivity of cereals (mainly rice, wheat and maize). Programmes introducing new seed varieties (and the use of fertilizers and pesticides) were supported and co-financed by the World Bank, the United Nations (FAO, United Nations Development Programme) and donor organizations. These programmes have generally been less successful in Africa (Wiggins, 2014).

Due to the rapidly increasing productivity in major OECD countries in particular, the 1970s and 1980s were characterized by domestic overproduction, resulting in domestic surpluses. The subsidized export of these surpluses tended to depress world prices, affecting agriculture production in other countries. Distortions to global markets reached a peak in the 1980s, with the overproduction of food in the European Union (EU) and an export/subsidy war between the United States of America (USA) and the EU further depressing agricultural prices in low- and middle-income markets. These effects, plus the increasing budgetary burden of government support for agriculture, were a justification for liberalization policies and for redefining the role and form of government interventions in agricultural markets. Moreover, by the end of the 1970s it had been increasingly recognized that the tendency for subsidies to encourage the intensification of production was environmentally damaging where the social and environmental costs (negative externalities) of production were ignored.

Since the 1980s, both external and internal pressures for reform have resulted in progressive liberalization in agricultural markets, with a prominent role of the General Agreement on Tariffs and Trade/World Trade Organization (GATT/WTO) as the international forum to discuss and agree on agricultural trade-related issues. In addition, deregulation of the financial markets including relaxed controls in many countries on flows of foreign direct investment (FDI) enabled and occurred alongside corporate consolidation

19. Other than SPS standards, environmental and social standards are not set in the WTO, which is a trade agency, but in international agreements outside the WTO. At present there are about 200 international agreements dealing with different environmental issues in force. For information on how environmental issues are dealt with in the WTO see: www.wto.org/english/thewto_e/whatis_e/tif_e/bey2_e.htm.

at multiple levels in the food supply chain. In developing countries, the start of processing transformation occurred together with FDI liberalization and the start of the privatization of parastatals and other state-owned agribusiness enterprises, specifically in countries that had a relatively early economic and urbanization growth spurt in the mid-1980s to early 1990s (e.g. Mexico, Central America, Southeast Asia) (Reardon & Timmer, 2012).

Over the last decades, governments in many high-income countries reduced production encouraging (direct) subsidies or price guarantees to farmers (OECD, 2011). At the same time, public standards were introduced or reinforced, which primarily apply to food safety, particularly sanitary and phytosanitary (SPS) standards relating to animal, plant and human health, but increasingly covering other aspects such as sustainability or social and labor standards.[19] In addition to these public standards, private standards have been introduced by retail and processing companies, which producers have to meet if they want to sell their products to global retailers and their intermediates. Standards largely refer to product quality and technical specifications, but may also encompass norms and standards related to environmental, social and ethical issues. Some standards only refer to raw materials, other include processing and manufacturing. One of the oldest certification schemes, still having a significant market share, is on organic products. The latter emerged in the late 1980s and 1990s in areas where national and global legislation were weak but the consumer and NGO movement around the globe demanded action. Indeed, most sustainability standards that are being adopted today were initiated by social movements (examples are Fairtrade and Rainforest Alliance) or individual companies (e.g. UTZ Certified, GLOBALGAP).[20] Although legally non-binding, voluntary standards may be important market entry hurdles, as the implementation costs are usually moved on to the producers rather than the retailers (Story *et al.*, 2008). Therefore, these (both public and private) standards are important drivers of change in the global food supply chain.

3.4.2 Food systems increasingly governed by downstream actors

Food supply systems are increasingly driven by consumer preferences, which are heavily influenced by food marketing and media (FAO, 2011c, Kearney, 2010) and fueled by income increases and urbanization, both affecting dietary and lifestyle patterns. This is key in understanding the governance changes of the food supply chain. These changes provide fertile ground for modern food retail formats (Lawrence & Burch, 2007, Reardon & Timmer, 2012), whereas the increasing demand for processed and differentiated products has expanded opportunities for the food industry to increase its scale and scope of production. As well as an increasing food demand in volume and variety, the emergence of new technologies and government policies are two additional important drivers of consolidation. Companies have sought to acquire relevant technological and biotechnological capacities and to serve large markets to share the fixed costs associated with investments in new technologies, and large firms appear to be better able to address the changes in (stricter) government regulations governing health, safety and environmental impacts of food products. Large food companies and restaurant chains also have a scale advantage in marketing, which has led to a number of 'global brands', many in the sphere of confectionary, soft drinks, beer and fast food restaurants.

The result has been a – still continuing – process of consolidation of the food input supply and processing industry and the retail segment

20. Currently there are over 170 'sustainability standards' worldwide (see www.standardsmap.org). The United Nations Forum on Sustainability Standards (UNFSS) is a forum that gathers stakeholders with the aim to address information needs and discuss concerns. The forum works towards addressing the sustainable development impacts of these standards and harnessing them to support pro-poor sustainable development objectives and facilitate access to global markets in developing countries. See www.unfss.org.
21. See businessvibes.com for the overall overviews. A series of food industry related websites also provide national data. For instance, the four big supermarket chains in the UK are reported to have a combined market share of 76% in of the UK grocery market in June 2013 (www.kamcity.com), and the top four in the USA a market share of approximately 40–50%, number one accounting for more than 25% of the supermarket industry's total revenue (www.businessinsider.com).

of the food system. Firms have also sought strategies to achieve a competitive advantage in cost and quality in an environment of rapidly consolidating sectors and markets, applying governance mechanisms such as contracts and standards (to steer suppliers toward meeting the quality demanded by the market). In the context of less guaranteed prices offered by government policies, the effect has been a greater weight of the downstream segments in the agro-food supply chain's power balance.

In the USA and Western Europe, the input and processing segments of the food supply chain have been rapidly consolidating, mainly driven by cost efficiency considerations (Fuglie *et al.*, 2011, OECD, 2013b, Saitone & Sexton, 2012, Sexton, 2000). A similar if not more rapidly emerging process has taken place in food retail (OECD, 2013b, Reardon & Timmer, 2012). Global food retail sales are about US$7 trillion annually, with supermarkets/hypermarkets accounting for the largest share of sales (Agropoly, 2013). Most of the leading global retailers are US and European firms as large multinational retailers expand their presence in developing countries and small retail firms increasingly account for a smaller share of total food sales. The top 15 global supermarket companies account for more than 30% of world supermarket sales. With improved technologies and economies of size, these retailers enjoy operating cost advantages over smaller local retailers[21] whereas the growth of private label products and the point-of-sale data generated by checkout scanners and barcodes has helped shift bargaining power from the product suppliers to the increasingly-concentrated retailers (Senauer & Seltzer, 2010). Table 5 provides an overview of the rate of concentration in the food supply chain, emphasizing the strong position of a small number of companies in the input, processing and retail segments, while the farm sector remains very fragmented.[22]

Table 5. Concentration in the Food Supply Chain – A Global Perspective

Agricultural input industry	Farms	Food processing industry	Food retailers	
Turnover: US$520 bn Of which Animal feed: US$350 bn Seeds: US$35 bn Fertilizer: US$90 bn Pesticides: US$45 bn	Agricultural value added: US$2,175 bn	Turnover: US$1, 377 bn	Turnover: US$7,180 bn	Consumers
Market share of top 10 corporations: Animal feed: 16% Seeds: 75% Fertilizer: 55% Pesticides: 95%	Globally 1 billion farmers with around 450 million farms, of which an estimated 85% small-scale with less than 2 ha. 20-24 million farmers in OECD countries (national stats).	Market share of top 10 corporations: 28%	Market share of top 10 corporations: 10.5%	
Major companies: Animal feed: CP Group (Thailand), Cargill (USA), New Hope Group (Taiwan, China); Seeds: Monsanto (USA), DuPont (USA), Syngenta (Switzerland); Fertilizer: Yara (Norway), Mosaic (USA), Agrium (USA); Pesticides: Syngenta (Switzerland), Bayer (Germany), BASF (Germany)	USA: largest producer of maize and soya beans; EU: largest wheat producer; China: largest rice producer	Major companies: Nestle (Switzerland), PepsiCo (USA), Kraft (USA), ABinBev (Brazil), ADM (USA)	Major companies: Walmart (USA), Carrefour (France), Schwartz Group (Germany), Tesco (UK), Aldi (Germany)	

Source: (Agropoly, 2013)

22. A segment that could be added to this figure is food service and catering (e.g. restaurants, schools, hospitals), including the fast food chain, which along with the growth of supermarkets has shown a rapid rise over the world. The observed growth is not only from the multinational companies, but also from domestic firms. The spread of fast food chains over the world also illustrates the rapid change in diets, which seem to be getting more uniform globally. For an overview of global fast food chains see: www.forbes.com/pictures/feji45hfkh/top-10-global-fast-food-brands-2 (accessed on 6 March, 2014). Estimates indicate that 50% of US food expenditures are out-of-home. Global figures are not available.

However, it is in the developing economy's retail sector that the consolidation of influence and market share has been most dramatic over the last two decades. Latin America (particularly Brazil) has led the way with rises in supermarket dominance from an average of around 15% in the 1990s to current levels of more than 60% share in overall food retail. This is closely followed by other countries, including South Africa, which rose very rapidly (in particular since the end of Apartheid in 1994) to 55% in 2003 (Reardon *et al.*, 2003). Since 2006, India has seen a rapid increase in supermarkets, mainly in the presence of large domestic conglomerates that have invested in retail (Reardon & Minten, 2011), while the modern food retail sector is emerging rapidly in China, with many international retailers already present and growing fast (Garnett & Wilkes, 2014, McLoughlin *et al.*, 2012, USDA, 2012). Retail distribution channels, though, are still highly fragmented in these two large countries, with some emerging regional food retail concentration.

3.4.3 Implications of 'supermarketization' for food market structures and resource use

Implications of consolidation trends in food retail and processing are related to the supplier-buyers relationships. Most food supply chains are dominated by a few large companies, often multinationals exerting market power (being exerted by procurement, i.e. buyer power), which is illustrated by price setting behavior and/or determining other business conditions suppliers have to comply with. For more examples from literature, see (OECD, 2013b). As indicated above, governance mechanisms such as contracts and private (quality) standards are increasingly used, resulting in – next to all positive effects of increased efficiency by reducing transaction costs and of responding to consumer preferences for attractive priced quality products - a deepening of the dependency of suppliers on their client as suppliers invest in specific assets to comply with the conditions set by their product buyer. Consequently, competitive pressures in the supply chain are high and profitability in upstream industries is generally low, increasing further pressure to rationalize production processes and to produce against lowest possible costs. The emphasis on economizing and rationalizing production is fostering the treadmill of increasing scale of production in the processing component of the food supply chain, implying in most cases a more capital-intensive production process.

Disproportionate buying power, though, tends to depress prices that food producers at the bottom of those chains receive for their produce. This in turns means lower incomes for these producers, which may have an impact on their ability to invest for the future (e.g. in product and production process innovation that contributes to sustainable farming and processing).

At the primary level, the consolidation trends in the food processing and retail industry further pressure the rural farming community to follow the same path and increase its scale and intensity (of using external inputs) of production. With a declining number of buyers putting downward pressure on the prices farmers receive, the latter are forced to search for strategies to maintain profitability. Two strategies (that are often combined) to remain economically viable are to increase the scale of production (in order to reduce costs) and/or to improve productivity (that is producing more per unit area and/or unit of labor used). The emphasis on increased labor and land productivity implies that a farmer will generally use more fertilizers, more productive seeds, plant protection products, antibiotics and genetics and/or increase the number of animals per hectare, in cases beyond their technical optimum, leading to high environmental impacts. This is especially the case when inputs such as fertilizers and pesticides are cheap compared to the cost of labor and land. In some cases, these inputs are even subsidized. Also, crop and livestock production is typically becoming more spatially separated, leading to nutrient deficiencies in crop areas and surpluses in other areas. In analyzing the rapid changes in Chinese food systems, Garnett and Wilkes

(2014) illustrate the impact of changing diets on livestock production and its intersect with multiple environmental issues. According to the authors, the transformation of the livestock sector in China in the last 35 years has created massive problems of manure surpluses polluting soils and water, while overgrazing in pastoral regions contributes to land degradation.

3.5 Summary and conclusions

Food systems vary highly across the world. They span a wide spectrum from 'traditional' subsistence based systems to 'modern' systems in urbanized societies, with most people depending on food systems that lie somewhere between these extremities. These 'intermediate' types of food systems are rapidly evolving. Most food systems, even the most traditional ones, are to some extent linked with each other through the exchange of food or feed commodities (trade), genetic materials, technology and processed foodstuffs, or through food prices. Moreover, modern and traditional types of food systems can occur in a country or region alongside one another.

In this stylized dichotomy, 'traditional' food systems involve farmers and fishermen using low-tech growing and harvesting techniques, usually selling their commodities relatively unprocessed. Crop yields and livestock productivity are typically low, partially because external inputs (such as fertilizers) are relatively expensive. In contrast, 'modern' systems depend on a range of inputs for producing food, and a range of inputs for storing, transporting, processing and retailing activities. While labor is expensive, some inputs such as fertilizers, pesticides, seeds and fossil fuel are relatively cheap. Farmers therefore tend to avoid risks of lower crop yields by overusing these cheaper inputs. This not only results in an 'efficiency gap' between actual and potential efficiency, but leads to high environmental impacts as well. Next, specialization into crop or livestock farms can have large effects on natural resource use and environmental impacts, too.

Food systems in Latin America, Asia, Eastern Europe and some African countries are rapidly evolving towards modern food systems. While production is still largely dominated by small- and medium-sized farms, supermarkets and food companies are enhancing their market position, leading to the 'supermarketization' of these food systems. This in consequence leads to profound changes in both supply chains as well as in changes in consumption patterns.

The governance of food systems has changed dramatically over the last 50–60 years, due to the liberalization of agricultural and financial markets that started in the 1980s, the transformation and consolidation process in the food chain and the 'rolling back' of the state. The private sector – food processors, retailers and input suppliers such as seed companies – now dominates some aspects of governance arrangements in many food systems. The central role of private actors is enhanced by ongoing processes of consolidation of the input and processing industries, as well as of the retail and food service sectors.

Credit: ssguy, Shutterstock.com

Chapter 4

Socio-economic drivers impacting on food demand, production and food system outcomes

4.1 Introduction

In Chapter 3 it was demonstrated that there are different food systems around the world and that they are evolving, driven by socioeconomic developments and framed by biophysical circumstances. It described the governance features of current dominating types of food systems around the world and the dynamics in food system governance in the past that were due to the liberalization of agricultural and financial markets. This chapter deals with future expectations of population growth, urbanization and income growth, and their projected impact on food consumption levels and patterns. The latter will affect food production and the further evolution of food systems around the world, and consequently impact the use of natural resources and the environment. Projections of these key socioeconomic drivers described in the sections below provide a regional perspective of consumption pattern shifts that might take place in the coming years. Projections on agricultural markets presented in this section are generally based on the OECD/FAO Agricultural Outlook, which presents a baseline up to ten years ahead assuming a 'business-as-usual' situation implying no policy changes beyond those already known. The projections are, therefore, not 'unavoidable' results of trends and the continuation of current policies; if they occur, undesired outcomes can be mitigated or altered by policy responses.[23] Future developments of these drivers (population/urbanization, income, food demand, policies) for the coming decades demonstrate the challenge to enhance resource efficiency, which is further emphasized by the unsatisfactory outcomes of present food systems that are summarized in Section 4.5.

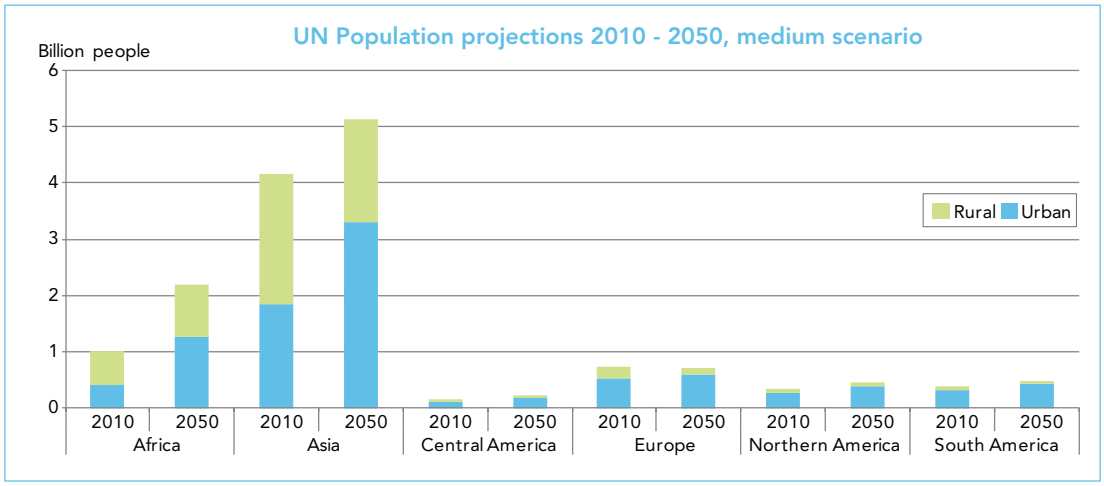
4.2 Population growth and urbanization

One of the main determinants of current and future food demand is the global population growth. According to the UN medium growth scenario, the global population is projected to increase from 6.9 billion people in 2010 to 9.3 billion people in 2050 (UNDESA, 2013). There are marked regional variations: Europe's population is projected to decline, while Africa's will double (Figure 4). China's population is projected to peak in around 2030. By 2020, India is expected to be the most populated country. In 2025 two thirds of the population is expected to live in Asia, especially in already densely populated countries like China, India and the South East part of the continent (Indonesia, Malaysia, Vietnam, etc.). These countries are also assumed to show the highest economic growth in the coming ten years, according to OECD-FAO projections (OECD & FAO, 2014), with profound effects on their economic structure (see Box 2). The population increase (in %) is expected to be the largest in Sub-Saharan Africa. In developed and emerging countries in particular, the population will age.

When aggregated at the global scale, the population growth will be almost exclusively in cities. The number of people living in urban areas is projected to increase by 75% over the period 2010–2050. As a consequence, the number of megacities will increase as well (Figure 5). In some regions, particularly in Sub-Saharan Africa, the rural population is also expected to increase, by around 60%.

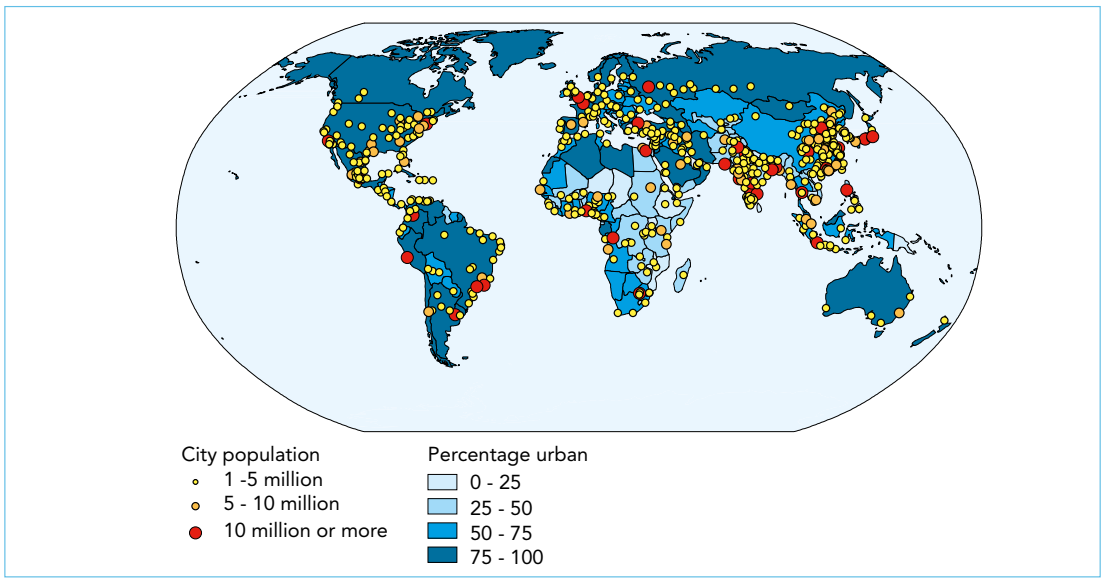
23. There are many sources and studies providing quantitative food market projections, using economic models. A comparison of the results of ten global economic models shows large differences in outcomes (such as projected food demand), which are explained by differences in assumptions on economic relations and variables taken into account. See Schmitz C., van Meijl H., Kyle P., Nelson G.C., Fujimori S., Gurgel A., Havlik P., Heyhoe E., d'Croz D.M., Popp A., Sands R., Tabeau A., van der Mensbrugghe D., von Lampe M., Wise M., Blanc E., Hasegawa T., Kavallari A., Valin H. (2014) Land-use change trajectories up to 2050: insights from a global agro-economic model comparison. *Agricultural Economics*, 45: 69-84. DOI: 10.1111/agec.12090, ibid., Valin H., Sands R., Van der Mensbrugghe D., Nelson G.C., Ahammad H., Blanc E., Bodirsky B., Fujimori S., Hasegawa T., Havlik P., Heyhoe E., Kyle P., Mason-D'Croz D., Paltsev S., Rolinski S., Tabeau A., van Meijl H., von Lampe M., Willenbockel D. Ibid.The future of food demand: understanding differences in global economic models. 51-67. DOI: 10.1111/agec.12089. for an evaluation of these models. The examples presented in this report refer to OECD/FAO projections that are published on an annual basis in the Agricultural Outlook with a time horizon of ten years ahead.

Figure 4 Population growth and urbanization per region



Source: (UNDESA, 2011)

Figure 5 Urbanization and megacities by 2025



Source: (UNDESA, 2011)

The increasing number and share of the population living in urban settlements will have important effects on the local and regional food systems. Physical distances between food-producing and food-consuming areas will increase, implying a greater role for trade and distribution. Moreover, urban food consumption patterns tend to shift to processed and convenience food, which could be sourced from local or regional suppliers but may also be imported. In areas of rapid urbanization the number of people living in traditional food systems is likely to decrease as increased food demand from cities provides local farmers with opportunities to become more integrated in evolving food systems in which specialization and applications of modern technology (e.g. cooling, ICT) are important characteristics. This would require investments in local supply chains, yet would also lead to further pressure on natural resources, especially in densely populated areas and/or countries with a weak natural resource base. Moreover, the food security situation of the rural population (including smallholder farmers who are unable to connect with the urban

market, whilst many of them are net-food buyers) may worsen if increasing demand for food from growing cities leads to local price rises. In regions where intermediate food systems are already developing, the increasing urbanization may encourage a shift towards modern food systems.

4.3 Implications for food demand

Growth in population size and income per capita leads to increasing demand for food *and* a shift from starch-rich towards more sugar/fat-rich foods. As income per capita rises, people's diets change from one that is largely rich in carbohydrates to a diet which is richer in calories, sugars, lipids and to more livestock based products and vegetables (UNEP, 2014). (Alexandratos & Bruinsma, 2012) show that per capita consumption of rice and wheat levelled off in both developed and developing countries after the late 1980s, whereas an increasing share of cereals goes to feed as livestock sectors grow. Overall, and especially in developing countries, consumption of meat and (to a lesser extent) dairy shows a significant increase in per capita consumption. Figures from some of the emerging economies of China and Brazil illustrate the shift in diet and food consumption patterns towards livestock products: China went from 14 kg/year/per capita in the early 1970s to 52 kg/year/per capita in 2010, and Brazil went from 40 kg/year/per capita to 78 kg/year/per capita over the same period (Alexandratos & Bruinsma, 2012).

The result of this process is the nutritional transition that has major implications for food supply and natural resource use as typically the production of livestock based food requires more resources: for example, instead of grain being directly consumed by humans it is used as animal feed for livestock production which is then consumed by humans. This is overall a more inefficient process in food energy terms, but also requires much more land for cereal production and grazing (Arets *et al.*, 2011, UNEP, 2014). Moreover, as wealth increases, dietary patterns turn to more convenience, pre-packaged, chilled and processed food, that is transported over long distances, implying a generally fossil energy-intensive process and a food system with a web of nodes of specialized companies and chains. Global data on these aspects are scarce, yet information from different sources and different countries can be retrieved. For instance, consumer market research summarizing data from a sample of country reports show that since 2002 sales of packaged food jumped by 92% to US$ 2.2 trillion in 2012 in these countries; in emerging economies like Brazil, China and Russia sales are three to four times their level in 2002 (The Economist, 2012)[24]. Soft drinks are an important product on these market (Wong, 2014). The market for packaged foods and drinks is expected to grow in emerging regions, while due to reasons such as health concerns and an aging population, markets for these products will slightly shrink in Western Europe and Northern America. Environmental impacts of these food sales trends are not only related to the fact that foods are increasingly packaged or chilled, but also that these foods are more processed and livestock based, hence requiring more land, water and fossil energy compared to a vegetarian, crop based diet.

Regional food consumption patterns

Currently, there are large contrasts in food consumption patterns between countries and world regions. These differences have various causes: cultural (as tradition plays an important role in food consumption), economic (incomes, affordability of food), biophysical (local cropping patterns vary depending on climate and soil conditions) and social (for example rural versus urban).

Also the per capita intake of meat shows distinct geographical differences in terms of types and quantities. Per capita meat consumption

24. Reference is being made here to a journal, as the original data source is not publically available

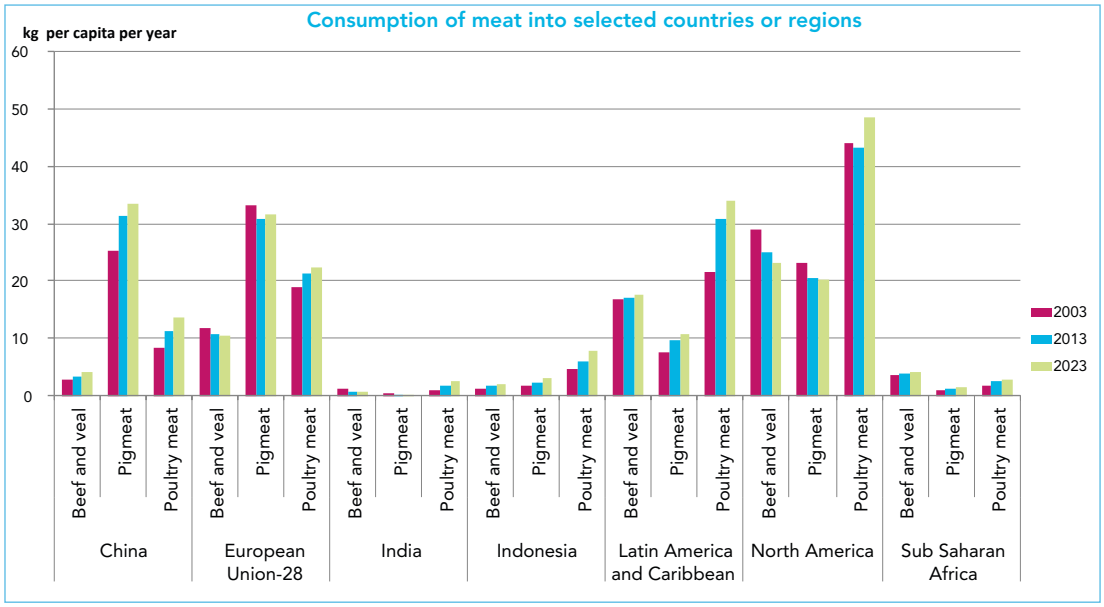
Box 2 Rapid changes in Southeast Asia

Food consumption patterns and food supply chains are changing rapidly in Southeast Asia, where both urbanization and increased prosperity are major forces. One of the main drivers of change in food consumption patterns is the rise of the middle income class: people are moving out of poverty and arrive in an income class where they can spend 6–20 US$ per capita per day. It is expected that Indonesia will become the 7th-largest economy in the world in 2030 (from 16th today); and that the number of people in the 'consuming class' will increase from 45 million today to will be 135 million in 2030 (McKinsey, 2012). The population in the region is young (50% under the age of 30). People's choice for food is increasingly steered by aspects such as convenience, health and indulgence. This leads to a strong increase in sales of processed and packaged food products such as mineral water, ice cream, powdered milk and instant noodles. The example of the projections for Indonesia indicates the scale of growth the food market may envisage in this rapidly developing economy.

is relatively low in India, Indonesia and Sub-Saharan Africa (Figure 6). Poultry meat (chicken) consumption has increased particularly in Latin America. In the EU, consumption patterns are quite stable, with pig meat being the most consumed meat. In the USA, chicken and to a lesser extent beef are the most consumed types. Globally, chicken meat and dairy consumption are expected to increase by 20% over the next 10 years. Also the consumption of pig meat and beef is projected to increase, both by around 14% (OECD & FAO, 2013). In the longer term (up to 2050), the global total consumption of meat, dairy and eggs is estimated to increase further, albeit at a slightly slower pace, due to a slower population growth and saturation in regions like China.

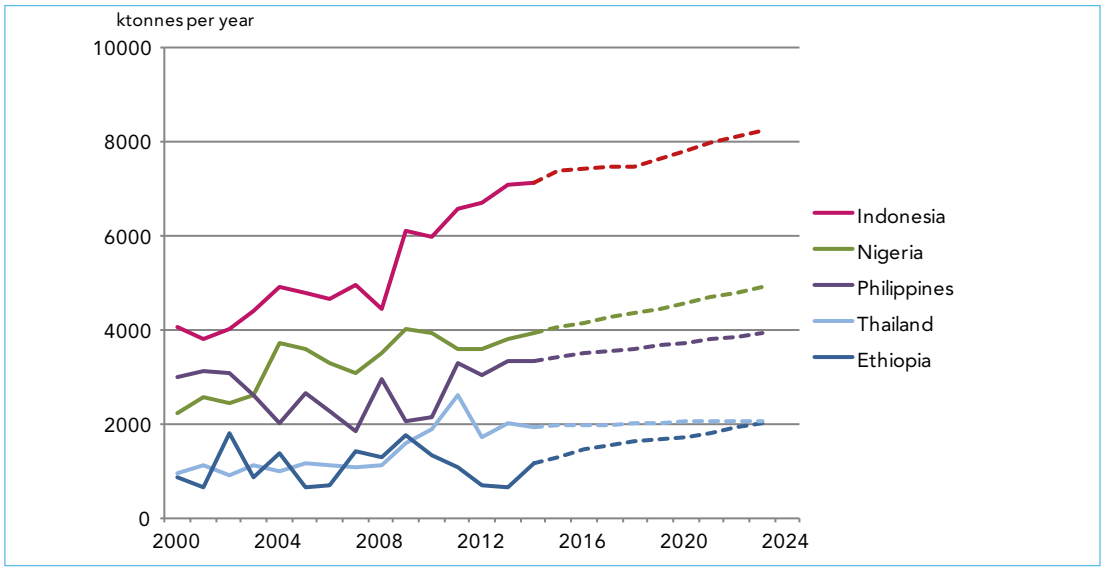
The current per capita consumption of cereals also varies strongly between countries and regions, both in levels and type of cereals consumed (Figure 7). In Europe and North America, wheat is the dominant cereal. The principal cereal is rice in Southeast Asia and maize (coarse grains) in Sub-Saharan Africa and Latin America. In India and China, wheat and rice are equally important in the food basket. Consumption of cereals per capita in Sub-Saharan Africa is expected to increase, especially that of coarse grains and rice (OECD & FAO, 2014). This may reflect higher overall consumption rates, but could also imply a shift from traditional staple crops (like root crops and bananas) to cereals.

Figure 6 Per capita consumption of meat in selected countries or regions



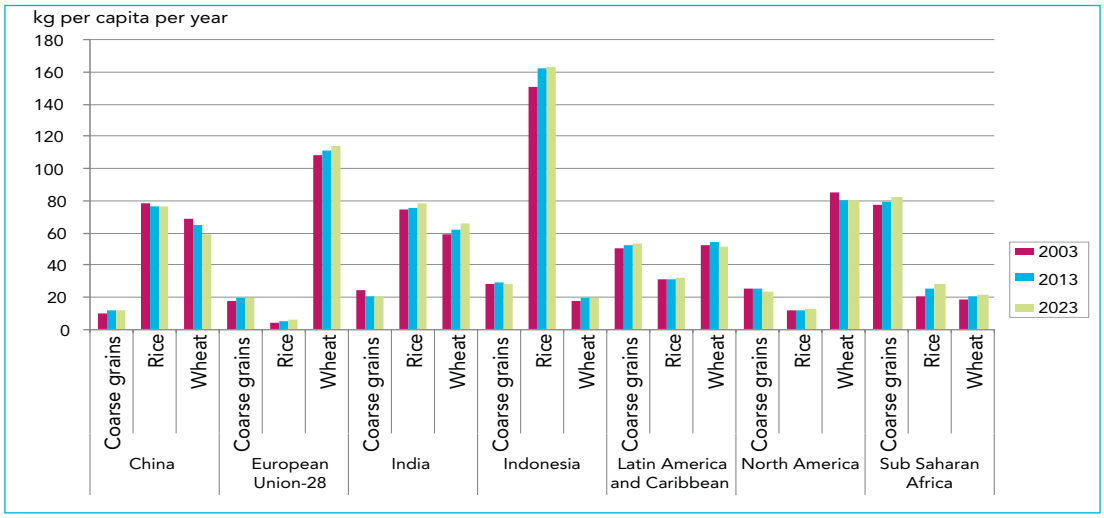
Source: (OECD & FAO, 2014)

Figure 7 Past and projected wheat import in five selected tropical countries (in 1000 t per year)



Source: (OECD & FAO, 2014)

Figure 8 Per capita consumption of cereals in selected countries or regions



Source: (OECD & FAO, 2014)

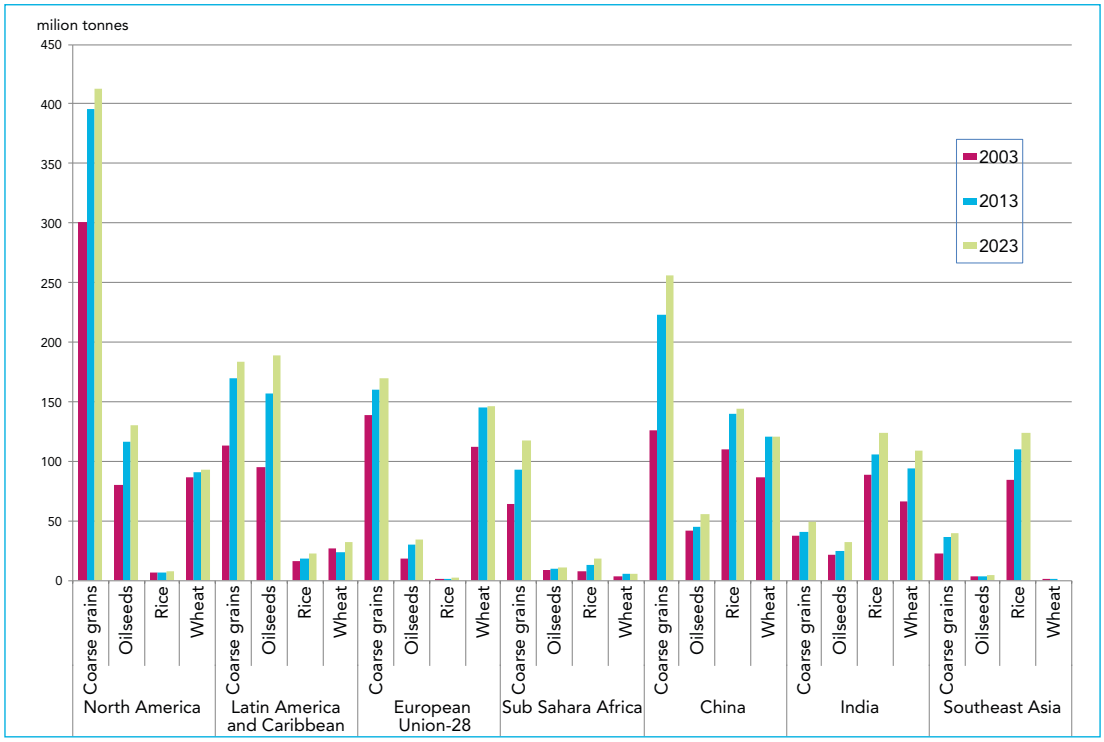
4.4 Trends in global food production and trade in response to changing consumption patterns

4.4.1 Developments in crop production and trade

In order to satisfy the growing demand for food, feed, fuels and biofuels, the agriculture and fishery sector will need to expand production. Currently, the USA, China, the EU27, India and Latin America are main producers of cereals, and Latin America and the USA produce large quantities of oil crops (Figure 9). Generally speaking, OECD/FAO projections indicate that developing countries will become more dependent on food imports as food consumption will increase faster than the growth in agricultural production.

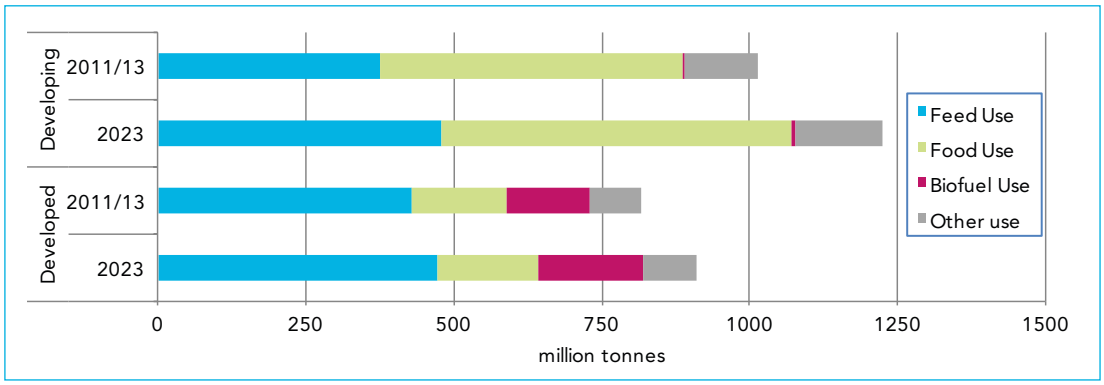
This imbalance between consumption and production areas for major food crops is also reflected in trade balances, which show main importing countries and regions such as China and the EU for oil crops (or protein meals) and China and Sub-Saharan Africa for cereals (UNCOMTRADE). Main exporting regions are Latin America (oil crops) and the USA (both cereals and oil crops). (OECD & FAO, 2014) projections for the next ten years confirm these net trade positions, whereas FAO's longer term projection up to 2050 (FAO, 2012b) shows that the imported quantity of cereals by net importers among the developing countries will almost double over the period 2010–2050. This implies that some developing countries will increasingly depend on international food markets for their food supply. These markets are generally thin (meaning a small share of production is traded internationally) and therefore often feature strong price fluctuations, that are next to the results of harvest also affected by government policy interventions (see (CFS, 2012a, HLPE, 2011)). Food security in countries that rely increasingly on food imports will therefore benefit from open markets, which connect food shortage regions with those where food production is abundant.

Figure 9 Current and projected production of cereals and oilseeds in a number of selected regions



Southeast Asia is based on four countries: Indonesia, Thailand, Vietnam and the Philippines.
Source: (OECD & FAO, 2014)

Figure 10 Evolution of cereal utilisation shares (wheat and coarse cereals) in developed and developing countries between the base year (2011/13) and 2023



Source: (OECD & FAO, 2014)

The expected increase in meat and dairy consumption also has significant implications for feed demand and consequently for resource use: in 2011/13, about 20% and 55% of total wheat and coarse grain production respectively was already used as feed and these percentages will slowly increase in the coming decade (OECD & FAO, 2014). Also, more wheat and coarse grain will be used as biofuels, largely in developed countries, although biofuel use as a share of total cereal production will slightly contract, partly due to the fact that an increasing share of biofuel production will be from sugar (ethanol) and vegetable oils (biodiesel from soybeans, palm oil, rapeseed oil).[25] Figure 10 summarizes the projected evolution of cereal utilization in developed and developing countries over the next ten years.

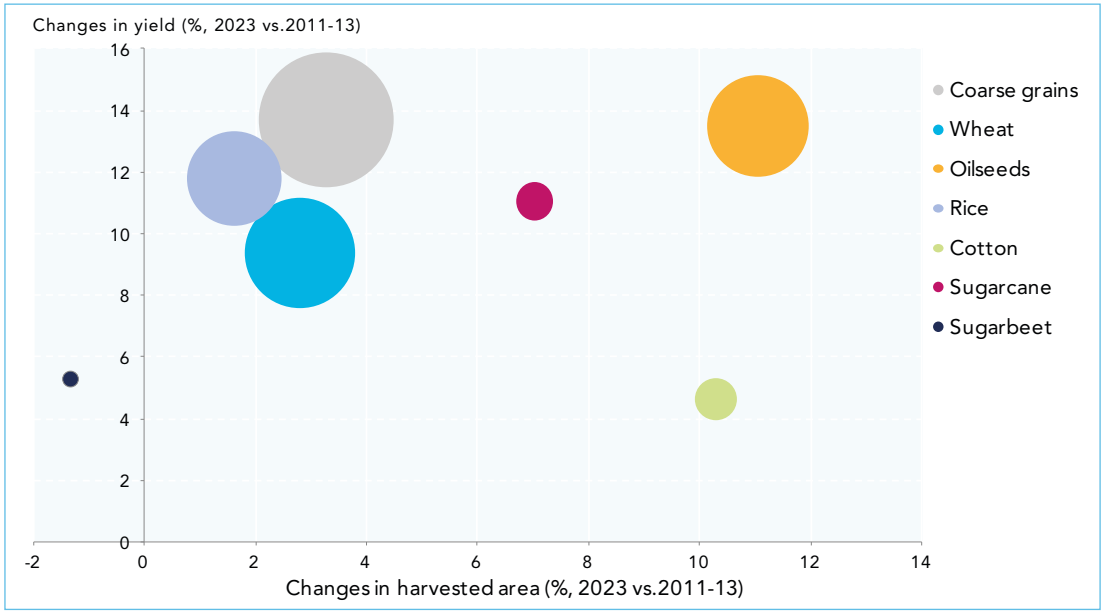
4.4.2 Increase in yields is expected to remain the main driver of production growth

A main question is how the additionally needed crop production will be produced: from higher yields per hectare[26], or from additional (new) cropland. In the Green Revolution, crop yields increased remarkably, but in various regions and for various crops crop yields stagnated (Grassini *et al.*, 2013, Weidema, 2006). As previously pointed out by the IRP, the growing demand for food will lead to an expansion of global cropland as yield growth alone will not be able to compensate for the expected surge in global demand (UNEP, 2014). The options to expand production either by area or yield increase (or a combination of the two) vary by region and by crop.

According to the (OECD & FAO, 2014) projections for the coming ten years, yields of the most important crops will increase by around 8–16% over the next decade whereas the harvested areas of these crops will grow by 2–10% (Figure 11). The main sources of production increase will therefore be higher yields and increased cropping intensity, representing 75% of the required increase. The remaining 25% will be based on cropland expansion; an estimated 8–10 million hectares per year over the next ten years (OECD & FAO, 2014).

25. Governmental policies (notably in the EU and in the USA), in combination with high oil prices, have led to a large increase in biofuel use in recent years and are expected to continue to have an impact on biofuel demand.
26. This could also include a higher cropping intensity, i.e. more crops per year (or less fallow time between crops).

Figure 11 Increase in yield and harvested areas for main crops



Source: (OECD & FAO, 2014)
Note: The size of the bubbles indicates the proportion of harvested area of one crop relative to all crops

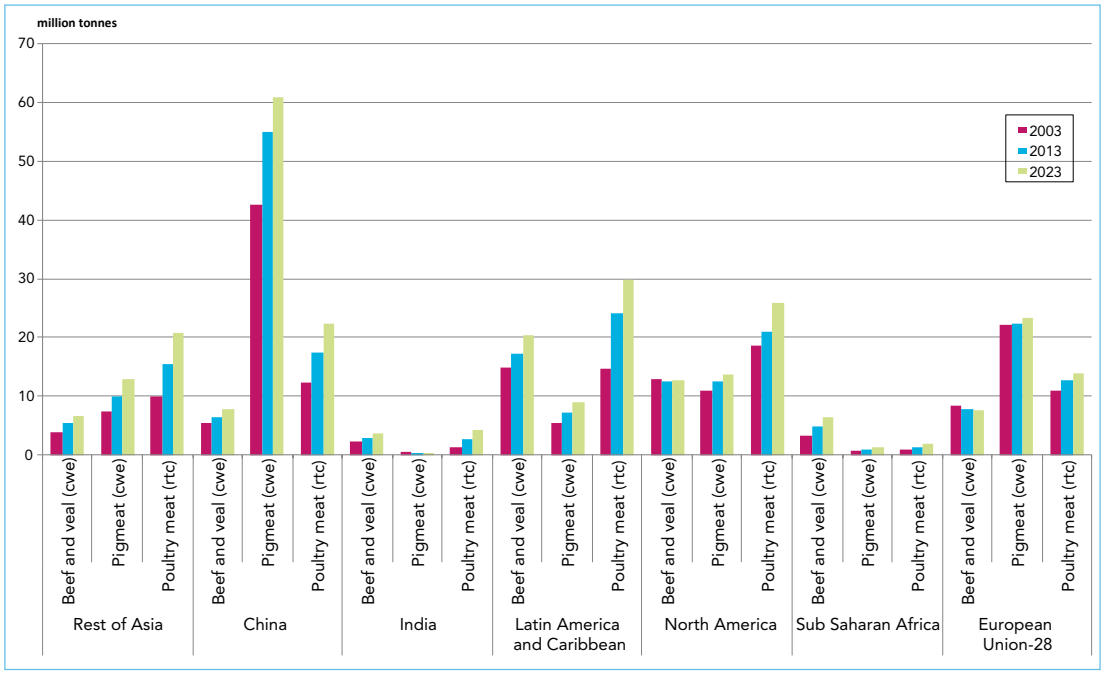
For the longer term, projections of land use changes show much variation, as demonstrated by a comparison of different agro-economic models (Schmitz *et al.*, 2014). The various models[27] project a an increase in global cropland area of between -100 million hectares to +300 million hectares over a period up to 2050. The largest average cropland expansion by far is projected in Africa (+121 million ha), followed by Latin America (+57 million ha). Cropland areas in Europe, the area of the former Soviet Union and North America are on average projected to remain stable or even contract somewhat, particularly in the Mediterranean.

4.4.3 Large increase in livestock production

Global meat production is expected to increase by around 15% for pig and beef and by 25% for poultry in the period 2011/13–2023. Meat production is projected to remain unevenly distributed between the various regions (Figure 12). The rapid growth in livestock production in Asia is projected to continue, albeit at a slightly slower pace than before. Asia overtook the OECD as the main production region of meat in around 2012. Also in Latin America, production is expected to increase. In relative terms, Sub-Saharan Africa shows the largest increase in production, but this is from a very low starting point. The developments in supply and demand imply that both the African and the Asian continents import an increasing volume of meat, notably of poultry meat in the projections up to 2023. OECD countries as well as Latin America (Brazil, Argentina and Uruguay) will remain large meat exporters. In China where meat production growth is expected to continue too, the livestock sector is highly reliant on feed grains (Garnett & Wilkes, 2014). Expansion of meat and dairy production has led already to a higher proportion of coarse grains in the country's total grain production, and will require much more imports of coarse grains and oilseeds for feed purposes (OECD and FAO, 2014a), showing the global dimension of the close interaction between livestock and crop/feed production in modern food systems.

27. The comparison includes four partial (PE) and six general equilibrium (GE) models. The PE models are MAgPIE, GLOBOIM, GCAM and IMPACT. The GE models are all based on the GTAP database: AIM, FARM, GTEM, ENVISAGE, MAGNET and EPPA. The models differ substantially in how they model land supply and the amount of potential land, and are heterogeneous in other key features as well, such as spatial dimensions, data sources and technological change.

Figure 12 Livestock production in various regions

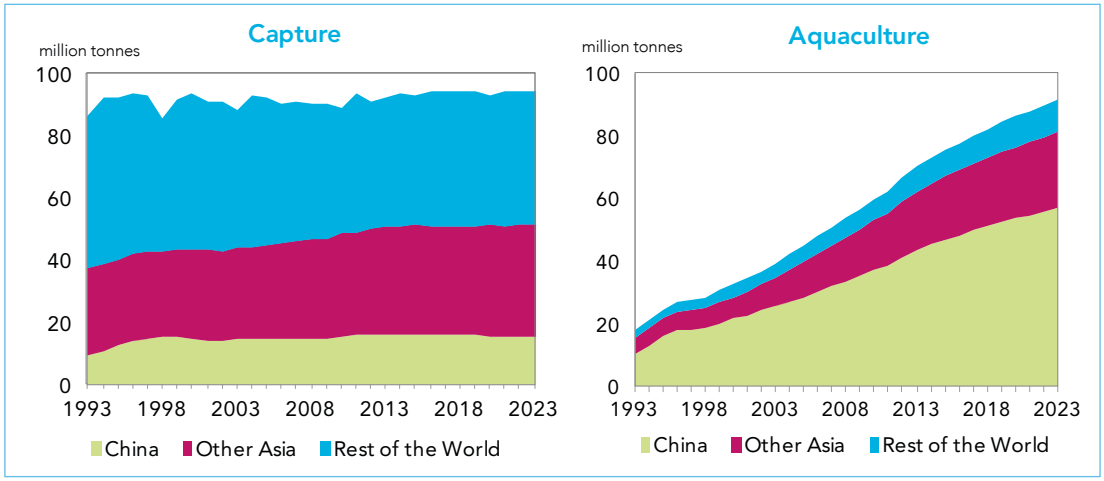


Source: (OECD & FAO, 2014)

4.4.4 Fisheries and aquaculture

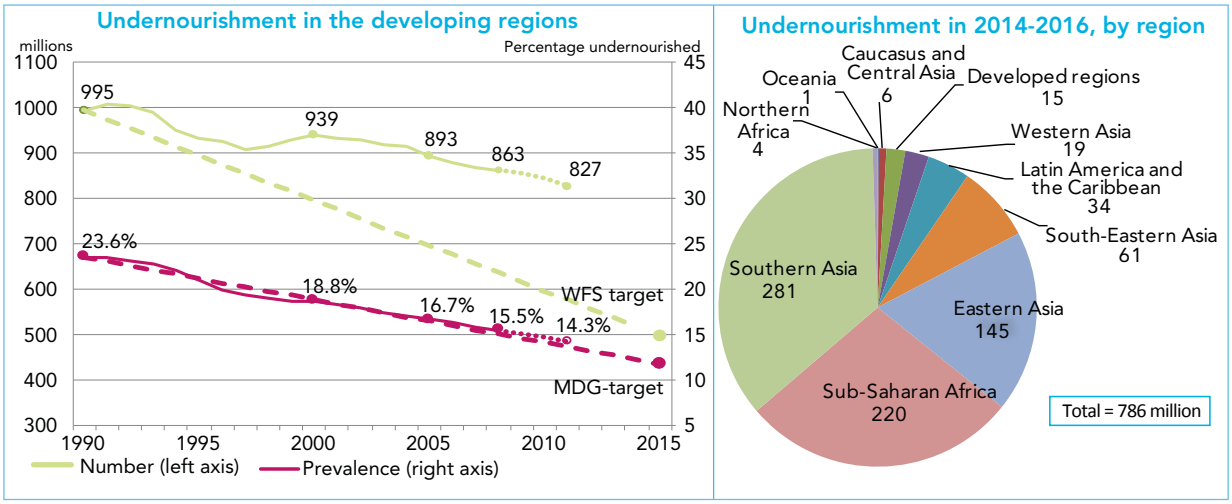
Captured supply is expected to remain stable, while fishery production by means of aquaculture is expected to increase steadily (Figure 13 and Box 3). This therefore requires additional feed. This is mainly land-produced feed in the form of cereals and protein crops, but still large amounts of fish meal and oil are used as well (although the proportion of global fish production used as fishmeal has decreased from an average of 23% in the 1990s to 10% in 2012 (HLPE, 2014b). Fish catches are expected to remain stable as many marine fish stocks are already overexploited (see Section 5.7).

Figure 13 Fishery production in live weight equivalent



Source:(OECD & FAO, 2014)

Figure 14 Prevalence of undernourishment



Source: FAO (2015e)

4.5 Food system outcomes for food security

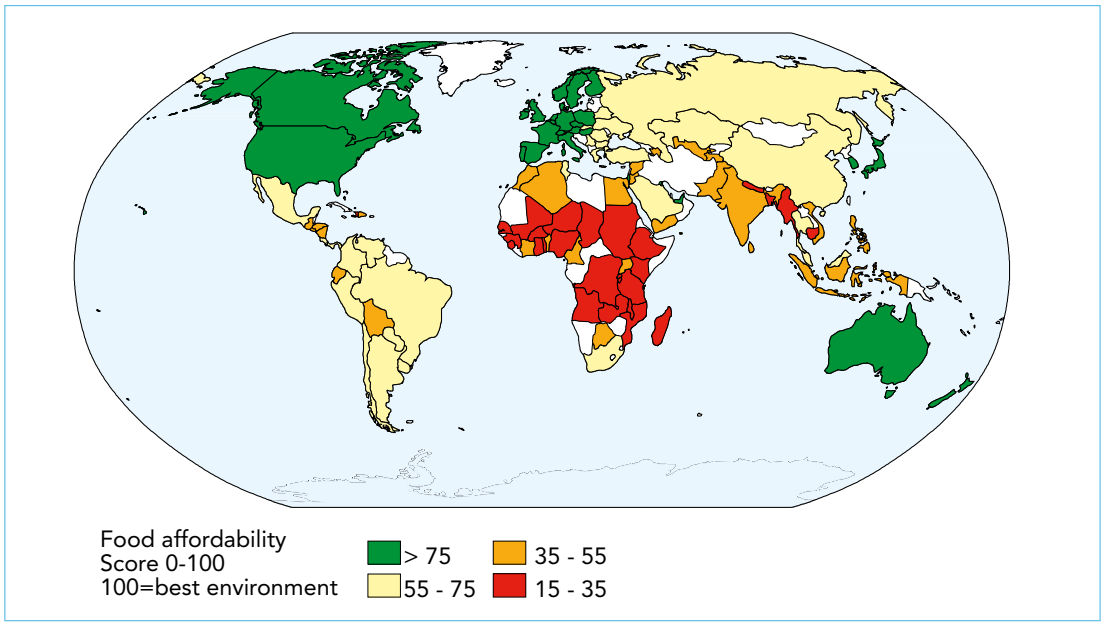
The previous sections show how socioeconomic drivers result in increasing future food demand and shifts in food consumption patterns to animal products. This will increase the challenges to increase resource efficiency and improve natural resource management in a way that these resources remain a resilient basis for future food production. As argued in chapter 2, the issue of natural resource use is highly connected with food security, through the interactions between environmental impacts of natural resource use and the socioeconomic conditions of food production and distribution. Using the concept of food systems would help to structure and analyze these (two-way) interactions. The High Level Panel of Experts on Food Security and Nutrition (HLPE) defines a sustainable food system as a 'food system that ensures food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition of future generations are not compromised' (HLPE, 2014a). A key question is whether current food systems have satisfactory outcomes in terms of food and nutrition security. If not, how to enhance these outcomes while improving natural resource efficiency? This section provides some insights in a number of food system outcomes for food security and consequences for natural resource use.

4.5.1 Number of people undernourished

Despite the great increase in food production volumes in recent decades, current food systems have not been able to eradicate hunger. In 2014, about 795 million people were undernourished globally. This is 216 million less than in 1990–92 (FAO (2015e) (Figure 14). The largest number of undernourished are found in Southern Asia, Sub-Saharan Africa and Eastern Asia, where over 80% of the undernourished are found. While in many regions the number of undernourished people has declined, it is more or less stable in Southern Asia, and it has increased in Sub-Saharan Africa from 176 to 220 million people.

Three quarters of all hungry people live in rural areas, mainly in Asia and Africa. Many of these rural poor depend on smallholder-based agriculture to improve their livelihoods. According to the (FAO, 2012b) study *World Agriculture Towards 2030/2050*, there will only be a modest reduction in the number of undernourished people in the decades ahead. The main reason for this is that many countries start with adverse initial conditions such as 'low national average food availability, high undernourishment, high population growth and also poor land and water resource endowments' (FAO, 2012b). Improved utilization of these scarce land and water resources can thus play a crucial role in poverty alleviation in rural areas of developing countries.

Figure 15 Food affordability



Source: Global Food Security Index (EUI, 2014)

4.5.2 Food price development

Prices and income levels and development determine to a great extent the affordability of food. Figure 15 presents an overview of the food affordability situation in the world, measured by the Global Food Security Index (EUI, 2014) of the Economist Intelligence Unit.[28] The situation is worst in the low-income countries in Sub-Saharan Africa, plus several low-income countries in Asia and the Caribbean. Densely populated countries like Egypt, India, Vietnam and Indonesia have a slightly higher score.

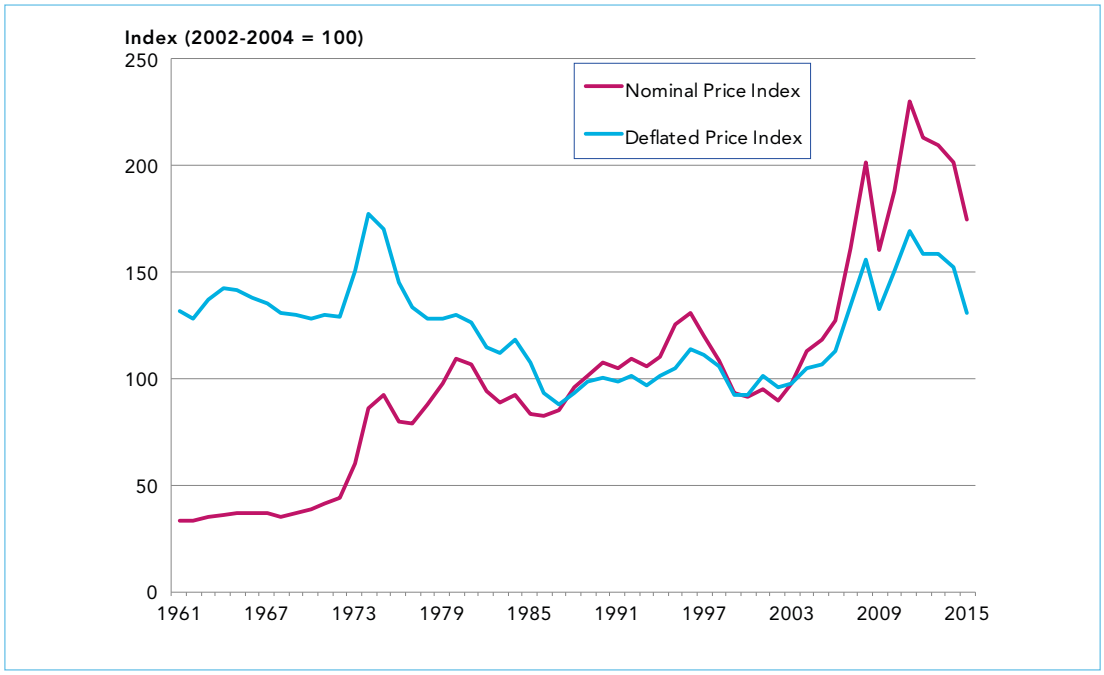
Developments in food prices show considerable fluctuations for recent decades. Periods of declining levels alternate with upward trends in prices, which show peaks in the mid-1970s and in 2008 and 2011, with 2014 prices down compared to 2011 but still close to the 2008 levels (see Figure 16). Since the early 2000's, prices (both in nominal and deflated terms) show an overall remarkable upward trend driven by population and income growth as two fundamental drivers of food demand, next to, among others, the use of feedstock for biofuels. Food has started to become more expensive over the last two decades, which might become a problem for the lower income classes that spend a significant part of their (low) income on food and are net buyers of food, therefore making that category very vulnerable to price peaks.[29] A continuation of the increasing trends in food prices may endanger food security for these lower income classes, both in developed and less developed countries.

OECD-FAO medium term projections do expect prices of major commodities to rise up to levels above the pre-2008 period as global food consumption continues to increase (OECD & FAO, 2014). These projections for the next ten years also assume a slowly increasing crude oil price, which will encourage further biofuel production.[30] This highlights the increasing linkage between

28. The Global Food Security Index (GFSI) of the EUI (2014) looks at affordability through two primary lenses – whether an average individual in a country has sufficient means to purchase food, and the public structures that have been established to respond to personal or societal shocks. Together these provide a holistic treatment of affordability, exploring elements of ability to pay and cost under a broad array of environmental conditions.
29. Food price fluctuations raise great concerns in developing countries given the large share of income spent on food by the poor, and the importance of agriculture as a source of income for many poor people. The challenge for policy is to identify (a combination of) policies to ensure both the livelihood security and food security of vulnerable people. See Beekman G., Meijerink G. (2010) *Reducing food price variability in Sub-Saharan Africa,* The Hague, LEI Wageningen UR, World Bank (2014a) *Food Price Volatility, Food Security and Trade Policy Conference.* For a discussion of the usefulness of government-run or market-based instruments to stabilise prices and/or managing risks related to price variability.

the agricultural and energy market caused by biofuel programmes implemented by the US, EU, Brazil and many other countries (see also (HLPE, 2013a)). Although biofuels have not been the most dominant contributor to the recent food-price inflation (see e.g. (Zilberman *et al.*, 2012), prices of agricultural commodities and crude oil increasingly correlate since the introduction of biofuel programmes in the US: ethanol prices follow oil prices and prices of corn and other cereals adjust to a change in the price of ethanol (Marimpi, 2014, Merkuseva & Rapsomanikis, 2013). Hence, fossil fuel market developments affect agricultural commodity markets increasingly and in two ways as agriculture is both a user *and* a producer of fuel. Modern agriculture is heavily reliant on fossil fuel derived inputs such as fertilizers and fuel, while food processing, preserving/cooling and transport and distribution are energy-intensive activities too. As a result, the global food supply is highly dependent on fossil fuel and food prices continue to be pressured upwards by fossil energy prices that tend to increase over time due to increasing global demand and the depletion of currently known reserves. In addition, biofuel production is encouraged by mandatory policies and affected by fossil fuel price developments. All in all, if fossil fuel prices increase, agricultural production costs increase and biofuel production becomes more attractive. Both tendencies have an upward pressure on food prices unless food production increases through land area expansion or the more intensive use of the currently available agricultural area. Increasing demand for agricultural commodities for biofuels highlights the additional need for pursuing higher yields based on improved resource use efficiency.

Figure 16 Food price developments 1961–2014



Source: (FAO, 2014b)

30. A reduction in demand – due to economic decline in China and some other emerging economies - in parallel with an expansion of supply caused a significant drop in fossil fuel prices in 2014 and 2015. The World Bank Commodity Price Forecasts to 2025 project prices to increase again in 2017 and onwards (http://www.worldbank.org/en/research/commodity-markets, retrieved 22 January 2016).

4.5.3 Rural livelihoods in the context of rapidly changing and consolidating food systems

Whereas in developed economies agriculture is a relatively small economic activity, it is a major if not dominant source of income and livelihood in many developing countries. According to the (World Bank, 2007), agriculture is a source of livelihood for an estimated 86% of rural people. It provides jobs for 1.3 billion smallholders and landless workers, 'farm-financed social welfare' when there are urban shocks, and a foundation for viable rural communities. Of the developing world's 5.5 billion people, 3 billion live in rural areas – nearly half of humanity. Of these rural inhabitants an estimated 2.5 billion are in households involved in agriculture, and 1.5 billion are in smallholder households.

A total of 1.3 billion people live on less than US$1.25 a day (in 2005 purchasing power parity); this level is defined as living in extreme poverty (World Bank, 2014b). Half of this population is concentrated in Africa and another 30% lives in South Asia. Three out of every four poor people in developing countries live in rural areas, and most of them depend directly or indirectly on agriculture for their livelihoods. Therefore, in many of these countries agriculture is a strong option for spurring growth, overcoming poverty and enhancing food security. Increased agricultural productivity generates higher incomes and creates income-generating opportunities for otherwise destitute population groups, offering a recognized way to escape the poverty trap in many rural areas. However, many smallholders are not able to use the opportunities provided by increasing resource efficiency as they are not well-integrated in markets or included in the (increasingly lengthy) food supply chains dominated by an progressively concentrated retail segment (FAO, 2013b, Kirsten *et al.*, 2009, Wiggins, 2014). Processors and retailers tend to have a preference for suppliers that have a certain scale, in order to guarantee the requested volumes in the appropriate quality and on time. Among the risks faced by agri-processors in setting up business relations with smallholders are difficulties in getting the latter to comply with standard requirements on products and other contractual agreements, as well as problems (and costs) relating to communication and coordination with a large number of suppliers. Smallholders, on their side, face serious constraints in accessing essential inputs (feed, fertilizer, seeds, capital, etc.) and in selling their products. The problems are worsened by the lack of public institutions necessary to support market-based transactions, such as those for enforcing property and/or user rights (of land or water resources) and contractual agreements.

4.5.4 Food losses and food waste

A characteristic of current food systems is the significant food losses and waste. This adds to food insecurity, spoils natural resources (such as land, water, minerals) as well as human resources. Across the food chain, a substantial percentage (20–30%) of agricultural produce is lost for food intake, and further proportions are used for animal feed and biofuel. This is approximately equal to a loss of 1.3 billion tonnes per year (Gustavsson *et al.*, 2011). Most experts differentiate between food losses and food waste; a distinction which is also relevant when thinking about solutions. Food that gets lost, spilled or spoilt before it reaches its final product or retail stage is called food loss. Food waste refers to food that is of good quality and fit for human consumption but that does not get consumed because it is discarded either before or after it is spoiled (Lipinski *et al.*, 2013). It needs to be stressed that numbers on food waste and losses need to be considered with caution, as studies employ different definitions and indicators and there are gaps in data availability (HLPE, 2014a).

(Gustavsson *et al.*, 2011) provide an illustrative global overview of current levels of food loss and waste. In Europe and North America, the per capita overall food loss and waste is estimated to be between 280–300 kg per year, while in Sub-Saharan Africa and Southeast Asia this amount is between 120–170 kg, and in the other regions between 210 and 240 kg per year (Figure 17). The figures in this study show that food waste (at consumption level) has a higher share in total food loss and waste in developed countries than in developing countries. The authors'

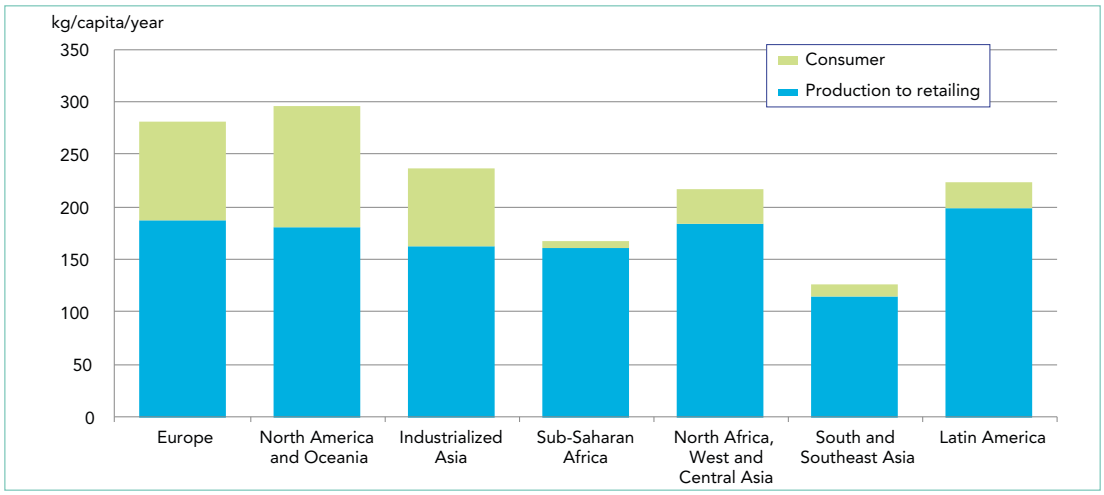
background figures also indicate that the nature of food losses differs per region. In developed countries, food production losses mainly occur in the food processing stage (loss of food parts during standardized preparation of specific products). However, 40% of the total estimated losses and waste in developed countries occur at the retail and consumer level, representing around 222 million tonnes; almost as high as the total net food produced in Sub-Saharan Africa (which is around 230 million tonnes). In developing countries, around 40% of food losses and waste occurs during the post-harvest stage but losses at the field stage are also prevalent. For instance, in Sub-Saharan Africa the losses in cereal grains range from 5–40% of the total production. Post-harvest losses in fruit and vegetables in Sub-Saharan Africa range between 30–40 %, although the extent of these losses varies according to region, season and commodity. Recent studies in India, Ghana, Rwanda and Benin show even higher losses ranging from 30–80% in different commodities (Kitinoja et al. (2011) cited in (HLPE, 2014a).

4.5.5 Food consumption trends and health

As income rises, people tend to shift from starch-rich to sugar/fat-rich foods, with more animal protein products (meat and dairy) and fruit and vegetables. An increase in dietary diversity can have positive effects on health compared with a diet dominated by cereals, roots and tubers. However, increased consumption of sugar/fat-rich food per capita does not always have positive effects: many countries struggle with obesity. Figure 18 below shows the prevalence of obesity in the world indicating that it is not only a problem in some high-income countries but also in many developing countries, where almost two in three of the world's obese people live.

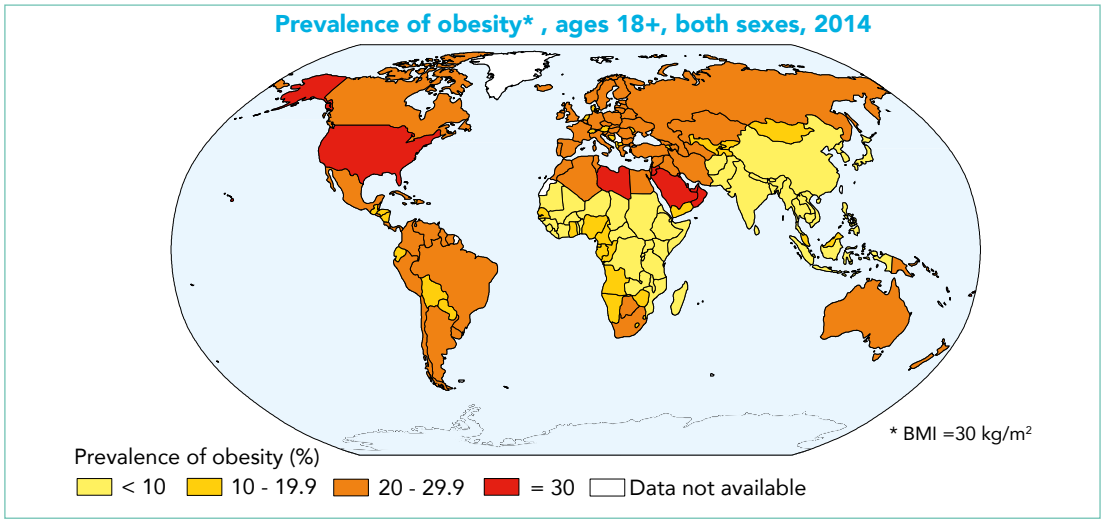
Overweight and obesity is a fast-growing, globalizing problem with well over two billion adults overweight or obese in 2013: worldwide, the proportion of adults with a body mass index (BMI) of 25 kg/m^2 or greater increased between 1980 and 2013 from 28.8% to 36.9% in men, and from 29.8% to 38.0% in women (Ng *et al.*, 2014). Causes are related to food consumption habits and lifestyle: overweight is linked with an increased intake of foods that are high in calories and an increase in physical inactivity due to the increasingly sedentary nature of many forms of work, changing modes of transportation and increasing urbanization (WHO, 2013). Overweight and obesity should be tackled by energy rebalancing between calories consumed and calories expended.

Figure 17 Per capita food losses and waste in different regions (kg/year)



Source: (Gustavsson *et al.*, 2011)

Figure 18 Prevalence of obesity



Source: (WHO, 2014)

Overweight and obesity are associated with high individual and societal costs. Firstly, they lead to increased risks of life-threatening diseases.[31] This implies huge costs to national health systems. To illustrate this: treating the projected growth in preventable weight-related diseases in the USA and UK alone was estimated at $66 billion a year (Metelerkamp, 2013) an amount that equals Luxembourg's GDP. Secondly, adults with overweight have a poor health condition and are less productive and efficient than they could be, implying a significant cost of overconsumption from an economic perspective too. A specific concern is the increase of childhood overweight, the prevalence of which is increasing dramatically in all regions, of the world, particularly in Africa and Asia. In its Global Nutrition Targets 2025 the WHO has set an implementation plan to stop the increase of childhood overweight, including a mix of policies and actions aimed at changing behavior and reducing social risk factors which lead to unhealthy weight gain in children (WHO, 2012).

Like overweight, undernourishment (insufficient intake to meet energetic needs) and diets lacking essential micronutrients both affect global public health. According to the recent GBD study[32] (Lim *et al.*, 2013), the disease burden due to childhood underweight, including communicable disease, has fallen substantially since 1990, from around 8% of the total disease burden to around 3% in 2010. The decrease is substantially higher in Asia than in Africa. At the same time, the disease burden due to excessive food consumption increased substantially. For instance, the disease burden due to overweight (high Body Mass Index) rose from 2.2% to almost 4% of the total disease burden (TDB) worldwide. In developing regions too, the disease burden due to overweight and obesity more than doubled. Especially in Africa, both underweight and overweight constitute predominant risk factors simultaneously.

Taken together, dietary risk factors account for 10% of the total global disease burden, which is higher than the main individual factors, which are smoking including second hand smoke, and high blood pressure (6.5% and 7% of the TDB respectively). The relative high position of 'low fruit', 'low nuts and seeds', 'low vegetables' and 'low omega-3' on the GBD list of risk factors implies that there is more to healthy food communication than advising a lower intake of saturated fats. There seems to be cause to pay

31. Cardiovascular diseases, diabetes, musculoskeletal disorders and some cancers (WHO (2013) *Obesity and overweight Fact sheet N°311 updated on March 2013,* http://www.who.int/mediacentre/factsheets/fs311/en.
32. The Global Burden of Disease (GBD) study is a comprehensive regional and global assessment of mortality and disability from major diseases, injuries, and risk factors. GBD is a collaboration of over 500 researchers representing over 300 institutions and 50 countries.

Box 3 Case study aquaculture

Opportunities of aquaculture for food supply and income generation (smallholders as well as private businesses)

Aquaculture is the fastest-growing food-production sector in the world, now providing almost half of the global fish supply (FAO, 2012a, Hall *et al.*, 2011). In 2012, world aquaculture production attained an all-time high of 90 million tonnes (live weight equivalent) valued at US$144 billion. This includes 67 million tonnes of food fish (US$138 billion) and 24 million tonnes of aquatic algae (mostly seaweeds, US$6.4 billion) (FAO, 2014c). The fast growth rate in farmed food fish production resulted in average annual per capita consumption of farmed fish rising by almost seven times, from 1.1 kg in 1980 to 8.7 kg in 2010 (FAO, 2012a). For global fish availability to meet projected demand, it is estimated that aquaculture production will need to more than double by mid-century, rising to roughly 140 million tonnes in 2050 (Waite *et al.*, 2014).

In 2010, the Asia and the Pacific region produced 53.1 million tonnes of aquaculture products (excluding aquatic plants) which accounted for 89% of the global aquaculture production (Funge-Smith *et al.*, 2012). In terms of value, this is 80% of the total value of global aquaculture. Nine of the top 10 fish producing countries in the world are in Asia, all of which started from small-scale aquaculture. Small-scale aquaculture has not only supplied animal protein to the rural poor but has also generated income and has also served as a gateway to commercial farming and export earnings, such as catfish (*Pangasius*) farming in Vietnam and shrimp in Thailand (Bhujel, 2012).

Globally, aquaculture provided almost 19 million on-farm jobs in 2012, 96%t of which were located in Asia (FAO, 2014c, Waite *et al.*, 2014). When accounting for secondary sectors such as fish processing and marketing, as well as for workers' families, the number of people reliant on aquaculture for a living rises to more than 100 million (Waite *et al.*, 2014). Small-scale aquaculture also offers important livelihood opportunities for women in developing countries through their direct involvement in the production, processing and sale of fish (FAO, 2014c). Aquaculture also addresses poverty and food insecurity through a variety of routes and at various scales (Beveridge *et al.*, 2010). It offers a means for smallholder farmers to diversify production, thereby providing nutritious food for their own families, and sometimes those of their neighbors, while also generating surpluses for sale. Aquaculture enterprises from micro to large scale, providing fish exclusively for sale, create farm income and employment opportunities throughout the value chain and provide affordable, highly nutritious food in response to market demand.

Natural resource and environmental implications (risks, opportunities)

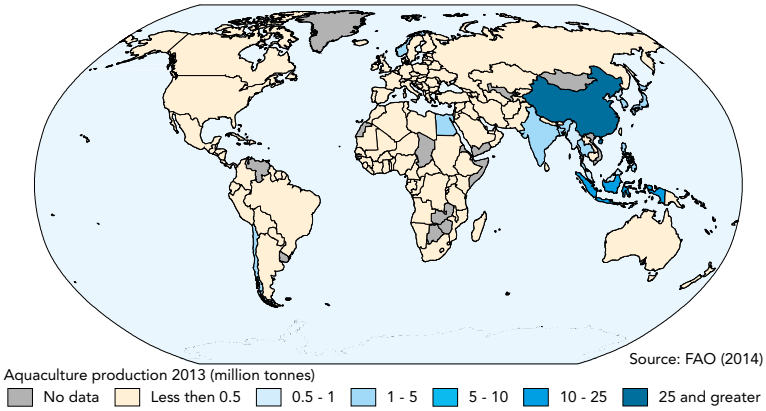
Fish in aquaculture systems is on average more efficient than most terrestrial livestock systems in converting feed into protein (HLPE, 2014). Yet, for most species the availability of fish feed is one of the key issues for the future, especially in the case of fishmeal (FAO, 2012b). Some species however, such as mollusks and filter-feeding finfish (e.g. silver carp, bighead carp) do not require feeding.

Aquaculture is also constrained by local environmental factors and the carrying capacity of the environment where production occurs. Especially coastal areas are vulnerable. Furthermore, the aquaculture production system contributes to eutrophication (Bouwman *et al.*, 2013a, Hall *et al.*, 2011). However, aquaculture can potentially enhance resilience through improved resource efficiencies and increased diversification of farmed species, locales of production, and feeding strategies (Troell et al. 2014). These would require the development of a diversity of aquaculture species; the promotion of co-products from the crop, livestock, and fisheries sectors for feeds, the design of infrastructure that uses renewable energy and the implementation of management practices that minimize wastes and environmental impacts.

The "Blue Frontier" report (Hall *et al.*, 2011) outlines interventions on innovation, regulation and policy, technologies management, monitoring and compliance, and consumer and markets. Also, investing in science and technology is important for achieving more sustainable aquaculture development. The following are among the key areas for improvement that are particularly relevant to major aquaculture counties in Asia region (Hall *et al.*, 2011): (i) reduction of the dependency of some aquaculture production systems on fishmeal and fish oil, and where used assuring such ingredients derive from more sustainable sources; (ii) increased use of water and energy audits to foster better practices that reduce environmental resource demands; (iii) investments in improving fish strains through selective breeding and also focus on selection for feeding efficiency and disease resistance; (iv) analysis of climate change related vulnerabilities and adaptation strategies, shift of the location of aquaculture to new areas that become more suitable.

Finally, to provide wider ecosystem stewardship and improved governance of the sector, FAO is promoting "Blue Growth" as a coherent approach for the sustainable, integrated and socio-economically sensitive management of oceans and wetlands, focusing on capture fisheries, aquaculture, ecosystem services, trade and social protection of coastal communities (FAO 2014). The Blue Growth framework promotes responsible and sustainable fisheries and aquaculture by way of an integrated approach involving all stakeholders, anchored in the principles set out in the benchmark Code of Conduct for Responsible Fisheries of 1995.

Figure B.1 Geographical distribution of aquaculture production 2013



(Source: Adopted from Waite et al. 2014).

more attention to 'healthy food components' that might be missing in our diets.

Considering the key findings of the Global Burden of Disease study with respect to dietary risk factors, *diverse diets* appear to be the key to healthy food consumption.

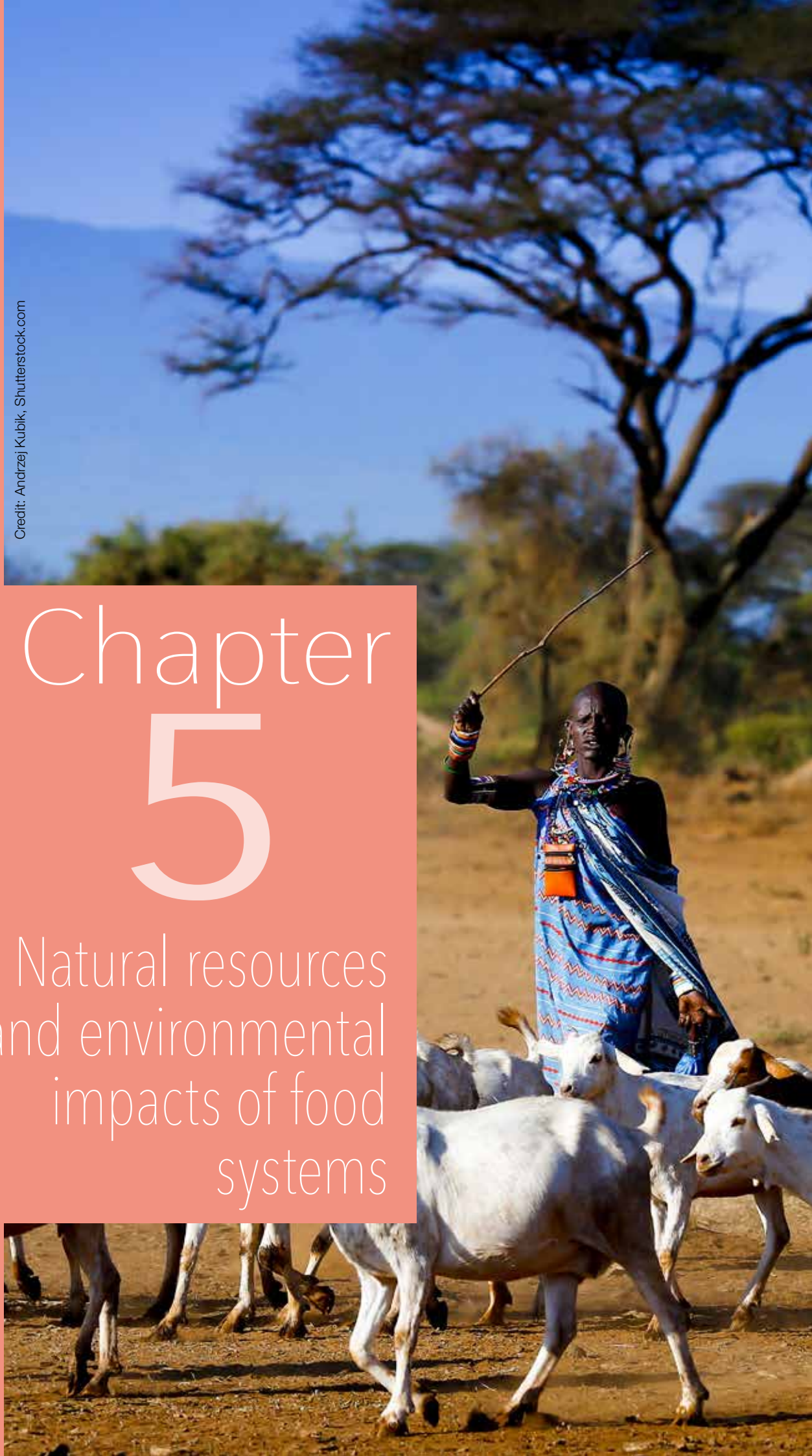
Turning to a more healthy diet could have significant implications for at least part of the present food system as it includes a significant reduction of meat and dairy consumption levels and more fruits and vegetables. This will have significant impacts on natural resources as meat and dairy sectors are particularly intensive users of land (including fodder production) and water.

4.6 Summary and Conclusions

Food demand is expected to increase and change drastically in composition over the coming decades due to the increasing population coupled with increased wealth, and ongoing urbanization, especially in regions outside the developed countries. Figures from the emerging economies of China and Brazil illustrate this shift in diets, by showing a rapid increase in per capita meat consumption over the last 40 years. Globally, the expected increase of meat and dairy consumption has large implications for feed demand and consequently for resource use. Over the next 10 years, around 75% of the additional crop production projected will be based on higher crop yields; the rest from an increase in growing areas. Increases in fish consumption over the next 10 years will be based on a 35% expansion in aquaculture production, with supply from captured fish expected to remain stable. For aquaculture to grow, additional feed is needed too. Aquaculture is becoming a major pressure on the marine environment, due to nutrient losses in coastal areas.

The increasing size, wealth and share of the population living in urban settlements will lead to important changes in local and regional food systems. Physical distances between food producing and consuming areas will increase, implying a greater role for trade and distribution. Moreover, urban food consumption patterns tend to shift to processed and 'western' style convenience food. Especially in a number of Asian and African countries, an increasing share of these foods are imported for different reasons: local supply chains are less cost-efficient than globalized supply chains, some crops cannot be grown domestically (such as wheat), or the local land base is not enough to produce satisfactory volumes. Moreover, many smallholders are not able to increase production as they are not well-integrated in markets or included in the (increasingly lengthy) food supply chains dominated by an increasingly concentrated retail segment.

Current food systems have several unsatisfactory outcomes in terms of food and nutrition security. First, over 800 million people are still suffering from chronic hunger. In addition, over 2 billion people suffer from micronutrient deficiencies. Three quarters of all hungry people live in rural areas, mainly in Asia and Africa. Many of the rural poor depend on smallholder-based agriculture to improve their livelihoods. Second, food losses and waste are significant, about one-third of the mass of food available for human consumption is lost. In developing countries most food loss occurs in the field and during post-harvest storage, whereas food waste in high-income countries is mainly at retail, restaurant/catering/hospitality and domestic consumer stages. In addition, the loss of food for potential consumption represents a significant unnecessary use of natural resources. And third, there is a strong increase in obesity and diet-related diseases. As income per capita rises, people's diets change from one that is largely rich in carbohydrates to a diet richer in calories, sugars, and lipids, with more livestock-based products and vegetables. In combination with an increasingly sedentary lifestyle, this has led to a sharp increase in obesity. Globally, more than two billion people are currently overweight or obese. In Africa in particular, both under- and overweight constitute predominant disease risk factors simultaneously.



Credit: Andrzej Kubik, Shutterstock.com

Chapter 5

Natural resources and environmental impacts of food systems

5.1 Introduction

The previous two chapters described current food systems and current and projected food production and consumption trends. This chapter focuses on the natural resources needed for food system activities (Table 1) and their environmental impacts (Table 2). As can been seen in Table 1 the actual use of most resources is concentrated in the primary production stage (farming, fishing, aquaculture). The main exceptions are fossil fuels (currently 70% is for off-farm activities) and minerals for packaging. Minerals in the form of nutrients (as P, K, etc.) flow through the food system.

Given the fact that most resources are used in the primary production stage, it might seem that the 'food system lens' is not fully used in this chapter. As the next chapters will clarify, the key to a more sustainable and efficient use of resources at the primary production stage is often in the hands of other actors in the food system. Still, to better understand the real issues concerning natural resources and food systems, an assessment per natural resource is essential. In the first part of this chapter a brief description is given of the current and projected state of the main renewable and non-renewable resources, as well as the consequences of their unsustainable or inefficient use. Each subsection closes with a brief summary of biophysical options for the more efficient and sustainable use of the particular resource. The current and projected environmental impacts of food production and consumption are described in Section 5.9. The chapter closes with an overview of the resource use and environmental impacts of different food products and diets (Section 5.10).

5.2 Land, landscape and soils

5.2.1 Land use and food systems

Humankind has increasingly transformed land and ecosystems in order to increase food production or other outputs, leading to major changes in biodiversity, biogeochemistry and climate (Ellis *et al.*, 2013). Currently, of the 149 million km^2 of total global land area, 15 million km^2 (1500 million hectares) are predominantly being used for crop production (including permanent crops and fallow land) and around 34 million km^2 for rangelands (including grassland and other areas growing primarily native vegetation) (FAO, 2011e). Globally, croplands produce the largest share of food, although the contribution from other sources (rangelands, fisheries, hunting and gathering) should not be underestimated. In some traditional food systems, these sources even provide a major part of the diet. Within food systems, land is predominantly used for primary production, although locally large areas are allocated to other activities such as food processing, retail and restaurants. Due to high local concentrations of the population, for example in urban centers, food demand exceeds local production potential in many areas, leading to large trade flows within and between countries (Chapter 4). **Soils** are a major component of the land resource, since soil quality is an important determinant of the suitability of land for agriculture, in combination with other land characteristics (such as slope) and climate. **Landscapes** refer to interacting ecosystems related to the spatial configuration of heterogeneous types of land use. Both agricultural as non-agricultural ecosystems (like forests or wetlands) can provide essential supporting and regulating ecosystem services to agriculture, such as pest and disease control

and water regulation (See also Section 5.5 on Biodiversity and ecosystem services). Cropland and pasture land provide important ecosystem services as well (Wood *et al.*, 2000a), such as water and climate regulation, but also disservices (for example disturbance of watersheds).

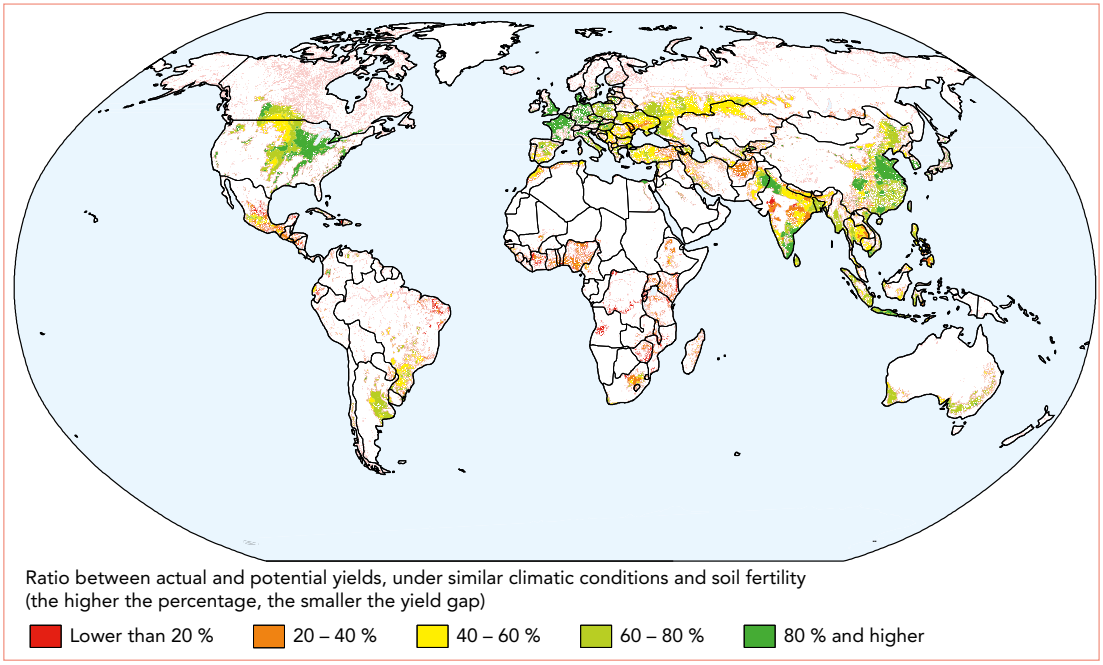
Large differences in land potential

Not all land on earth has the potential to sustainably support agricultural production. For a particular piece of land, this potential is a function of both the land's current production potential and the land's resistance and resilience to degradation (UNEP, 2016). FAO distinguishes three classes of potential cropland: prime, good and marginal/unsuitable (FAO, 2011e). Globally, 28% of the cultivated land is classified as prime quality, and 53% as good. The productivity of inputs such as labor, seeds, water and nutrients is higher on prime land than on good or marginal land. As discussed in UNEP's report 'Assessing global land use' (UNEP, 2014), the potential of a specific piece of land is not static: land potential can be increased through innovation and investments. It can also decline through soil loss and other forms of degradation. The land quality of a certain plot or region can be improved by good management, but can also deteriorate in the case of poor management. Much of the current prime agricultural land has been improved over time: soil acidity has been corrected by liming and soil fertility has been increased through fertilization and amendments to organic material. More dramatic and long-term changes to land potential have been achieved through the modification of water flows through the soil via terracing and the installation of surface and sub-surface drainage systems. Terraces can actually *increase* soil erosion when not maintained, resulting in a net loss of potential productivity. Terrace abandonment often occurs when labor costs rise, reducing the profitability of managing steep lands for agriculture.

5.2.2 Are current and future land use efficient and sustainable?

The important question is whether the current use of land, soils and landscape is efficient and sustainable. As clarified in Chapter 2, the 'efficiency' of land use is defined here as land productivity or crop yields, which should be assessed against its potential productivity. This latter aspect is important as not all land or soils have the same potential. As Figure 19 shows, the main areas with large yield gaps are in developing and emerging countries. There are however important exceptions: large parts of Asia and South America have relatively small yield gaps, whereas parts of the USA and Russia have significant yield gaps. Much research has been conducted that shows the difficulty of exactly defining the potential yield level (Licker *et al.*, 2010, Neumann *et al.*, 2010, Phalan *et al.*, 2014). Rather than focusing on the potential yield, it seems more fruitful to acknowledge that yield gaps exist, and to determine effective ways of increasing crop yields and the productivity of pastures. It is important to place the existence of yield gaps within the context of food systems and the socioeconomic system as a whole. On the one hand, the biophysical causes of yield gaps are driven by socioeconomic factors (see Chapter 3 and 4) as well as by other components of the food system. On the other hand, higher crop yields could lead to higher labor productivity and better socioeconomic outcomes. Higher crop yields could reduce the need for additional agricultural land and thus slow down the rate of deforestation. This last mechanism is however disputed, as various rebound effects can occur. On a local scale, more efficient agriculture is likely to be more profitable and could thus locally lead to an expansion of the cultivated area (Lambin *et al.*, 2014). On a global scale, higher crop yields will probably lead to lower commodity prices, and thus stimulate the demand for products as meat and biofuels.

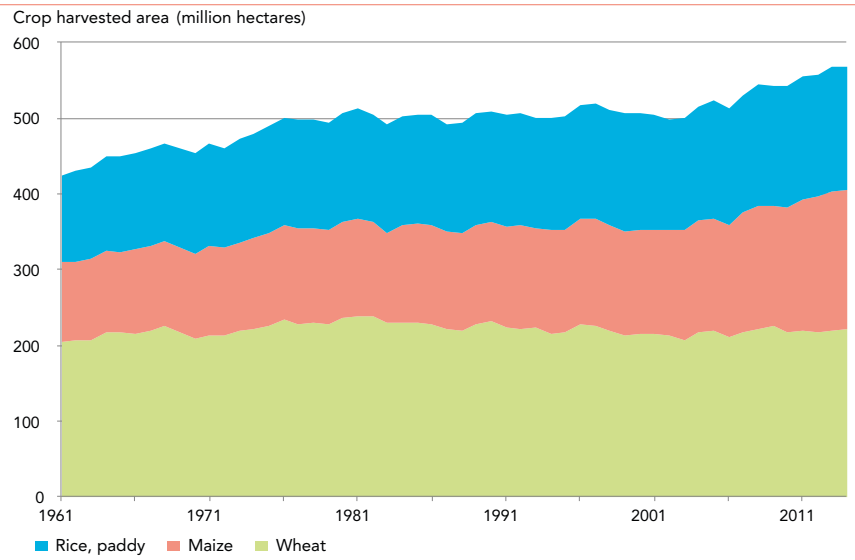
Figure 19 Yield gaps for wheat, maize and rice combined for the year 2000



Source: (PBL, 2012)

Over the last 40 years, increases in crop yields have greatly contributed to crop production growth and have in many cases probably prevented large-scale land conversion. However, (Grassini *et al.*, 2013) have demonstrated that this period includes two separate phases, one with a modest increase in harvested area for rice, wheat and maize in the period of 1980–2000 (see Figure 20) at 1.6 million ha per year, and another one with an annual increase of 9.8 million ha per year over the period of 2002-2011. The authors link this stronger increase to the observation that the yields of wheat and rice in particular reached a plateau in major production areas as East Asia for rice and Northwest Europe and India for wheat.

Figure 20 Trends in total harvested area of staple crops and three major cereal crops



Source: (FAO, 2015a)

Unsustainable use of land: soil and land degradation are taking place in many areas

Soil degradation is defined as a change in the soil health status resulting in a diminished capacity of the ecosystem to provide goods and services[33]. Land degradation has a wider scope than both soil erosion and soil degradation in that it covers all negative changes in the capacity of the ecosystem to provide goods and services (id). Forms of land degradation are soil erosion (by wind or water), chemical (contamination and nutrient depletion) and physical degradation (soil compaction). Based on the global assessment of Oldeman et al. (1991) (GLASOD), (Middleton & Thomas, 1997) estimate that about 7 million km^2 of grassland and about 5.5 million km^2 of cropland are degraded. This means that about 25% of the global agricultural land (50 million km^2) is degraded. Accelerated soil degradation has reportedly affected as much as 500 million hectares (Mha) in the tropics, and globally 33% of earth's land surface is affected by some type of soil degradation (FAO, 2015b). (Wood *et al.*, 2000b) concluded that over 40% of agricultural land has been moderately degraded, and another 9% strongly or extremely degraded since the mid-1990s. (Bai *et al.*, 2008) found that around 22% of agricultural land has been degraded since around 2005. Estimates of the scale of land degradation vary considerably so that accurate numbers are hard to provide. According to FAO, an estimated 33% of soils is moderately to highly degraded due to erosion, nutrient depletion, acidification, salinization, compaction and chemical pollution (FAO, 2015b). It is disconcerting that we know so little about one of the most important resources for humankind. An underlying issue for this uncertainty is the fact that there is no consensus between different disciplines (economists, agronomists) of what land degradation actually means and what is consequences are (Eswaran *et al.*, 2001).

Land and soil restoration can improve their quality and productivity. Over the last decades, restoration projects have been successfully carried out (see Box 9). Many countries have regulations in place to prevent land degradation, for example by prescribing certain measures such as counter ploughing, wind breaks and cover crops. This certainly has led to less land degradation. Certain forms of soil degradation, such as soil compaction, are more difficult to regulate.

Projected land use

In order to meet the growing global food and feed demand (see Chapter 4), but certainly also due to more local developments (Lambin *et al.*, 2001), the total crop area is still growing, especially in South America, East and West Africa, and South and Southeast Asia (Grassini *et al.*, 2013). At the global level, yield increases are estimated to contribute 90% to the growth in crop production that is expected until 2050; for developing countries this figure is around 80% while for developed countries it is almost 100% (FAO, 2012b). This implies that 20% of crop production increases in the developing world will come from cropland expansion. This expansion is often at the expense of natural areas such as forests, wetlands and rangelands. The largely policy-driven increase in demand for biofuel and bio-energy creates an additional demand for croplands (UNEP, 2014). In addition to the net expansion of cropland, there is also a gross expansion of cropland as a consequence of growth of urban areas and soil degradation (UNEP, 2014). This important effect is usually not taken into account in land use projections. Under business-as-usual conditions the net expansion of cropland will range from around 120 to 500 Mha between 2005 and 2050, while the gross expansion of cropland might be in the range of 320 to 850 Mha (UNEP, 2014).

There is much debate and uncertainty on how much cropland (and pastures) will be needed in the future, as well as how much and where additional land suitable for agriculture is actually available (Chamberlin *et al.*, 2014, Deininger & Byerlee, 2011, Lambin *et al.*, 2013, Schmitz *et al.*, 2014). How much additional cropland is needed depends in theory on three determinants: the total demand for agricultural products (food, feed, fuel and fibers), the increase of crop yields

33. http://www.fao.org/soils-portal/soil-degradation-restoration/en/

on existing land and the initial crop yields on the new land. However, local factors such as population density and the socioeconomic context also play an important role. According to (Lambin *et al.*, 2001), land cover changes are driven by peoples' responses to economic opportunities, as mediated by institutional factors in an increasingly globalized world.

5.2.3 Consequences of unsustainable or inefficient land use

Unless current agricultural land is used more efficiently, population growth and an increased demand for food, feed and biofuels are likely to lead to cropland expansion, resulting in the additional conversion of natural vegetation and consequent loss of biodiversity and ecosystem services.

Land degradation could exacerbate this problem, as it typically leads to lower crop yields, and consequently to a demand for more new croplands, as well as to a lower efficiency of other inputs. Soil erosion can cause serious problems downstream, such as flooding and sedimentation. Land degradation also affects livelihoods. Many people are facing a downward spiral of land degradation, falling yields and the lack of means to invest in land quality improvements (Tittonell & Giller, 2013). Over 40% of the very poor live in degraded areas (Conway, 2012).

Unsustainable land management has large implications for future crop yields and related food production, as following generations will also crucially depend on productive land. The sustainability of land use should therefore be assessed at a timescale of hundreds (or even thousands) of years.

5.3 Water

5.3.1 Water and food systems

Fresh water of good quality is essential for humans, as well as for crop and livestock production, and for land-based aquaculture. In the rest of the food system, water is also needed for activities such as food processing, preparation and waste disposal. However, because of the dominance of agriculture in food systems' total water use, this section will focus on that aspect.

Vast amounts of water are needed for food production. It is estimated that the daily average per capita water use for food production is nearly 4 000 litres (Hoekstra & Mekonnen, 2012). Rain-fed agriculture depends on 'green' water, whereas irrigated agricultural depends on a combination of 'green' and 'blue' water[34]. Irrigated agriculture currently accounts for 70% of the total global 'blue' water withdrawals. In richer countries, this is around 42–44%, mainly because water use in other sectors is higher (OECD, 2010). Around 18% of the global crop area is irrigated, while this produces about 40% of the total crop production (Gleick *et al.*, 2002, MA, 2005a). In many areas, water is the main limiting factor to increase crop production. A good and reliable supply of water to the plant (either by rainwater or through irrigation) is thus key in enhancing the overall resource efficiency of agriculture.

Water as a natural resource has a number of important characteristics that makes it different from other natural resources:

- Water is not actually used, but evaporates and becomes part of the larger water cycle.
- The availability of water is highly localized. An excess of water in one region cannot easily be transported to regions with water shortages. Currently, around one third of the global population is living in countries suffering from a medium to high water stress (OECD, 2012).
- In many regions, the presence of sufficient water for crop growth is uncertain, as the quantity and timing of rainfall is uncertain.

34. Green water is water stored in the soil or temporarily on top of the soil or vegetation. Blue water refers to fresh surface and groundwater, in other words, the water in freshwater lakes, rivers and aquifers: http://www.waterfootprint.org/?page=files/Glossary.

- Access to irrigation water is often regulated, as many farmers as well as other users compete over its use.
- Water is in principle a renewable resource. In certain regions, however, water is being used from aquifers that contain 'old' water, which can be hundreds of years old. This will finally lead to depletion of these aquifers; in this case water can be considered a non-renewable resource.

Globally, there are large regions with irrigated agriculture where crop production is under stress due to irrigation water shortage (Figure 21). The irrigated area has doubled over the last 50 years, mainly due to its large increase in Asia, where it led to a rapid growth in crop production. In order to improve a reliable supply of surface water for irrigation, dams have been constructed in many rivers, and local reservoirs have been built for the temporary storage of water. In some regions the use of groundwater sources for irrigation has intensified, largely driven by subsidies on electricity or diesel for pumping. The share of irrigated cropland area is currently small in Africa and South America, where there is certainly scope for expansion of the irrigated area.

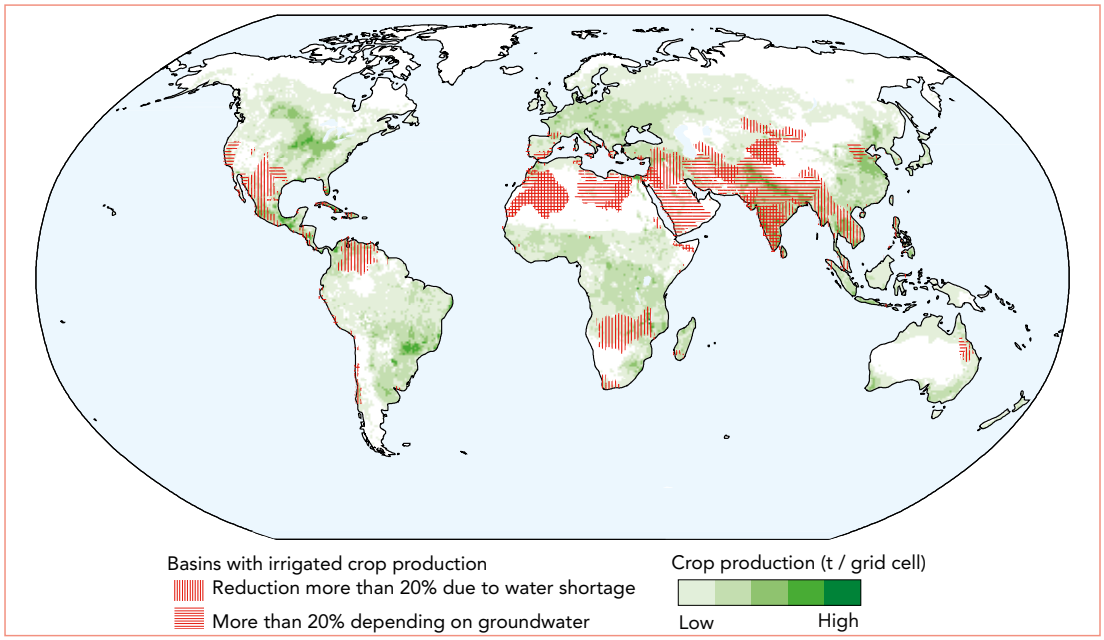
5.3.2 Is current and projected water use efficient and sustainable?

As with other resources, both an efficient and sustainable use of water is important. An *efficient* use of water refers to the ratio between the useful output (for example crop yield) and the total water use. A *sustainable* use refers in the case of groundwater wells to a situation of no depletion of aquifers, or in the case of surface waters to no large-scale pollution or disturbance of watersheds.

Sustainable use of water

The current levels of water use for irrigation are unsustainable in many cases. The current use of surface water has various negative environmental impacts, both on terrestrial and aquatic ecosystems. Farmers as well as regional and national authorities have carried out many interventions to enhance water availability. These interventions include damming of rivers, changing flow regimes, lowering the groundwater table and the draining of wetlands (De Fraiture *et al.*, 2014). Even though many interventions are quite small, their cumulative effect on a river basin can be substantial, leading to a changing water regime, often with large consequences for biodiversity, the local climate and people living downstream.

Figure 21 Regions vulnerable to crop production losses due to irrigation water shortages



Source: (Biemans, 2012)

In addition to surface water, *groundwater* is another water source for irrigation (see Box 4). Water is sometimes pumped from layers that are located very deep below the surface. Some of these water reserves have existed for hundreds of years. At least 20% of the world's groundwater aquifers are considered to be overexploited (Gleeson *et al.*, 2012). This leads to a lowering of groundwater tables, resulting in increased pumping costs, and lower availability of irrigation and drinking water. Especially in Asia (e.g. Upper Ganges) and North America (California), many large aquifers that are critical to agriculture are overexploited (Gleeson *et al.*, 2012).

Water-use efficiency

The water-use efficiency can be defined in several ways. The more narrow definition, widely used in irrigation is the (dimensionless) ratio between water arriving at plant level and the amount of extracted water (HLPE, 2015, WWAP, 2015). The broader definition also assess the water productivity: how much crop (or value) is being produced per volume of water applied (HLPE, 2015, WWAP, 2015). Hence, water productivity is closely related to the efficiency of other resources such as the quality of land and management practices.

In many regions the water-use efficiency (in terms of the narrow definition) is currently low (Molden, 2007, OECD, 2008) as a result of current practices of direct or indirect subsidies, as well as distribution mechanisms. Losses of 50% of water are common. In many countries relatively inefficient techniques are still being used, such as flooding or high pressure rain gun technologies, which use considerably greater quantities of water than low pressure sprinklers and drip irrigation techniques (OECD, 2008). In irrigated agriculture, water losses can already occur before the water has even reached the crop roots, for example through leakage in channels, direct evaporation during irrigation, foliar interception by under-canopy, transpiration by weeds or run-off and percolation losses caused by over-irrigation. Not all "lost" water from irrigations system is completely lost, as it often still returns to useful water flows and can be reused further downstream (HLPE, 2015).

Also in terms of the broader definition (including water productivity) large inefficiencies occur, for example due to pests, low soil fertility, unsuitable varieties or wrong timing of irrigation. A comprehensive global overview of current water efficiency in agriculture and along the food chain is however lacking.

Future use

According to the OECD Environmental Outlook, agricultural water use is projected to diminish slightly in spite of increased production (OECD, 2012). In certain regions, however, climate change will lead to lower or more unpredictable rainfall, thus increasing the need for irrigation. In addition, water use in other sectors (e.g. manufacturing and private household use) is projected to increase sharply due to population growth, increasing prosperity and urbanization. The number of people living in severely water-stressed river basins is projected to increase from 1.6 billion in 2000 to 3.9 billion by 2050, or over 40% of the world population of 2050 (OECD, 2012).

Climate change is expected to have a large effect on the availability of water in many regions, by affecting precipitation, runoff, hydrological flows, water quality, water temperature and groundwater recharge (HLPE, 2015). Due to reduced precipitation or increased evapotranspiration, droughts may intensify in some seasons and areas (idem). Without mitigation measures, this might lead to reduced crop productivity in certain regions (IPCC, 2014b). Climate change will also lead to sea level rise, which may lead to flooding of fertile coastal regions, as well as to salinization of freshwater resources in coastal areas.

5.3.3 Consequences of inefficient or unsustainable water use

Inefficient water use can have several negative consequences, such as a more rapid depletion of non-renewable water resources, lower crop yields than potentially possible or lower water availability for farmers, other users and downstream ecosystems.

Unsustainable water use will cause depletion of aquifers, which will mean that future generations

cannot profit from this source. Disturbance of watersheds, due to interventions in water systems, can negatively impact ecosystems and other human water uses. Salinization of soils is a major risk in many irrigated systems.

5.4 Minerals (nutrients)

5.4.1 Nutrients and food systems

Nutrients such as phosphorus, potassium, calcium and magnesium are not only essential for crop and livestock production, they are also essential for humans. The terms 'minerals' and 'nutrients' are partially overlapping: when it refers to their origin (mainly from mines) or chemical state, the term minerals is commonly used, whereas the term nutrients is more related to their use and function in plant production. The term nutrients as used in human nutrition compromises more than minerals.

Limited availability of one or more minerals in agricultural soils leads to lower crop yields or lower livestock production. In case of some nutrients it can also lead to low concentrations in food (e.g. iodine, selenium and zinc), with negative consequences for human health. Globally, soils vary largely in terms of the quantity of minerals they naturally contain. Weathered tropical soils are generally poor in minerals, while recent sediments (from rivers, seas, or volcanic) are typically rich. For crop production, the bio-availability of nutrients is the key characteristic, not the total nutrient content of soils. Some soils for example are phosphate fixating, thus limiting the availability for plants. Also the soil pH has a large influence on the availability of nutrients. Certain microorganisms can enhance the bio-availability of nutrients, for example in the case of fungi in mycorrhiza. In case of limited supply, minerals can be added in food systems, either as fertilizer; and/or as feed or food additive; and/or can be directly consumed by humans (such as iron).

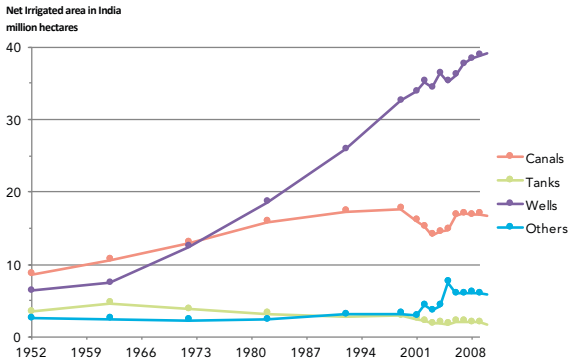
While in crop production the attention is usually focused on nitrogen and phosphorus, there are actually around 16 essential minerals for plants and humans combined (Table 6). Except for nitrogen, all minerals are mined. Nitrogen is not a mineral. It can be fixed from the air, either by biological nitrogen fixation (BNF) or by means of chemical fixation. This last process requires the input of fossil fuels. It is estimated that in 2005, globally about 120 Tg of nitrogen was fixed in the form of synthetic fertilizers, while BNF accounted for around 60 Tg per year (Sutton *et al.*, 2013). In traditional subsistence agriculture, people largely depend on the natural availability of minerals in soils. In order to boost crop yields, the use of mineral fertilizer has increased strongly over the past 50 years (Figure 23), especially in Asia, North America and Europe.

The global share of mined minerals used by food systems varies significantly from one nutrient

Box 4 Rapid growth of groundwater irrigation in India

Groundwater is a critical resource in India, accounting for over 60% of irrigation water and 85% of drinking water supplies. Although large investments in surface water irrigation projects were undertaken in the past, many farmers did not have good access. Due to various factors (including energy subsidies and the availability of small pumping equipment), many farmers opted for groundwater irrigation. As a result, groundwater is now the predominant source of water supply for irrigation in India (Figure B.2). The pressure on groundwater resources has continued to grow as, over the last 40 years, 84% of the total addition to net irrigated areas has come from groundwater (World Bank, 2010). The Upper Ganges aquifer in North-West India and Pakistan now has the largest groundwater footprint, meaning that more groundwater is being used than replenished (Gleeson *et al.*, 2012).

Figure B.2 Evolution of canal, tank and well irrigation in India 1950-2000



Source: (CWC/MWR, 2002)

to another (Table 6). Food systems (notably agriculture) are the dominant user of a number of macronutrients (P, K, S). Furthermore, around 10% of the total global use of the micronutrients boron and selenium takes place within food systems, whereas for many other elements the share of food systems in the total use is marginal. It is hard to assess whether and when certain minerals will become 'scarce' in the future. Based on current known reserves and current consumption, reserves seem to be adequate for 50-500 years, but this will also depend on future consumption and potential new reserves.

Deficiencies of macro and micronutrients in human nutrition can have severe effects on human health. For some elements, as iron and protein (source of amino acids, phosphorus and sulphur), deficiencies are largely related to dietary composition (e.g. low intake of meat and vegetables). For other elements (e.g. zinc and selenium) concentrations in food products can vary significantly depending on concentrations in the soil.

Figure 22 shows in a stylized form the flow of minerals in food systems, including the various issues concerning resource efficiency and environmental impacts. Many situations and issues are combined in this diagram; they do not occur for *all* minerals in *all* food systems. In many high-intensity food systems, the flow starts with the input of minerals through fertilizers[35], which are taken up by crops, which are then processed or used as feed. Livestock typically only retain 10–30% of the minerals consumed; the rest are excreted in the form of manure (and urine). Part of these minerals in manure are reused, another part is lost; the amount depends in part on the manure management. Crop and livestock products are transported from the farm and usually undergo one or more processing steps. In the case of meat production in particular, a large quantity of nutrients is retained in offal and bones. The minerals are consumed by humans and excreted. The largest part of these minerals end up in sewage systems or landfills and are transported to rivers and seas, often causing pollution issues (Bouwman *et al.*, 2013b, Morée *et al.*, 2013, Seitzinger *et al.*, 2010, Sutton *et al.*, 2013).

Table 6. Essential minerals (nutrients) needed in the food system, for crop and animal production as well as for humans

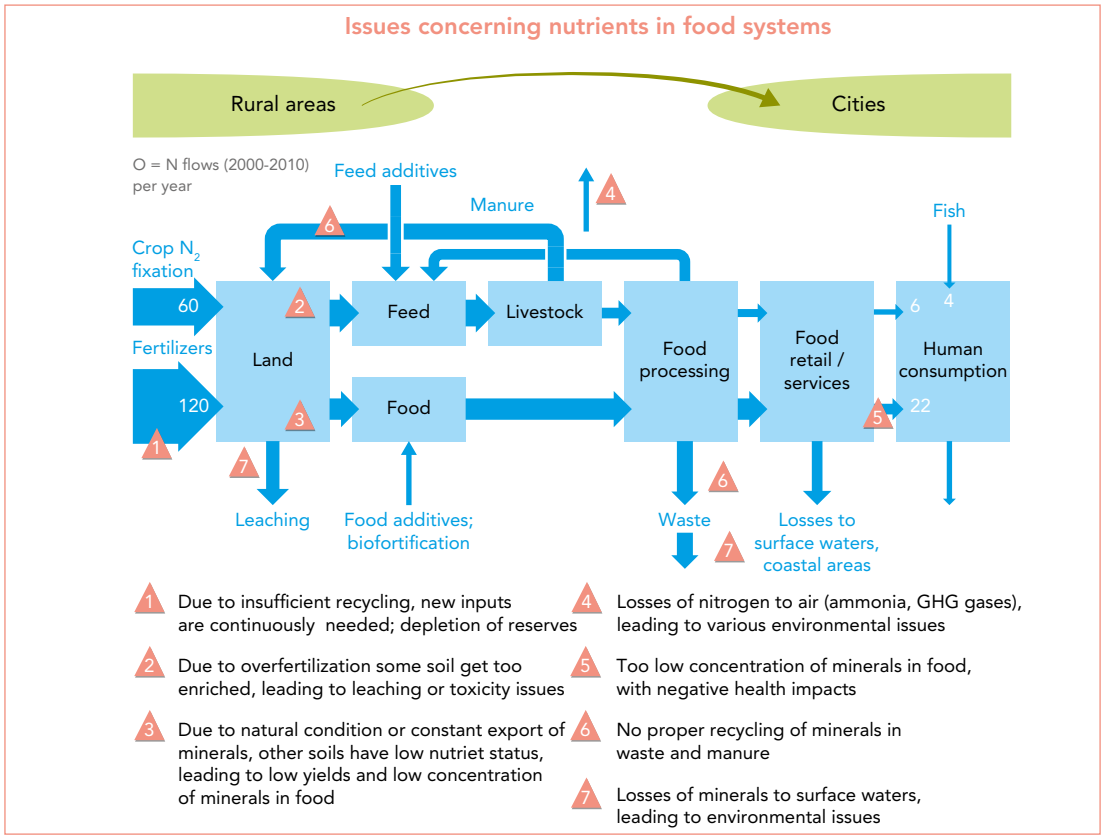
		Estimated share of agriculture or food in use	Deficiency issues in food reported	Toxicity / environmental issues
Macronutrients				
N[1]	Nitrogen	> 80%?	Protein related	Yes
P	Phosphorus	> 90%	Yes	Yes
K	Potassium	~ 85%	Yes	No
S[2]	Sulphur	~ 60%	Protein related	No?
Mg	Magnesium	< 10%	Yes	No
Ca[3]	Calcium	< 10%	Yes	No
Micronutrients				
Fe	Iron	< 1%	Yes	No
Zn	Zinc	~ 2%	Yes	Yes
Cu	Copper	< 1%	?	Yes
Mo	Molybdenum	< 1%	?	Yes
Mn	Manganese	< 1%	No	No
B	Boron	~12%	Yes?	?
Ni	Nickel		?	Yes
Essential for humans/animals				
Se	Selenium	~10%	Yes	Yes
I	Iodine	< 1%?	Yes	
Co	Cobalt	< 1%?	Yes (B12)	

Source: (USGS, 2013)

[1] This is not a mineral in the strict sense
[2] Sulphur is often not applied as nutrient, but as sulphuric acid being used to react with rock phosphate in order to increase the phosphorus availability for plants.
[3] Lime usually contains significant amounts of calcium and magnesium, but soil liming is carried out to increase the soil pH (decrease soil acidity), generally not to provide calcium. In cases, magnesium-rich lime is used to provide additional magnesium.

35. Nitrogen can also be fixed from the air by leguminous crops such as soy bean, clovers, etc. Nitrogen is different from the other nutrients in many respects.

Figure 22 Nutrient flows in food systems and various impacts



Source: Adapted from (Sutton *et al.*, 2013)

5.4.2 Is the current and projected use of minerals efficient?

As minerals are actually transferred from a fertilizer factory, via the field to the fork, the overall nutrient efficiency of the food chain can be calculated (see Chapter 2). The global average nutrient efficiency for nitrogen and phosphorus is only around 15 - 20% (Cordell *et al.*, 2009, Sutton *et al.*, 2013). This is a global average of two contrasting, but both unsustainable, situations: in the case of soil depletion this percentage is higher, whereas in heavily fertilized areas this percentage is lower. In many traditional food systems, the soil nutrient status is already low and the exported or lost minerals are not replenished, leading to low crop yields. Fertilizer use in Sub-Saharan Africa is currently very low at around 8 kg/ha (harvested area), both compared to other regions and compared to nutrient exports by crops. In many modern and intermediate food systems, fertilizer input per hectare is high, with low food chain nutrient efficiencies. For example, in China the whole food chain efficiency was only 9% for N and 7% for P in 2005 (Ma et al., 2010) (see Box 5: Case study of China).

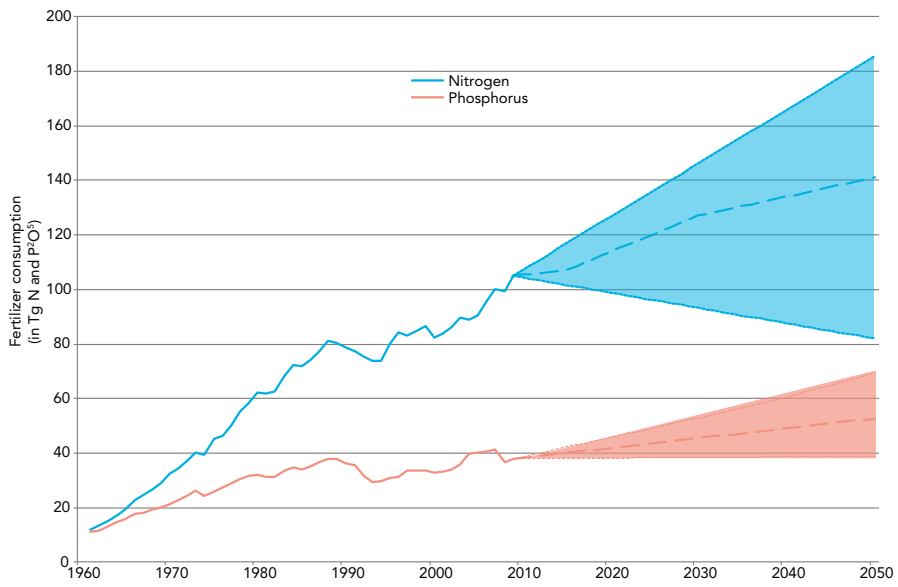
Flow of minerals from rural to urban areas

Most modern and intermediate food systems are characterized by a linear flow of minerals from rural areas to urban areas. Globally, an estimated 4% of urban N and P flows were recycled back to agriculture in 2000 (Morée *et al.*, 2013), whereas most of the minerals ended up in sewage systems (and finally rivers and coastal waters) or landfills. Significant amounts of minerals are also lost between fertilization and human consumption, due to the over-fertilization of crops, concentration of livestock production in certain regions with poor reuse of minerals in manure, and food processing. For example, in some processes, nutrient-rich proteins are separated from carbohydrates and only the latter used (e.g. beer brewing and sugar production).

Use of fertilizers is projected to increase

The issues concerning minerals are expected to aggravate due to population increase, urbanization (see Chapter 4, meaning larger flows of minerals to cities) and increased livestock production (Bouwman *et al.*, 2009, Bouwman *et al.*, 2013b, Neset & Cordell, 2012, Sutton *et al.*, 2013). According to most projections, the global fertilizer consumption will increase (Figure 23) in order to facilitate a growing crop production. (FAO, 2012b) estimate an increase in total fertilizer consumption (N+P+K) from 166 million tonnes in 2006 to 263 million tonnes in 2050. Fertilizer use is especially projected to increase in Sub-Saharan Africa, South Asia and Latin America. Regions with currently high fertilizer application rates (East Asia, many of the OECD countries) are not expected to experience an increase. The increased fertilizer use and manure production, related to the larger livestock production (Chapter 4) is expected to lead to larger nitrogen and phosphorus surpluses and thus to higher losses to the environment (Bouwman *et al.*, 2009).

Figure 23 Trends and projections in global consumption of nitrogen and phosphorus fertilizer



Source: (Sutton *et al.*, 2013)

5.4.3 What are the consequences of an inefficient use of minerals?

The current inefficient use of minerals (nutrients), as well as nutrient deficiencies in soils, leads to a number of serious issues:

- A low nutrient status in soils generally leads to low crop yields. The low nutrient availability (not only of N, P and K, but also of micronutrients) is one of the main causes of yield gaps. Due to an ongoing flow of minerals from rural areas to cities, this issue is expected to aggravate.
- For some minerals (zinc, selenium), insufficient concentrations also lead to quality deficiencies in crops, which can lead to health problems for animals and humans. An estimated 17.3% of the world's population is at risk of inadequate zinc intake, with higher risks in Sub-Saharan Africa, India and Indonesia (Wessells & Brown, 2012).
- The low farm-to-fork efficiency in most food systems implies that 'fresh' minerals are constantly needed as fertilizer to maintain current levels of crop production. This leads to a rapid depletion of current stocks of a number of minerals (P, K, Zn and Se for example). In the case of nitrogen, it means that significant amounts of fossil fuels are needed to produce fertilizer.

- The low efficiencies also imply that there are large losses of nutrients to the environment, and an accumulation of certain minerals (e.g. copper and zinc), leading to soil and food quality issues. Losses of ammonia (nitrogen) to the air lead to the disturbance of terrestrial ecosystems. Losses of nitrogen and phosphorus lead to the eutrophication of surface and coastal waters, which can lead to the large-scale disturbance of marine ecosystems, with consequences for food production from marine sources.

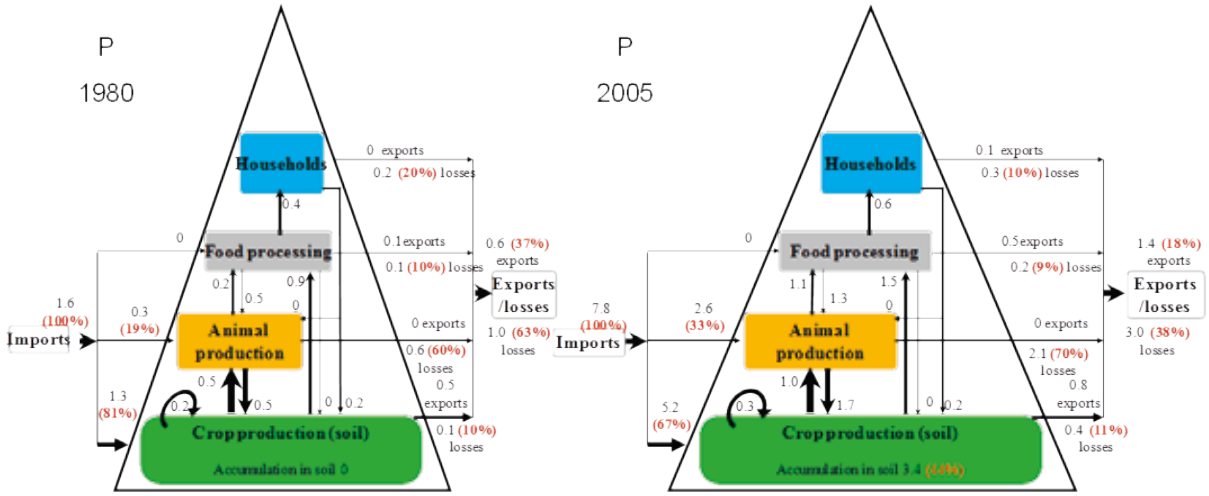
Box 5 Case study of China

China currently feeds 22% of the global population using only 9% of the world's arable land. Population increases and dietary changes are expected to result in an 80% increase of China's demand for animal-derived food by 2030. National grain production has increased from around 100 to 500 million tonnes due to the introduction of high-productivity varieties, irrigation and the increased use of mineral fertilizers.

Ma et al. (2010) modelled annual nitrogen (N) and phosphorus (P) flows in the food chain for China's 31 provinces. The food chain is assessed in four compartments: soil and crop production, animal production, food processing and households (human diet). Total inputs of 'new' N and P into the food chain in 2005 were 48.8 and 7.8 Tg, respectively (see Figure B.3 for data flows on P). Only 4.4 Tg N and 0.6 Tg P reached households as food. Total N losses to water and atmosphere almost tripled between 1980 (14.3 Tg) and 2005 (42.8 Tg). Estimated P losses to water systems increased from 0.5 Tg in 1980 to 3.0 Tg in 2005. In the whole food chain the efficiency decreased from 16% to 9% for N and from 19% to 7% for P between 1980 and 2005 (Ma *et al.*, 2010). The main reasons for the decreasing nitrogen and phosphate use efficiencies in the food chain are (i) changes towards a diet with more animal-derived protein, (ii) over-fertilization in crop production, and (iii) the decoupling of crop and animal production, which has led to less recycling of manure nutrients.

Various promising nutrient management concepts and technologies have been developed and tested in research, especially in crop production. Adoption of these concepts and technologies in practice is however still negligible. Key actions include (1) nutrient management in the whole food chain (2) improved animal waste management, based on coupled animal production and crop production systems, and (3) much greater emphasis on technology transfer from science to practice, through education, training, demonstration and extension services.

Figure B.3 Flows of N and P in the food pyramid in China at national level in 1980 and 2005



Source: (Ma *et al.*, 2010)

5.5 Biodiversity and ecosystem services

5.5.1 The relevance of biodiversity and ecosystem services for food systems

Biodiversity and ecosystem services are crucial natural resources for primary food production in all its forms: agriculture, aquaculture, fisheries, hunting and gathering (Le Roux *et al.*, 2008, MA, 2005b). The first essential step for all food production is primary production by plants, mainly in the form of crops, semi-natural vegetation (grasslands) and algae (fisheries). Agro-ecosystems are both providers and consumers of ecosystem services. Besides depending on biodiversity and ecosystem services, food systems also put major pressures on biodiversity and ecosystem services. As a consequence, food systems affect the functioning of ecosystem services and biodiversity at large: it is estimated that around 60% of all global loss of terrestrial biodiversity is related to the food sector (PBL, 2014a).

Biodiversity is generally defined as the variety and variability of animals, plants and microorganisms at the genetic, species and ecosystem levels. This variety is necessary to sustain key functions of ecosystems, their structure and processes. Ecosystem services are defined as benefits people obtain from ecosystems. The Millennium Ecosystems Assessment divides ecosystem services into four categories: provisioning services (such as food via hunting, agriculture or fisheries), regulating services (such as pest control), cultural services (for example cultural, recreational and spiritual) and supporting services (for example nutrient recycling), which forms the basis for the services of the other three categories (MA, 2005b). The definition of ecosystem services points only to the benefits, however one should be aware that nature can also provide disservices for crop and livestock production, for example grazing by flocks of geese, locust plagues or food raiding by apes (Ango *et al.*, 2014). As for the other resources, the key question is whether biodiversity and ecosystem services are currently managed sustainably and efficiently. Genetic resources for crop and livestock production are an important aspect of biodiversity, which will be treated separately (Section 5.5.5), as will marine resources (Section 5.6).

Table 7 provides a more systematic overview of the benefits of regulating and supporting ecosystem services for various food system activities, as well as the impacts of food production on terrestrial and aquatic biodiversity. Ecosystem services are certainly not only relevant for agriculture; they are essential or at least important for all food system activities.

The dependence on ecosystem services appears to be most relevant for traditional food systems, which to a large extent still depend on these services for all food system activities. In many traditional food systems, a certain portion of food is still based on hunting and gathering, while cooking is done with fuel wood. The decomposition of crop and household residues (and related nutrient recycling) is dependent on bacteria, and agriculture still largely relies on ecosystem services for pest and disease control.

In modern food systems, a number of these services have been replaced by external inputs such as pesticides, fertilizers and fossil fuels for farm machinery and cooking. Even so, most high external input farmers still depend on ecosystem services such as pollination, biological pest and disease control and the regulation of soil structure and nutrient recycling (for example through the decomposition of plant residues). However, many farmers are not fully aware of their dependency on ecosystem services.

Table 7. Benefits from ecosystem services on various food system activities and impacts of these activities on terrestrial and aquatic biodiversity

Activity	Benefits from ecosystem services	Impact on terrestrial biodiversity and ecosystem services	Impact on aquatic biodiversity
Agriculture (croplands, rangelands) and livestock production	Seed and breeds provisioning Primary production Nutrient cycling Water cycling Regulation of water, air and soil quality Pest and disease control Pollination	Land use / removal of vegetation, encroachment, affecting both biodiversity as well as EGS (such as climate and water regulation). Nutrient losses (N, P, etc.) Emissions of pesticides, GHGs Contribution to climate change Infrastructure	Leaching of N, P, pesticides Water use / changes in water management Soil erosion and sedimentation Introduction of invasive species
Hunting, gathering and fishing	Primary production Water cycling Regulation of water, air and soil quality Pollination	Change of both plant and animal species composition, encroachment	Changes in species composition Introduction of invasive species
Aquaculture	Primary production Nutrient cycling Pest and disease control	Land use especially in coastal areas	Conversion of wetlands and coastal zones Introduction of invasive species Emission of nutrients (N, P, etc.)
Fisheries	Primary production Fish stocks		Changes in marine ecosystems and species composition
Food preparation	Yeasts and bacteria for food conservation and preparation Bio-energy (fuel wood)	Nutrient losses (N, P, etc.) Losses of organic substances GHG emissions	
Waste processing, sewage	Bacteria for decomposition Nutrient cycling Water cycling	Nutrient losses (N, P, etc.) GHG emissions	

Source: Adapted from (PBL, 2014a)

Food production affects biodiversity and ecosystem services in many ways (Table 7). It is estimated that food production is the main driver behind the significant loss of both terrestrial and aquatic biodiversity (PBL, 2014a). The main driver of terrestrial biodiversity loss is the huge amount of land needed for food production (PBL, 2010). The remaining level of biodiversity is particularly low on intensively managed arable land (due to removal of the original vegetation and introduction of monoculture practices), but even on semi-natural grasslands the biodiversity level is considerably lower than on natural grasslands (Alkemade *et al.*, 2012, Alkemade *et al.*, 2009). Terrestrial biodiversity is also negatively influenced by pesticide emissions, habitat fragmentation, nitrogen deposition and climate change (Alkemade *et al.*, 2009, Bobbink *et al.*, 2010), and food production contributes to each of these factors. It is estimated that in 2010 food production was responsible for around 60% of all terrestrial biodiversity loss (PBL, 2014a). Food production also has a negative impact on aquatic ecosystems through the leaching of nutrients (minerals) and pesticides (see Section 5.8).

5.5.2. Is the current and projected use of biodiversity and ecosystem services sustainable and efficient?

Agricultural systems are considerably more simplified than natural ecosystems. Even so, they are multifunctional and, in addition to the production of food, they provide a range of regulating, supporting and cultural ecosystem services (Pretty & Bharucha, 2014). The degree in which other ecosystems are provided differs widely between the various agricultural systems. In some regions, specific agro-ecosystems have developed with associated biodiversity, notably in regions that have been under cultivation for a long time. The use of biodiversity and ecosystem services is considered sustainable if

the provision of ecosystem services and other conservation values by an agro-ecosystem equals that of a system in the same environment and with the same level of agricultural output that is optimally managed for ecosystem co-benefits (Milder *et al.*, 2012). A first attempt to assess the potential supply of some current and future ecosystem services globally was made by (PBL, 2014a). Services such as pest control, pollination, erosion protection, wild food availability and the provisioning of water were, not surprisingly, found to be suboptimal and projected to decrease further, with the largest decrease for water provisioning. Carbon sequestration was projected to increase. As this assessment did not take into account agricultural productivity and there is currently no proper global or even regional monitoring system of the state of the various ecosystem services needed for food production (Cumming *et al.*, 2014), it is not possible to determine whether the current delivery of ecosystem services is *sustainable*. However, a number of threats can be identified:

- Overexploitation of provisioning services leading to the degradation of ecosystem services and production capacity such as overgrazing and fish stock depletion;
- Ongoing deforestation, drainage of wetland and removal of landscape elements, which will also impact certain ecosystem services such as pest control, water regulation and pollination;
- The (still) increasing share of monocultures, often based on crops with a narrow genetic base;
- Use of pesticides, antibiotics and other biocides that might disturb current ecosystems (including biodiversity in agricultural soils) and therefore the functioning of ecosystem services;
- Nutrient losses which may lead to large-scale changes in ecosystems, notably of wetlands, lakes and coastal seas, affecting for example fish stocks;
- Climate change which might impact the functioning of ecosystems and therefore the delivery of certain ecosystem services (IPCC, 2014b).

The pressure on biodiversity is expected to increase due to the projected increase in food production leading, among other things, to the expansion of crop areas and increased nutrient losses (PBL, 2014a).

Diversity is not only important for the proper functioning of ecosystems, diverse diets are also important for human health. It has been well established that less diverse diets not only present a risk in terms of nutritional quality due to a lack of vitamins and micronutrients, but that they also lead to higher risks in terms of the overconsumption of calories (Khoury *et al.*, 2014).

On the positive side, it can be noted that farmers and other land managers and actors (governments and the private sector) are starting to realise the importance of ecosystem services and therefore are more willing to invest in the protection and proper management of ecosystem services. Sometimes this results in payment schemes for the maintenance or enhancement of certain ecosystem services such as clean water and landscape elements. An initiative at global level is The Economics of Ecosystems and Biodiversity (TEEB) which draws attention to the economic value of biodiversity and growing costs of biodiversity loss and ecosystem degradation. Through various studies and country initiatives, TEEB aims to capture the economic values and benefits of ecosystems and biodiversity, and points out to ways in which decision makers could integrate their value into policies (TEEB, 2014). Data and other information to judge whether ecosystem services are currently used *efficiently* are also lacking. Potentially, farmers could in various ways rely much more on ecosystem services and less on external inputs such as fossil fuel, pesticides, and irrigation water, while simultaneously arriving at higher yields. Examples are biological pest control, better water infiltration and thus reduced need for irrigation through improved soil structure, reduced soil tillage as well as higher crop yields through better soil structure, as well as better pollination and water regulation at the landscape level. In many cases, the availability of relatively cheap external inputs (such as fossil fuels and pesticides) has reduced the need to rely on

ecosystem services. In terms of knowledge and technology, much innovation still seems possible to enhance the efficient and sustainable use of ecosystem services.

5.5.3 What are the consequences of inefficient and unsustainable use?

There are many important consequences of the current largely inefficient and unsustainable use of biodiversity and ecosystem services. A number of high-profile studies have highlighted and underpinned the importance of biodiversity and ecosystem services for food production, as well as society as a whole, such as the Millennium Ecosystem Assessment (MA, 2005b), the TEEB approach (TEEB, 2010) and other UNEP publications (UNEP, 2012). Without being exhaustive, a number of essential consequences of inefficient and unsustainable use are:

- Loss of resilience of agro-ecosystems, which lowers the capacity of these systems to cope with shocks such as climatic events and certain pests and diseases, resulting in lower crop yields;
- Lower delivery of certain ecosystem services, such as pollination, (resulting in lower crop yields, especially for crops supplying essential nutrients such as vitamins A and C, folic acid and iron (Eilers et al., 2011));and fuel wood (leading to higher fossil fuel input);
- Higher need for certain inputs such as pesticides and nutrients, replacing ecosystem services;
- Lower regeneration of fish stocks, leading to lower fish catches.

5.6 Genetic resources

Genetic resources are an important aspect of agro-biodiversity, including aquaculture[36]. Over the last century, plant and animal breeding have been professionalized and are now largely practiced by private companies and public research institutes. In developing countries, the 'informal' seed sector is still important. The general aim of breeding is to increase the production of useable products (such as eggs, meat, milk, wool, grains, fruits and nuts), with the desired quality (taste, nutritional composition and storage), while minimizing the use of resources (land, water, and nutrients) and in some cases co-generating ecosystem services. This can be achieved in various ways: by selecting high-yielding plant varieties, by increasing the tolerance to certain environmental pressures (salinity, extreme temperature and drought), and by increasing the resistance to viruses and fungi or the tolerance to insect pests. High-yielding varieties typically require optimal conditions to produce well, and these varieties generally perform less well under harsh conditions. For farm animals, aspects such as high growth rates, high productivity (or high feed conversion rates), longevity (for dairy cows, sheep, goats and laying hens) and behavior are important criteria. Due to plant and animal breeding, substantial progress has been made over the last 50 years in terms of yields per hectare, feed conversion, growth rates and productivity (milk, eggs), although in some cases this has been at the expenses of robustness (to disease and adverse climatic conditions) and animal welfare (Dawkins & Layton, 2012). For farmers, not only the genetic potential of seeds is important, but also the general quality in terms of absence of disease, moisture content, physical purity, genetic purity, vitality and germination.

Plant breeding started by selecting food plants (or animals) with desired characteristics. About 100 years ago, plant breeding became based on deliberate pollination. An important development was the introduction of hybrid seeds, based on the principle of heterosis. This means that a specific cross can outperform both parents. Maize was the first species in which heterosis was widely used to produce hybrids. A disadvantage of hybrid seeds for farmers is that they have to buy

36. Genetic resources as discussed here refer to plant and animals as directly used for agricultural production. Other genetic resources such as soil biodiversity, pollinators and pests are implicitly included in the previous section on Biodiversity and ecosystem services.

new seeds every year. After 1950, other breeding techniques were introduced, such as plant tissue culture and techniques (based on certain chemicals or radiation) to generate mutants. A relatively new technique is marker-assisted selection, which is used for quick selection on certain properties. Genetic engineering (also called genetic modification) is another recent, but contested technique (see Box 6 Genetically-modified crops).

The above-mentioned progress in performance has created some risks: in plants, but perhaps even more relevant for animals, the trend towards genetic uniformity has narrowed the genetic base and hence the susceptibility to certain diseases or pests and the ability to perform under diverse conditions. (FAO, 2015c) report that 'traditional production systems that harbor diverse genetic resources have been marginalized and a narrow range of international transboundary breeds have become more widely used'.

Animal welfare is in some cases affected, for example in the case of high growth rates in broilers. In certain regions, imported seeds and breeds have replaced local varieties, thus reducing agro-biodiversity, but often also reducing the resilience as local breeds are generally better adapted to local conditions. In traditional food systems, farmers still largely use seeds from the informal sector, while in 'modern' food systems most seeds are provided by commercial firms.

The efforts of private actors concentrate on the improvement of commercially interesting crops often in combination with certain agro-ecological zones. The improvement of 'orphan' crops is often neglected, while these crops play an important role in regional food security. Examples are millet, many tubers (as yams) and local vegetables. This issue is addressed in the form of plant and animal breeding programs of public research institutes, such as the Consultative Group for International Agricultural Research (CGIAR) institutes and many national research institutes, as well as by specific initiatives such as the African Orphan Crops Consortium (AOCC). In many regions, a combination of formal and informal seed systems are important, as for example in Sub-Saharan Africa.

5.7 Marine and inland aquatic resources

5.7.1 Marine resources and food systems

The two principle ways in which food systems rely on marine and inland water resources are through capture fisheries and aquaculture. In 2010, these two sectors jointly accounted for 16.7% of global animal protein consumption, with 60% of the population acquiring over 15% of their protein intake from fish (FAO, 2014c, PBL, 2014a). Fish and seafood products account for 10% of global food-related trade, with an expected growth in demand for the coming decades (Garcia & Rosenberg, 2010). Of the total fishery production of around 160 million tonnes, 50% stems from marine fisheries and 7% from inland fisheries. Inland aquaculture provides another 27%, and marine aquaculture another 16% (see Box 3 on aquaculture). Fisheries, aquaculture and related industries are an important source of income: an estimated 660 to 820 million people (workers and their families) totally or partly depend on it (HLPE, 2014b).

Marine fisheries systems are highly heterogeneous, with large variations in gear, capacity, marine system targeted (e.g. pelagic versus demersal fisheries) and value chain in which they are embedded. Fisheries range from traditional, low-capacity, subsistence-based systems that operate on an exclusively local scale to fully industrialized fisheries that operate within a long and complex value network that covers large geographical distances. In some cases, these different systems compete with each other for resources. The annual contribution to the global economy of activities directly and indirectly related to capture fisheries is estimated at USD 380 billion (Dyck & Sumaila, 2009). The

marine fisheries sector currently supports 260 million jobs worldwide (Teh & Sumaila, 2013).

In contrast to global capture fisheries, which are stagnating (possibly due to unsustainable use, see below), the aquaculture sector is growing rapidly. With an average annual growth rate of 8.6% between 1980 and 2010, this is the fastest-growing food production sector (FAO, 2014c, PBL, 2014a). Most of the aquaculture sector is land-based. This section focuses exclusively on marine aquaculture.

5.7.2 Are marine resources used efficiently and sustainably?

Studies reveal that global fishing capacity has increased by an estimated ten-fold since the 1950s (Watson *et al.*, 2013), amongst others due to the introduction of super trawlers. Apart from the increase in fishing power, global fishing fleets have also expanded their reach. The development of industrial-scale diesel powered vessels with sophisticated locating equipment and refrigeration has enabled increasingly longer trips (Swartz *et al.*, 2010).

In spite of the increased fishing power and expansion of global fishing grounds, the average catch per unit of effort (expressed in terms of engine power) has decreased to half of what it was 50 years ago (Watson *et al.*, 2013). Globally, marine capture fisheries production has been stagnating since the late 1980s (Pauly *et al.*, 2005). This suggests that the increased fishing pressure has led to an increasing decline in fish abundance and a resulting decrease of the energy efficiency of the global fishing effort.

This finding is corroborated by the fact that, in 2011, 29% of the 'commercial' fish populations were estimated to be overexploited; a proportion which has been increasing since the 1970s, although the percentage dropped from 32.5% in 2008 (Figure 24). Another 61% of these populations are fully fished.

With a global demand for fish that is expected to increase from 140 million tonnes in 2004 to 227 million tonnes in 2050 under a business-as-usual scenario, capture fisheries will not be able to meet the future demand (PBL, 2010).

Box 6 Genetically-modified (GM) crops

New techniques ('biotechnology') have been developed over recent decades to improve genetic characteristics of crops and animals. These supplement traditional methods of crop and animal breeding. The application of genetically modified (GM) crops, a particular type of biotechnology, is controversial, with strong advocates both for and against it (see for example (Mannion & Morse, 2012)).

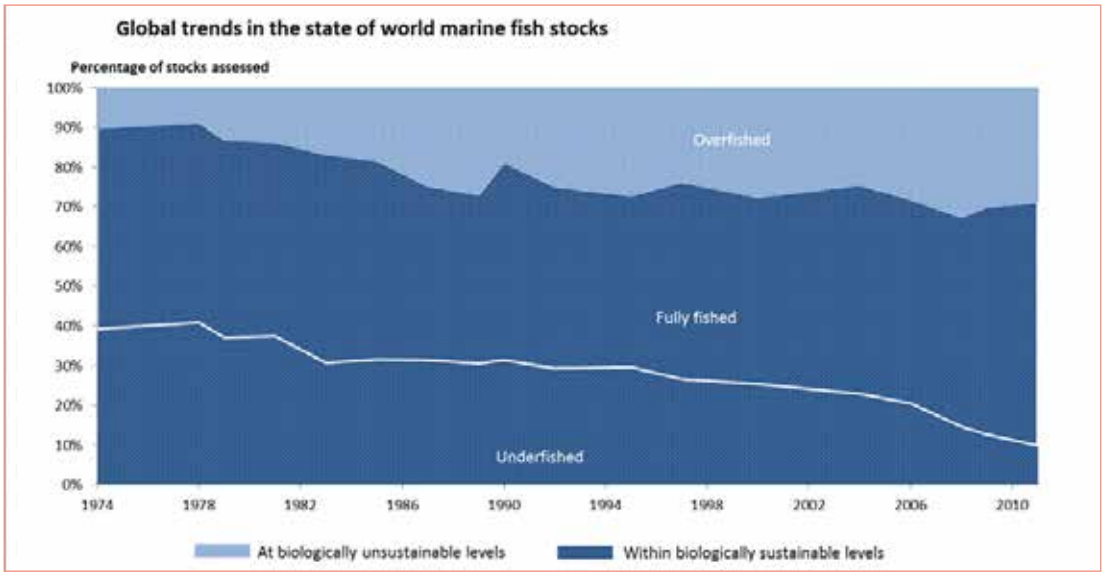
GM varieties with pest management traits (Bt traits) and herbicide tolerance (HT, sometimes called Roundup Ready) became commercially available for crops such as soy, corn and cotton from 1996 onwards (Fernandez-Cornejo *et al.*, 2014). Globally, around 170 million hectares (around 15% of the total global cropland area) were planted with GM crops in 2012 – mainly maize, cotton, soybean and rapeseed (Fernandez-Cornejo *et al.*, 2014). In some countries, the share of GM crops is more than 90% for crops such as soy, maize and cotton (as in the USA). In the USA more than half of the cropland area is planted with GM crops. In other regions (especially the EU) GM crops are hardly grown. This difference is mainly due to differences in legislation, as well as in the public acceptance of GM crops.

Advocates of the use and development of GM-crops point at current advantages such as higher crop yields (e.g. herbicide-tolerant crops), and savings in labor and agrochemicals (e.g. crops with Bt traits). They also point at potential new applications, such as drought tolerant crops, and crops that are resistant to certain diseases (Whitty *et al.*, 2013). Opponents of GM crops point to potential side effects on human health (e.g. possible allergies), ecological damage (due to the spread of GM genes to organic crops and wild relatives), the development of herbicide-resistant weeds, and the over-use of herbicides, impacting groundwater quality. Beside these biophysical reasons, critical questions are raised whether smallholder farmers would benefit from GM-crops (Azadi *et al.*, 2015, Jacobsen *et al.*, 2013). Opponents also state that the development of GM crops is done by a small number of companies, who make large profits on GM crops.

While GM crops are already widely used, some scientists doubt however whether they will really have improved stress tolerance (for example drought tolerance) or faster growth rates (e.g. improved photosynthetic efficiency) for two main reasons: first of all, natural selection has already tested more options than humans ever will. It is unlikely that 'nature will have missed simple, trade-off-free options' (Denison, 2012). Connected to this is the second argument: it is likely that the required modifications are highly complex, whereas in the current GM crops only one trait has been added.

While laying out some arguments for and against GM, this report takes a neutral position in the debate.

Figure 24 Status of fish stocks 1974–2011



Notes: Dark shading = within biologically sustainable levels; light shading = at biologically unsustainable levels. The light line divides the stocks within biologically sustainable levels into tow subcategories: fully fished (above the line) and underfished (below the line).
Source: (FAO, 2014c)

In addition to the expected inability of the current marine fisheries to supply the future demand, there are serious concerns about the effects of fisheries on marine biodiversity. Large predatory fish declined by 52% between 1970 and 2007 (Hutchings *et al.*, 2010). The overexploitation of fish stocks also leads to local endangerment and even extinction (Dulvy *et al.*, 2014). Currently, 550 species of fish are listed as vulnerable, endangered or critically endangered by IUCN.

Another issue concerning the efficiency of the global fisheries sector involves by-catch and discards. By-catch refers to fish that are caught unintentionally; these fish can either be landed or discarded. The discard is the proportion of a catch that is not landed but returned to the sea (mostly dead or dying) because it is not marketable, outside the allowed quota or under the minimum landing size. By-catch can also include marine macrofauna and iconic species such as dolphins and sea turtles (Wallace *et al.*, 2010). According to the FAO, recorded discards amounted to 6.8 million tonnes or 8% of the total recorded catch in the period 1992–2001. The Northeast Atlantic and the Northwest Pacific together account for 40% of discards, due to the high discard rates of many EU and some Japanese fisheries. Shrimp and demersal finfish trawl fisheries are the main contributors, with over 50% of total estimated discards and only 22% of the total catch (FAO, 2005).

The concerns about the sustainability of fishery practices could be alleviated by increased aquaculture production, and this has been suggested by many as a viable option. However, aquaculture comes with its own concerns.

Marine aquaculture operations are associated with a number of risks. The most important ones are introductions to local ecosystems (escapees, diseases, genetic material), resource exploitation for feeding (fish meal, overgrazing), nutrient losses due to fish droppings leading to eutrophication, contamination due to chemical/medicine use, loss of sensitive ecosystems (e.g. mangroves) and predator control. There are significant parallels with the issues about intensive livestock cultivation. Concerns regarding mariculture sustainability are highest in places where non-native species of a high trophic level are cultivated under intensive conditions for the export market (Trujilo, 2008).

In spite of these potential risks and concerns, aquaculture can also enhance local ecosystem productivity and contribute to biodiversity when managed properly (Chopin *et al.*, 2012, Drent

& Dekker, 2013, Saier, 2002). Together with the potential alleviation of the pressure on wild fisheries, this makes aquaculture a viable option for the sustainable use of marine resources.

5.7.3 What are the consequences of the inefficient and unsustainable use of marine resources?

The global decline of fish stocks is thought to have far-ranging negative impacts on the regulation of food web dynamics (Holmlund & Hammer, 1999, Jackson *et al.*, 2001, Pauly *et al.*, 1998). The removal of top predators can lead to a trophic cascade resulting in dramatic changes in species composition, in other words an increase in small pelagic fish and crustaceans resulting in a decrease in herbivorous zooplankton with a possibility of harmful phytoplankton blooms as a consequence.

Many demersal fisheries also directly damage coastal ecosystems. Bottom trawling is thought to have detrimental effects on some benthic habitats, although these effects are highly variable and dependent on the ecosystem type (Burke *et al.*, 2011, Waycott *et al.*, 2009). Furthermore, dynamite and poison fishing threaten an estimated 55% of coral reefs worldwide (Burke *et al.*, 2011).

The increasing fossil fuel requirements of fisheries due to the fishing efforts being located progressively further away from coastal areas causes concerns regarding greenhouse gas emissions and the sustainable use of resources other than the marine resources themselves. A general shift to fossil fuel intensive methods such as deep sea fishing and bottom trawling aggravates this concern. These effects could backfire on the availability of marine resources, as their supply is thought to be highly sensitive to increased emissions and the effects of global climate change (PBL, 2014a).

Many OECD and other countries have indirect fuel subsidies (mainly in the form of fuel tax concessions). The estimated total value of fuel tax concessions for OECD countries was in 2008 USD 2 billion (Martini, 2008). Fuel tax exemptions reduce the relative cost of fuel and thus will not encourage fishers to use less of it (OECD, 2005). This might have negative implications for marine resources and carbon dioxide emissions.

5.8 Fossil fuels

The use of fossil fuels in food systems is very diverse: from no or very limited use in traditional food systems, to use in all food system activities in modern food systems. Fossil fuel is a non-essential input for food production: humankind has survived for thousands of years without the use of fossil fuel. The use of fossil fuel in the primary production stage in particular has led to a vast reduction in human labor and caused an enormous rise in labor productivity. Notably ploughing, threshing and milling used to be very labor-demanding activities, and still are in many developing countries. Mainly due to the mechanization of these activities, labor productivity in agriculture and the production of basic food products (such as bread and milk) has increased by a factor of 100.

It is estimated that the food sector currently accounts for around 30% of the world's total end-use energy consumption, of which more than 70% is used beyond the farm gate (FAO, 2011a). Excluding human and animal power, the on-farm direct energy demand is around 6 EJ/yr. This energy is used for purposes such as pumping water, cultivating and harvesting crops, heating protected crops, and storage. Indirect energy demands total around 4 EJ/yr, while the synthesis of nitrogenous fertilizers consumes approximately 5% of the annual natural gas demand (around 5 EJ/yr). Fisheries consume around 2 EJ/yr. These figures illustrate how heavily dependent agriculture and fisheries currently are on the energy sector. Still, the largest part of fossil fuel use is in other food system activities, notably for the transport, cooling, processing and preparation of food.

5.9 Environmental impacts

The various food system activities have a large impact on the environment (Section 2.6), many of which are intrinsically related to the use of natural resources in food systems (see Figure 2). Major environmental impacts include:

- Impacts on terrestrial and aquatic biodiversity, mainly due to changes in land use and ecosystems (see Section 5.5 above), as well as impacts on air, soil and water quality.
- Impacts on water, air and soil quality, mainly related to nutrient losses and emissions of pesticides and other agents (antibiotics, residues of veterinary medicines).
- Greenhouse gas emissions contributing to climate change.

The environmental impacts usually have a feedback on both the renewable resources needed for food production and on resources needed outside the food system. An example of the first is the impact of food system activities on water quality, making water less suitable for irrigation purposes. An example of the latter is the effect of pollution from agricultural sources on drinking water quality. The feedbacks are sometimes very local with a short timeframe (for example water contamination), whereas in other cases the feedbacks are via global systems with a time horizon of decades (e.g. GHG emissions leading to climate change).

5.9.1 Water quality

Water quality is affected in many ways by food system activities, and in the form of various pollutants: nutrients, heavy metals, pesticides, hormones, plant growth regulators, medicine residues, bacteriological contamination and organic compounds (from food processing and food wastes). Some issues can be primarily local, such as pollution in the form of organic compounds (such as food waste, or effluents from food processing plants), which can lead to dead rivers or lakes due a high biological oxygen demand. Other forms of pollution have an effect at a continental scale (e.g. nutrient losses), or even global scale (e.g. residues of persistent pesticides like DDT). In many developing countries (e.g. India), pesticide residues in drinking water have become a major challenge (Van Drecht *et al.*, 2009). Continuous consumption of contaminated water leads to severe health risks.

Nutrient losses (especially of nitrogen and phosphorus) are already leading to major environmental problems around the world (Seitzinger *et al.*, 2010, Sutton *et al.*, 2013). The main pathway is to diffuse water pollution through the leaching of nitrogen and phosphorus from agricultural soils to groundwater and surface waters. In some regions, wind or water erosion is also an important pathway, especially for phosphorus, when nutrient-rich topsoil particles are blown or washed away. Nutrient losses cause various problems, including excessive nitrate concentrations in drinking water (impacting human health) and the eutrophication of lakes and coastal waters (Sutton *et al.*, 2013). This eutrophication can lead to dead zones, hypoxia, fish kills and algal blooms, which might lower marine production (Heisler *et al.*, 2008). In some cases, however, moderate increases of nitrogen and phosphorus in coastal waters can increase marine production, although they often affect species composition. Other pathways of nutrient losses are losses in the form of waste water from the food processing industry and sewage. It is estimated that the annual global N and P emissions from sewage could increase from 6.4 Tg N in 2000 to 12-16 Tg N in 2050, and for phosphorus from 1.3 Tg P to 2.4-3.1 Tg P (Van Drecht *et al.*, 2009).

Due to increased fertilization, livestock production, aquaculture production and urbanization, emissions of nitrogen and phosphorus to groundwater and surface waters are expected to increase in the coming decades. One of the driving forces is the increase in positive soil N and P budgets due to over-fertilization and concentrated applications of manure (Bouwman *et al.*, 2013b). In combination with higher emissions from urban areas, the total load of N and P to surface waters is projected to expand, which will aggravate the environmental problems described above (Seitzinger *et al.*, 2010).

5.9.2 Soil quality

Agricultural soils can become polluted by food system activities, but also by other human activities. Risks within food systems include the use of pesticides, fertilizers and manures. Phosphate fertilizers in particular can be contaminated with cadmium and other heavy metals. Animal manure sometimes contains relatively high concentrations of copper and zinc, which are used as nutrients and sometimes as growth promoters in livestock production.

Contaminants from outside the food systems are for example those related to emissions from industry such as heavy metals, persistent organic pollutants or acidifying components such as sulphur dioxide and Nitrogen Oxide (NOx). These contaminants can make large areas unsuitable for agricultural production; either because crop production is directly affected, or because the food being produced is contaminated. As mentioned earlier, the contamination of certain flows (such as manure or crop residues) can also hamper the options for recycling.

As most contamination is related to local sources, there is hardly any global data available on the present extent of contaminated soils. A major consequence of most forms of soil contamination is that once a soil is contaminated, the soil will remain contaminated for hundreds or thousands of years. Remediation (the removal of pollution or contaminants) is often very expensive and typically costs much more than the cost of prevention.

5.9.3 Air quality

In the case of air quality too, food system activities are both a source and a victim. Major sources from food system activities are: ammonia emissions (from manure and fertilizers), pesticides and black carbon (related to the combustion of fossil fuels and biomass, including crop residues). Air pollution from non-agricultural sources can lead to soil contamination (as described above). Ammonia emissions and consequent deposition can lead to ecological damage. Atmospheric nitrogen deposition exceeds 5 kg per ha per year across half of the 'global biodiversity hotspots' and G200 ecoregions (Bleeker *et al.*, 2011). Certainly not all of this nitrogen deposition is related to agricultural sources; in many regions the combustion of fossil fuels is a major source of NOx.

Burning of crop plant residues (e.g. wheat and rice straw) after harvesting also leads to air pollution. Indoor air pollution from inefficient stoves using traditional fuels is estimated to cause almost two million premature deaths, per year. Approximately a million of these deaths are caused by lower respiratory infections or pneumonia in children. The other million deaths mainly concern elderly, due to chronic lung disease and lung cancer (WHO; UNDP, 2009).

5.9.4 Greenhouse gas emissions

Greenhouse gas emissions occur during all food system activities, mainly in the form of CO_2 (from sources such as fossil fuels, land use and deforestation), CH_4 (enteric fermentation, manure management and rice cultivation), and N_2O (mainly from manure and fertilizers). Table 8 shows the main sources of GHG emissions from the food sector for the year 2010, mainly based on (FAO, 2014a) and (Vermeulen *et al.*, 2012). It also includes an indication of probable range, as a number of sources are either difficult to measure, especially non-CO_2 emissions (IPCC, 2014a), or because the share of agriculture in the source is uncertain (as for example in case of deforestation). Much of the data on GHG emissions available is specified according the IPCC/UNFCCC categories. According to the IPCC/UNFCCC methodology, food system-related emissions are distributed over the categories *Energy* (i.e. transport and cooling), *Industrial Processes* (i.e. fertilizer and cement manufacturing), *Agriculture*, *Land Use, Land Use Change and Forestry* (*LULUCF)* and *Waste*. In some cases (i.e. deforestation) it is difficult to judge within one category (e.g. LULUCF) whether emissions are attributed to food production, timber production or other activities. Total GHG emissions from the food sector are estimated to be 10.6 – 14.3 gigatonnes CO_2-eq in 2010, being around 24% (21-28%) of total anthropogenic GHG in that year.

Of all food system activities, agricultural production (including indirect emissions associated with land-cover change) still contributes to approximately 80% of total emissions. In industrialized and urbanized regions, the share of agriculture in total food systems emissions is lower, due to larger GHG emissions from other food system activities (Vermeulen *et al.*, 2012).

Table 8 demonstrates that deforestation is the dominant source (22% of food system related emissions), followed by CH_4 emissions (17%) from enteric fermentation (mainly from cows, sheep and goats). N_2O emissions from manure and synthetic fertilizers are also a substantial source, particularly as the global warming potential of N_2O is about 300 times that of CO_2. Other sources are N_2O from cultivated soils and CH_4 from rice cultivation. Globally, around two thirds of the GHG emissions from agriculture (including land-use changes) can be attributed to livestock production. According to the FAO, the global livestock sector was responsible for 7.1 gigatonnes CO_2-eq per year in 2005, being equal to 14.5% of total human-induced GHG emissions; beef accounts for 41% of the emissions from the livestock sector and milk production for 20% (Gerber *et al.*, 2013).

Total emissions from the 'Agriculture, Forestry and Other Land Use' (AFOLU) sector have decreased when comparing 2000–2009 to 1990–1999, mainly as a result of lower emissions from land-use change and forestry. Agricultural emissions from crop and livestock production grew from 4.7 gigatonnes CO_2-eq in 2001 to over 5.3 gigatonnes in 2011, with the increase occurred mainly in developing countries due to an expansion of total agricultural outputs (FAO, 2014a).

The largest sources of emissions for post-farm gate food system activities are refrigeration, followed by transport and packaging. It is estimated that 15% of the electricity consumed worldwide is for refrigeration (Vermeulen *et al.*, 2012). In retailing, refrigerant leakage from fridges and freezers accounts for a significant proportion of supermarkets' direct GHG emissions, while the preparation of food also contributes significantly to GHG emissions.

Future GHG emissions from agriculture may further increase by up to 30% by 2050 if no further mitigation measures and technical efficiency improvements are implemented (FAO, 2014a).

5.10 Food categories, resource use and human health

Human diets vary largely across the globe (see Section 3), based on aspects such as food availability, food prices, culture, and personal preferences. Differences in diet may lead to large differences in resource use and environmental impacts as some food categories are less resource-efficient or lead to more environmental impacts than others. One of the main distinctions is between animal- and plant-based products (Garnett, 2011, PBL, 2011, Tilman & Clark, 2014, Westhoek *et al.*, 2014). This difference is mainly due to the fact that animals consume more energy and protein than is embedded in the final products (meat, eggs and dairy). This is because part of the energy, proteins and minerals in feed are used for the animals' metabolism and another part ends up in inedible parts such as bones. In modern livestock production, feeds are used that would also be suitable for human consumption (e.g. cereals and soy beans); therefore it would be more efficient if humans were to eat this food directly. This is different in traditional livestock systems such as pastoralism, in which plant materials that are not suitable for human consumption are converted into edible products such as meat and dairy. In the past, most of the confined animals were mainly reared on by-products, and food losses and waste. Currently, large quantities of cereals and oil meals are being used as feed for confined animals.

However, it is not easy to compare individual products:

- Some production systems produce more than one product: for example dairy systems

produce meat and dairy. Dairy is a complex product, consisting of fats, proteins and lactose; a diet in which only fat-free milk products are consumed is therefore inconsistent with the natural production system, through which proteins and fats are inherently coupled.

- Food products are very diverse: some hardly provide any nutritional value (water, coffee, tea), some only provide energy and no nutrients (sugar, oil), and others provide a whole range of nutrients, such as vegetables, meat and fish. The difficult question is what should be the basis of comparison: per kg product, per unit of energy (kcal), or per unit protein? Some food products also contain components that might have negative health consequences when consumed in excessive quantities (such as salt and saturated fats).
- Even within one product (for example beef, milk or French beans), there are large differences in environmental impacts, depending on factors such as production system, season and transport distances.
- Food products typically require a large range of natural resources (land, water, minerals, etc.) and have a large range of environmental impacts. To use only the greenhouse gas footprint of different products would be an oversimplification. This is less so when the high greenhouse gas emissions are due to the use of fossil fuel (mainly related to transport, cooling and heating).
- Resource use is in some cases difficult to compare, for example land use (crops, meat) versus marine resources (wild fish).

Table 8. Estimates of GHG emissions (in or around the year 2010) of sources within the food system (Mt CO_2-eq/yr)

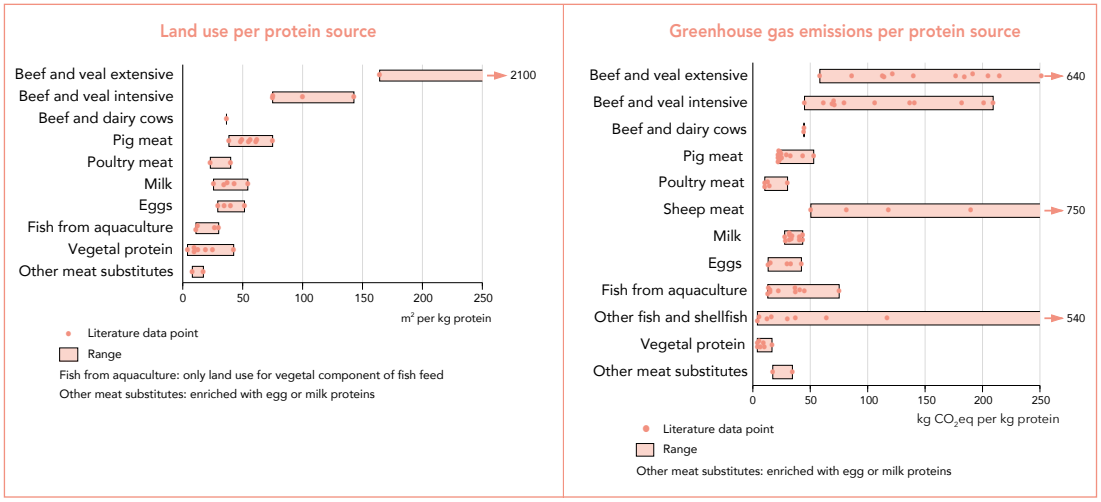
	Total global emissions 2010	Source
Energy use on farm	785	FAO, 2014a
Enteric fermentation	2071	FAO, 2014a
Manure management	362	FAO, 2014a
Rice cultivation	522	FAO, 2014a
Agricultural soils		
Synthetic fertilizer	725	FAO, 2014a
Manure applied to soils	185	FAO, 2014a
Manure left on pasture	824	FAO, 2014a
Crops residues	197	FAO, 2014a
Cultivation organic soils	133	FAO, 2014a
Savanna burning	287	FAO, 2014a
Burning crop residues	29	FAO, 2014a
Total direct agriculture *Uncertainty range*[1]	6120 *5485 – 7470*	
Forestry and land use related emissions		
Net forest conversion[3]	1850 - 3365	FAO, 2014a
Cropland	756	FAO, 2014a
Grassland	26	FAO, 2014a
Burning biomass	290	FAO, 2014a
Inputs production		
Fertilizer manufacturing	611	2007; IFA, 2009[2]
Energy use animal feed production	60	2007; Vermeulen 2012
Pesticide production	3–140	2007; Vermeulen 2012
Post-farmgate food system activities		
Primary and secondary processing	192	2007; Vermeulen 2012
Storage, packaging and transport	396	2007; Vermeulen 2012
Refrigeration	490	2007; Vermeulen 2012
Retail activities	224	2007; Vermeulen 2012
Catering and domestic food	160	2007; Vermeulen 2012
Waste disposal	72	2007; Vermeulen 2012
Total	10,640 – 14,250	

[1] These figures include an estimation of uncertainties, notably in the source *agricultural soils*, based on (FAO, 2014a, IPCC, 2014a)
[2] Based on (IFA, 2009) which estimates a share of 1.2% of fertilizer production in total energy consumption, increased with estimated N2O emissions from nitric acid production
[3] Attribution based on an estimated share of 50-90% of agriculture in deforestation related emissions

Over the last ten years, a large number of studies have been carried out that either compare various food products (especially with regard to GHG emissions and land use) or complete diets (Stehfest *et al.*, 2009, Tilman & Clark, 2014, Tukker *et al.*, 2011, Westhoek *et al.*, 2014). These studies unanimously conclude that livestock products lead to higher GHG emissions than plant-based equivalents. The same is true for studies on dietary shifts from typical high-meat, Western-type diets to diets with lower quantities of meat, dairy and eggs.

Figure 25 demonstrates the differences in resource use and environmental pressure expressed as land area and greenhouse gas emissions per kg of protein, based on a review of a large number of LCA studies. Land area is the highest for beef, although it should be noted that extensive beef in particular is fed on semi-natural grasslands. Poultry meat, milk and eggs require on average about two to three times more land per unit than vegetable types of protein, and pig meat even requires a factor of five more land. Similar differences have been found between the various protein sources and nitrogen emissions (Leip *et al.*, 2014).

Figure 25 Land use (left) and greenhouse gas emissions (right) per kilogram of protein



Source: (Nijdam *et al.*, 2012)

Table 9. Status of natural resources as needed for food system activities

Resource	Issues regarding sustainable use	Issues regarding efficiency
Renewable resources		
Land, landscape, soils	Around 33% of soils is moderately to highly degraded	In large regions: low crop yields
Water	Depletion and pollution of aquifers; disturbance of watersheds, eutrophication	In many regions inefficient or ineffective use of both rainwater and irrigation water
Biodiversity and ecosystem services	Loss of terrestrial and aquatic biodiversity and ecosystem services	Ecosystem services are often not used effectively
Including: *Genetic resources*	Narrowing of genetic base	
Marine resources	Around 29% of fish stocks overfished	Large quantities of by-catch; low yields due to overexploitation
Non-renewable resources		
Nutrients (minerals)	-	Low efficiency over food chain (15–20%)
Fossil fuels	-	Around 30% of all fossil fuel use related to food systems

5.11 Summary and Conclusions

Natural resources such as land and soils, fresh water, biodiversity (including genetic resources), marine resources (including fish stocks) and minerals are in many cases not managed sustainably or efficiently (Table 9). This creates risks for future food production, and simultaneously leads to considerable environmental impacts outside the food system: About 24% of all anthropogenic global greenhouse gas emissions are related to food systems. Main sources are direct and indirect emissions resulting from animal husbandry, the application of manure and fertilizers, rice fields, deforestation, the use of peatlands and the use of fossil fuels for farm activities and fertilizer production. In modern food systems, fossil fuel use for processing, transporting and cooling food is a major source as well. Water quality is in certain regions strongly affected by nutrient losses, leading to eutrophication of fresh water and coastal areas. Pesticides, organic food wastes and residues from antibiotics also impact water quality. Food system activities also affect soil quality, directly or indirectly.

Due to a combination of factors, the pressure on natural resources is expected to increase over the coming decades. Main factors are the increase in population (mainly in Asia and Africa), increased wealth combined with urbanization (leading to dietary shifts) and climate change. For example, due to the increased food demand, the cropland area is projected to grow by 2050, mainly at the expense of ecologically vulnerable areas such as savannahs and forests.

Credit: DONOT6_STUDIO, Shutterstock.com

Chapter 6

Understanding food systems in context: actors, behaviors and institutions

6.1 Introduction

This chapter explores the actors, behaviors and institutions that together shape current food systems. This context is useful when considering options towards environmentally-sustainable food systems as discussed in Chapters 7 (on biophysical options) and Chapter 8 (on socio-economic options). The identification of options which are likely to be adopted and successful requires an understanding of the context in which food system actors operate. It should be stressed, however, that understanding the role of actors and institutions in food systems requires specific diagnostics at the country, region or landscape level (Lieshout van *et al.*, 2010, North, 1990). The variety of institutional arrangements (such as national legislation) and the status of natural resources in different types of food systems, makes drawing general conclusions about these contexts highly problematic.

Section 6.2 outlines the array of food system actors and behaviors that form the basis for understanding food system dynamics, while the following sections identify the institutional arrangements that influence and guide their behavior: Sections 6.3 to 6.8 focus on the individual actors, ranging from farmers and fishermen, to non-governmental organizations (NGOs).

6.2 Food system actors and their behavior

Food system actors represent today the largest group of natural resource managers in the world. Therefore, when it comes to sustainability along the system, they are critical in both creating the problems and implementing the solutions. Many of these agents of change will require empowerment and knowledge to contribute to a positive transition (i.e. smallholder farmers, women, fisher folks, indigenous communities, etc.). Others will need incentives to change the way in which they operate and consume. The behavior of all of them will depend on their specific context.

Food systems actors, ranging from consumers, via food processors and farmers to the agro-input industry, live and act in a certain context. Important elements of this context (see also Chapters 3 and 4) are:

- Institutional and regulatory environment, including aspects as property and tenure rights, laws related to food safety, the environment, among others.
- The physical environment (nature and proximity to natural resources, infrastructure, proximity to shops for consumers).
- The social, economic and technical setting: education and training, gender and equity aspects; prices (of food, inputs, labor), related to aspects such as bargaining power, trade arrangements, price volatility and taxes. Available knowledge, technology and innovations also play a major role.
- Cultural aspects, such as religion, traditions, habits, norms and values.

This context is thus not only different for each food system actor, but is also highly country- and location- specific. Commercial farmers in developed countries operate in a completely different context than subsistence farmers in a developing country, and while the commercial farmer may use a range of fertilizers and agrochemicals, both depend on the same natural resources of soil, water, biodiversity, etc. to some extent. And the relevant elements of the context for a commercial farm (being for example labor prices, environmental legislation and commodity prices) are quite different from those of a city-dweller, who is influenced by aspects as eating habits, retail prices and marketing. In traditional food systems, the distinction between the various actors is much less clear, as people are for example both food producers as well as consumers.

6.3 Farmers and fishermen

The global community of farmers and fishermen is very diverse. Many low- and middle-income countries are still primarily agricultural with smallholder farmers and fishermen predominating the rural population (HLPE, 2013b). Due to the expected population growth, mainly in cities but also in rural areas, this number is likely to increase (Chapter 3) and hence these primary producers will continue to play an important role in food production and the direct management of natural resources. Smallholder farms are predominantly family operations, with often even more labor input from women than from men. They produce at least 56% of all agricultural production worldwide and in regions like Africa they are responsible for the production of up to 80% of the food consumed by the population (UN, 2014). Artisanal fishing is, in contrast, normally dominated by men, with women more engaged in processing the catch. In 'modern' food system, most of the agricultural production is produced by larger, specialized farms.

Due to various limitations, many smallholder farmers have not been able to increase their land and labor productivity. A typical limitation that many of these farmers face is the general context of rural poverty with inadequate infrastructure and limited access to agricultural inputs like knowledge and technology, feed, fertilizers, seeds and capital; and/or market opportunity. This situation is often worsened by the fact that these farmers often live in ecologically vulnerable environments where resources are depleted (Chapter 5). It is against this background that many smallholders have not been integrated into food supply chains that are part of a quickly transforming intermediate food system (FAO, 2013b, Kirsten *et al.*, 2009, Wiggins, 2014). If equipped with the appropriate knowledge, technologies and means of production, smallholder farmers can increase productivity and simultaneously regenerate or preserve natural resources. Improved production technologies and links to markets would reduce the pre and post-harvest losses. Moreover, addressing these farmers' conditions and limitations is not only a way to realize more efficient and sustainable management of resources. It could also give impetus to break the cycle of rural poverty and allow farmers to shift to other types of entrepreneurial activities. Wiggins (2014) points at case studies showing how smallholders in parts of Africa have been supported to intensify production and have been linked by small and medium enterprises to growing and diversifying food markets in urban Africa. As a result, these smallholders have been able to increase their income, which may improve their food security situation.

In fisheries, the contribution of small-scale producers (including inland fisheries) in terms of overall production and contribution to food security and nutrition is also often underestimated or ignored. More than 120 million people in the world depend directly on fisheries-related activities.

6.3.1 Institutional and regulatory environment

One of the important aspects for farmer and fishermen is the access to natural resources. Ostrom and others (North, 1987, Ostrom, 1990) showed how collectives of actors might coordinate or '*govern'* common pool resources, preventing unsustainable use by actors' *free riding*. Governing usually involves some form of organization, rules, contracts, rights or regulation; phenomena which can be summarized as institutions. Institutions generally enhance trust or overcome high transaction costs. In addition institutions allow for coordination, regulation of an array of individuals' behavior and decision making in collective action (Ostrom, 1990, Ostrom, 1992, Wansink, 2004). Institutions might come as local informal patterns or routines in community based cooperation, but might as well be governments, laws, formal ownership, policies or constitution.

Property rights and tenure regimes can be categorized into four groups: *private, common, state* and *open access*, each having their own institutions, dynamics and outcomes in terms

of sustainability, efficiency of resource use and environmental impacts (Table 10). In *open access* regimes, individuals can access and use resources in an unlimited fashion as there are no institutional arrangements or authorities to regulate and manage the resource. A typical example of a resource under an open access regime in many countries is groundwater (OECD, 2013a). As has been illustrated in Chapter 5, the depletion of aquifers and disturbed watersheds due to human intervention is currently a serious threat in various regions. Another example of a resource under an open access regime are ocean and marine resources (especially the international "high seas"), with similar outcomes: many fish stocks are currently overexploited resulting in lower fish yields (Chapter 5). Under *state property regimes*, state institutions own and regulate the resource, although it can also assign others to manage the resource on their behalf. A resource that is often typically managed under the state property regime is surface waters, access to and use of which are often regulated by state institutions at the river basin level. In *common property regimes*, local groups define the rules and conditions for where, when and how many resources may be withdrawn by the group members. In some regions, pastures and forests have been under this type of regime with traditional institutions managing a resource through customary laws. These traditional institutions' functioning has come under pressure. In *private property regimes*, individual actors own, manage and have the right to benefit from a resource. A typical example is agricultural land which is often owned privately by farmers or agribusinesses.

Table 10. Property rights regimes and institutional arrangements

	Private	Common	State	Open access[1]
Rights	An individual actor owns the resource and has the right to control and benefit from and to exclude others from the resource.	A group of individuals owns the resource, and has the right to control and benefit from and to exclude others from the resource.	The state owns and controls/ manages the resource or assigns others to do so on its behalf.	No one is assigned ownership and the resource is open to all potential users.
Responsibilities	The individual is responsible for the efficient and sustainable use and to refrain from imposing externalities on other individuals or groups. Local and national authorities allocate and establish clear tenure rights, and enforce rules to withhold or punish individuals who impose externalities on to others.	The community group is responsible for sustainable *management* of the resource. It establishes and allocates tenure rights and enforces rules to withhold or punish individuals who impose externalities on to other group members. The state defines legal frameworks that allow the functioning of formal and informal community groups, and prevent one group imposing externalities on to others. It also ensures clarity about who owns and controls landscape elements like water bodies and forests.	The state determines the capacity of the resource, allocates functions and determines optimal and efficient uses. It may assign use rights to others under framed conditions.	There are no rules or regulations. All individuals have complete autonomy in the amount and way in which resources are extracted or used.
Examples	Land, mines	Land, surface water, inland fish stocks	Surface waters, marine resources <200 miles	Marine resources >200 miles, ground water

[1] In some cases there is some kind of regulation, but only very weak and often not binding

6.3.2 Physical environment

The physical environment in which farmers and fishermen operate is one of the key determining factors. A number of characteristics, such as climate and general landscape conditions are mainly beyond direct human control, but others can be influenced. One important aspect is rural infrastructure like roads, telecommunication, irrigation, water supply and services that enable local production. Especially in developing countries (but certainly not exclusively), current rural infrastructure is underdeveloped. Improvements in rural infrastructure could in many ways lead to an improved use if natural resources, for example by reducing food losses, by making inputs cheaper and more timely available (such as fertilizers and water) and by facilitating knowledge exchange.

6.3.3 Social, cultural and economic environment

The social, cultural and economic environment substantially varies around the world. A large number of farmers are mainly subsistence farmers, for whom a stable supply of food is of key importance. Their decisions largely depend on the social and cultural context (for example which crops to plant), although many subsistence farmers are connected in various ways to markets.

At the other end of the spectrum are farmers in modern food systems, who operate in a commercial context, often specialized in one crop or commodity, and depend on prices of inputs, labor and produced commodities, as well as on credit facilities. In this context, companies in the food supply chain are the ones that exert large influence over farmers' decisions on how they manage resources (Chapter 3). A recurrent issue that farmers face is the low price they receive for their products and labor, which limits their ability to invest in new technologies and farming approaches. In the US for instance, the share of the consumer's food dollar that gets back to the farmer has dropped from 40 cents in 1910 to 7 cents in 1997; a similar trend occurred in the UK (Lang & Heasman, 2004).

Stronger position and bargaining power against downstream food actors could increase *resource efficiency* in food systems. Higher product prices in itself are not a guarantee for a more sustainable use of natural resources, to the contrary, in many cases this has led to the opposite result. But the combination of more stable prices (making for example investments in land quality and precision equipment possible) and remuneration by markets of better practices (for example in the form of certification schemes) could certainly be important.

Particularly in high income countries, an underlying reason for food loss is the overproduction by farmers who want to ensure the delivery of agreed quantities to their customers and who anticipate possible events like bad weather and disease outbreaks. In some cases, the surplus is sold to processors or as animal feed, but in many cases farmers also choose not to harvest crops because the related costs (labor, energy and transport) are expected to be higher than incomes; mainly due to low crop prices (Lipinski *et al.*, 2013). The same authors (Lipinski *et al.*, 2013) also refer to situations where customers like retailers either eventually buy less from farmers than initially agreed or refuse to buy at all due to non-compliance of the crops with desired standards for size, shape, weight, colour, etc.

Ways to strengthen the position and bargaining power of farmers are, for example, stronger farmer institutions such as cooperatives or associations.

6.4 Consumers and citizens

Consumers are a crucial node in the food systems. By exercising effective demand, they basically determine food production, although this demand is strongly influenced by food availability and income as well as by the 'food environment' (see below). People not only influence food systems in their role of consumers, they also act as citizens, who vote, have opinions, and sometimes organize themselves in for example NGOs. Food consumption patterns also have a large effect on peoples' health. And finally, consumers are partly responsible for food waste, particularly in more affluent societies.

Consumers are a very diverse group of people, ranging from rural poor, to urban poor and urban rich. Even within rich societies there are many people below poverty line, who spend a high share of their income on food, and for whom access to healthy food is as much a problem as it is for poor people in developing countries. A very dynamic and large group of consumers is the increasing middleclass in developing countries.

In an economic sense, not all people are 'food consumers'. Consumers are the people who spend money on food. In many countries, women are the main consumers, as they are responsible for meal planning and food purchases. They have to balance household budgets, as well as time. The time issue is important, both in food preparation (leading to a trend towards convenience), as well is in food purchasing (one of the factors behind supermarketization). A consequence of the trend towards convenience food is the observed loss of cooking skills (Meah & Watson, 2011).

Food consumption patterns are partly determined by food prices and household income. Socio-economic conditions are an important factor in changes of food demand and dietary patterns, which have been a driving force in food system transformation (Sections 4.2, 4.3 and 4.4) and its impacts on natural resources (Chapter 5). Culture, tradition and religion play a major role as well, with marked differences between various countries and societies. An important factor which determines consumption behavior are the dominating norms, values and beliefs about food. Although traditions are important, food consumption patterns are far from static, as can be seen by the large changes in food consumption patterns within the timespan of one generation.

The 'food environment', being the physical, social and economic surroundings that influence what people eat, plays a major role in determining food consumption patterns, especially in urban food systems. Food companies, restaurants, food vendors and retailers are actively influencing this food environment to tempt people to make certain choices. This influencing could be in various ways, ranging from advertising, packaging, location, to creating aromas or presentation in shops or restaurants. Changing this food environment could be an important lever towards dietary change and reducing food waste, and hence make a major contribution to increasing natural resource use efficiency. Partly as a consequence of this food environment, *ultra-processed foods* (including beverages) have become a dominant part of Western diets. These foods are often rich in sugars, fat and salt and lend themselves well to mass production, bulk storage and automated preparation. The nature of these products makes them cheaper to produce and attractive to promote and sell because they usually have high profit margins (Lang & Heasman, 2004), (Swinburn *et al.*, 2011).

Due to changes in food systems over the last century, many food items are now produced and distributed in complex food nets and lengthy supply chains. Consequently, citizens have limited information and insight into what they consume and what the consequences of their consumption behavior are. Raising people's awareness could therefore be an important lever for change, particularly if people are able to relate to the new information and messages they receive. In this sense, the current societal trends and debates on healthy food could be used as a vehicle to encourage discussions on sustainable food as well, particularly where healthy and sustainable foods coincide. Research by the UK government into consumer attitudes and behavior showed, for instance, that choices around food are mainly driven by health (81%) and the price of products, while environment is much less a concern (26%). A similar study among consumers in the EU-27 revealed similar findings, cited in (WWF, 2014).

6.5 Food companies, food service and retail

There is a large variation in the various types of companies who process, package, prepare and sell food for consumers. The large food companies and retailers attract most of the attention, but there are also many small and medium-sized enterprises, ranging from local food stalls, 'mom and pop' shops, bakeries and family-owned restaurants to (for example) medium-sized food processors. This ensemble of private actors makes the food sector the largest economic sector in many regions, such as the EU for example (Underwood *et al.*, 2013). Some of these actors operate mainly at a local level (within a large context), while other companies operate at a global level. Some of these global companies are well-known and have global brands (e.g. cereals, snacks, soft drinks, beers, coffee and sweets). Other global companies (more directly related to natural resources) operating at earlier stages in the food chain (e.g. seed, fertilizers and feed companies) are generally less well-known by the general public.

Private actors operate within a certain institutional, social and economic framework. Large food companies employ strategies to survive in highly competitive and saturated markets, where reputation is an important factor to acquire and bind new customers to their services or products. Companies expand to new customer segments, for instance among the urban middle class in emerging economies. They employ various strategies to create additional demand for their products, for instance through innovation, responding to market demand or by shaping people's norms and perceptions of food through the food environment (Esnouf *et al.*, 2013). In the context of highly competitive and globalizing markets, a company will generally strive to be cost-efficient which could often lead to externalization of environmental costs.

For many food companies, as well as fast-food restaurants for example, it is easier to make profit on calories (fat and sugar), i.e. rich, ultra-processed foods and beverages. This is one of the drivers of obesity and diet-related diseases like cardio-vascular diseases (Swinburn *et al.*, 2011).

In modern food systems, the strive for cost efficiency has encouraged the vertical integration in supply chains (see also Section 3.4). The process of consolidation has been accompanied by a shift in power from primary producers to actors downstream in supply chains. Particularly retailers who gained disproportionate buying power both in relation to primary producers and food companies with their own brands. While some of the major companies do operate from 'farm to fork', and hence have a direct influence on natural resources along the whole food system, many of the smaller downstream food actors do not directly manage resources for food production. Their decisions do however indirectly influence the way natural resources are managed, and this influence could work both in a positive and a negative direction.

6.6 Governments

Governments play different roles depending on their national context. In countries with a liberalized economy, governments tend to play a regulating and facilitating role. In other types of economies, governments (i.e. state controlled enterprises) sometimes take part in food producing, processing, trading and retailing.

Even in liberalized economies, governments (both national authorities as well as local authorities) exercise a large influence (although often implicit) on the way the food system is organized, as well as on natural resource management approaches and environmental impacts. This could be in the form of:

- financial instruments (taxes, import and export tariffs, subsidies, payments);
- legislation and regulation (or the absence of regulation), for example on food;
- by setting objectives for education (for example on nutrition);
- by stimulating and facilitating innovations, new initiatives, collaboration and cooperation.

Although natural resources are crucial input for food production, they are often not priced (e.g. water, fish stocks) or have low market value (e.g. land). The (FAO, 2004) indicates that the non-traded nature of natural resources and the lack of a market for the public benefit of these resources limits the incentive to maintain the resource and results in market failures. They suggest that putting a monetary value on resources and pricing their extraction would result in more efficient uses (e.g. water). Moreover, inefficient use of energy, fertilizers, minerals, and water are often encouraged by pricing resources below their true costs (e.g. through subsidies for irrigation, fertilizer and pesticides) (OECD, 2005; OECD, 2013a).

In many countries, the environmental costs (externalities) of the food system are not included in food prices (TEEB, 2015). Governments could promote the prevention of negative externalities through environmental regulations and standards. Financial incentives could also promote a shift to more sustainable practices. Such incentives could be created by taxing environmental impacts (nitrate leakages, water pollution from pesticides, GHG emissions and so on), while positive financial incentives could be created by rewarding those who assure the maintenance of ecosystem services, for instance through Payments for Environmental Services (PES) schemes. These are a way to encourage sustainable resource use that create positive externalities, such as appreciated landscapes, erosion prevention, downstream flood protection, watershed protection and hydrological functions such as water purification.

6.7 Non-governmental and other civil society actors

There are many NGOs and other non-state actors (e.g. civil society groups) actively engaged in the area of food systems and natural resources (Schilpzand *et al.*, 2010a). Some are small and local, while others operate at the global level. They also vary widely in objective: some have more socio-economic goals (e.g. strengthening the position of smallholders or women), others are more concerned with people's health, while others are mainly oriented towards nature conservation.

NGOs sometimes have a large role in initiating changes in food systems and can be major 'influencers' of state policy making. NGOs also influence the behavior of companies, especially large multinationals by a variety of strategies, ranging from cooperation and mutual support to 'naming and shaming'.

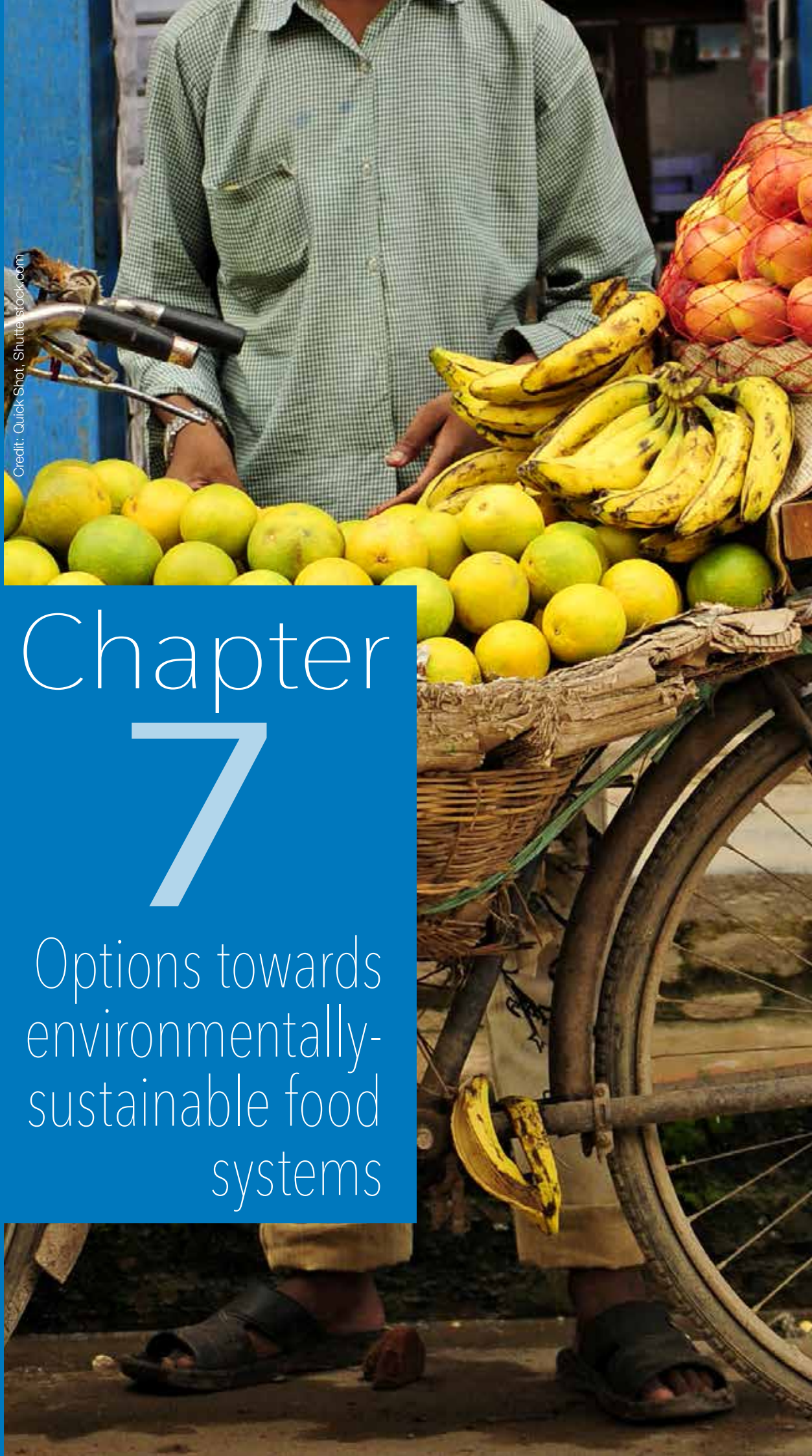
6.8 Summary and conclusions

In order to analyze why in many instances natural resources are not managed sustainably or efficiency, it is important to analyze the behavior of the various food system actors as well the context in which they operate. A better understanding of the governance of natural resources, as well as of food systems as a whole, is pivotal to identifying effective levers for change. It should be stressed, that understanding the role of actors and institutions in food systems requires country-, region- or landscape–specific diagnostics. The variety of institutional arrangements (such as national legislation) and the status of natural resources in different types of food systems, makes drawing general conclusions about these contexts problematic. Food systems actors live and act in a certain context, the elements of which can include: the institutional and regulatory environment (e.g. property and tenure rights, laws); the physical environment (nature and proximity to natural resources, infrastructure, proximity to shops for consumers); the social, economic and technical setting (e.g. education and training, gender and equity aspects); prices (of food, inputs, labor) and related aspects (bargaining power, trade arrangements, price volatility, taxes, available knowledge, technology and innovations); as well as cultural aspects (religion, traditions, habits, norms and values).

When analyzing this context, special attention should be given to the role of women, given their important role both in food production, as well as in food preparation and consumption. Property and tenure rights regimes have a large influence on the way certain renewable natural resources are governed. These regimes can be categorized as: private, common, state and open access, each with their own institutions, dynamics and outcomes in terms of sustainability, efficiency of resource use and environmental impacts. The absence of clear regulatory frameworks, rights and enforcement mechanisms has in many cases driven unrestricted use and caused the depletion of resources like water and land. To ensure the sustainable use of resources, a clear regulatory framework (with consideration of distributional effects) is needed to manage the access and use of resources and to regulate environmental impacts. Clear definition of roles and responsibilities for the regular monitoring and assessment of the environmental state of resources are also important. Additionally, financial incentives can be critical. Through taxes and subsidies governments can influence the use of certain inputs such as fossil fuel and fertilizers. Fossil fuel subsidies for irrigation purposes can drive the over-extraction of water. On the other hand, payments for environmental services (such as flood control or well-maintained landscapes) can encourage farmers to undertake actions to improve the delivery of environmental services.

Private actors are a very diverse group, ranging from very small businesses to large multinationals. Large food companies employ strategies to survive in highly competitive and saturated markets, where reputation is an important factor to acquire and bind new customers to their services or products. Companies employ various strategies to create additional demand for their products, for instance through innovation, responding to market demand or by shaping people's norms and perceptions on food through the food environment. In the context of highly competitive and globalizing markets, a company will generally strive to be cost-efficient which could often lead to externalization of environmental costs.

Consumers are a crucial node in the food systems. By exercising effective demand, they basically determine food production, although this demand is strongly influenced by food availability and income as well as by the 'food environment'. People not only influence food systems in their role of consumers, they also act as citizens, who vote, have opinions, and sometimes organize themselves in for example NGOs. NGOs can play different roles, ranging from a cooperative role, to a more activist role, for example by 'naming and shaming' individual companies.



Credit: Quick Shot, Shutterstock.com

Chapter 7

Options towards environmentally-sustainable food systems

7.1 Introduction

In Chapter 5 we asserted that many of the natural resources that underpin food systems are not managed sustainably or efficiently, and that increasing food demand due to population growth and increasing prosperity will increase the pressure on these resources (Chapters 4 and 5). Moreover, the food system leads to a number of environmental pressures, such as biodiversity loss and GHG emissions which in turn further undermine food production. Chapter 6 has highlighted a number of mechanisms behind the current functioning of food systems. That raises the important question of what can be done to steer food systems towards more efficient use of natural resources.

This chapter first explores what sustainable food systems could look like from a natural resource perspective (Section 7.2). An overview is also given of the options available to enhance the sustainable and efficient use of natural resources and to reduce negative impacts on the environment (Section 7.3). It is important to reiterate that food systems vary widely around the world. This means that there are large differences in the challenges and opportunities with regard to natural resources (Section 5) as well as in the ways to achieve progress in overcoming these challenges.

Section 7.4 gives a brief description of a number of options, in particular 'overarching', non-resource-specific options, both on the production side (such as reduction of food losses and increased feed efficiency) and on the consumption side (such as reduction of food wastes and dietary shifts). Finally, Section 7.5 summarizes some key literature concerning the potential effect of a number of biophysical options.

7.2 What do sustainable food systems look like from a natural resource perspective?

One of the key questions this report addresses is: 'What do sustainable food systems look like from a natural resource perspective?' There are many answers to this critical question. For example, some promote the use of GM crops, pesticides and antibiotics in order to increase agricultural productivity, thereby reducing pressure to covert more 'natural' land; others categorically reject these kinds of approaches and stress their negative impacts on biodiversity, environment and human health. When defined at a higher abstraction level however, consensus might be more attainable: few will reject the ambition for increased use efficiency of nutrients (and other inputs and lower greenhouse gas emissions, as well as the importance of sustainable land management. Discussion may than still arise about the speed, the technology to be applied and the final level of ambition: for instance, is the ambition to avoid soil erosion completely, or is some erosion acceptable in some cases? Furthermore, there are many trade-offs and potential co-benefits to be considered. Based on the conceptual framework as presented in Chapter 2, and the definition of sustainable food systems, **three main basic principles** for sustainable food systems from a natural resource perspective can be defined:

1. Sustainable use of renewable resources: no degradation.
2. Efficient use of all resources.
3. Low environmental impacts from the food system activities.

It is evident that sustainable food systems are not only about sustainable and efficient food production; the key challenge is to be effective in terms of food security, livelihoods and human health.

1. Sustainable use of renewable resources: no degradation

The sustainable use of the renewable resources in food system activities is essential to ensure the

continuity of primary food production (crop and livestock production, fisheries and aquaculture). Table 11 lists these resources and also provides a more specific interpretation of the meaning of 'sustainable' use for each one of them. An unsustainable use of these resources would not only have negative implications for food production, it might also lead to environmental effects outside the food system (see Chapter 2). An example is the clogging of rivers, lakes and reservoirs with sediment from soil erosion. Land degradation may also lead to the conversion of additional land into cropland or pastures to compensate for the lost productive land (UNEP, 2014). Pressures leading to an unsustainable use of natural resources may also come from outside the food system, for example in the form of contaminants.

2. Efficient use of all resources

Chapter 2 defines efficient use of resources as 'high output per unit of input', to be measured at various scales'. Table 11 lists what efficient use could imply for various resources.

An efficient use of both non-renewable and renewable resources is essential to transition towards more sustainable food systems, considering:

a. the amount of resources used within food system activities is generally related to environmental impacts: more fossil fuel use means more greenhouse gas emissions, lower land use for agriculture (due to higher crop yields) generally means less land conversion;

b. in the case of non-renewable resources (such as minerals and fossil fuels) a higher efficiency means a lower demand and thus a lower depletion rate.

One could therefore argue that increasing the efficiency of use is actually a means to move towards more sustainable use as it contributes to a low depletion rate (mainly at the global scale) or limits the environmental impacts of food systems This implies decoupling food production from resource use (UNEP, 2011a). For most resources, there is no absolute maximum that can be reached in terms of efficiency. However, some targets could be envisioned for fossil fuels and non-renewable nutrients. In the case of fossil fuels, the long-term ambition could be to replace all of these with renewable sources. In the case of non-renewable nutrients (e.g. P and K), the ambition could be to reach a 100% efficiency along the food chain, which implies that no 'new' minerals would need to be extracted from reserves to replace the lost minerals.

As discussed in Chapter 5, an optimal mix of the various inputs (including natural resources) is essential in crop production to reach a good overall efficiency. If one of the production factors (for example nitrogen) is limiting, other production factors (land, water, labor, seeds) are utilised sub-optimally. Similarly, if the use of nitrogen results in nitrogen leaching into groundwater and surface waters, its use is inefficient.

A key aspect of resource-efficient food systems is the ability to recycle materials and nutrients. The absence of contaminants of various kinds is therefore important as these can inhibit the proper recycling of food waste, manure and human excreta. Specific contaminants that inhibit recycling along the food chain include heavy metals, residues of pesticides or drugs (oestrogens, antibiotics, anthelmintic treatments) and antibiotic resistant bacteria. There might also be some more 'natural' causes such as zoonoses, parasites or plant pests and diseases that make recycling difficult. There are ways of restoring the usability of certain streams: for example, the proper composting of crop residues can kill certain types of pathogen. Human excrements (night soil) can contain pathogenic bacteria, virus and parasitic ova. With proper treatment these can be killed, making the recycling of nutrients possible, although certain risks may still exist.

3. Low environmental impacts from the food system

Given the current, let alone future, food demand, zero food system impacts on the environment is not feasible. The emission of certain greenhouse gases, or nutrient losses cannot be reduced to zero. Yet, these emissions should be reduced as much as possible. Contamination of various kinds could also affect soil and water quality and thus the sustainable use of these resources.

Table 11. Principles and indicators for sustainable food systems from the natural resource perspective

	Principle of sustainable use	Indicator of efficient use *In italics: ambition at food system level*	Indicator of reduced environmental impacts
Renewable resources			
Land, landscapes and soils	No or very limited land degradation (in all forms) / soil erosion, prevent contamination, maintenance of landscape diversity, aiming at sustained crop yields	Optimized crop yields, closing the 'yield gap' without increasing environmental impacts *No further land needed in food systems*	No / limited conversion of natural areas into agricultural land; maintenance of landscape diversity
Water	No depletion of groundwater / disturbance of water systems; prevent pollution / contamination	High water-use efficiency along food chain *Low total amount of water needed in food systems*	Limited changes in hydrological regimes
Biodiversity	Conservation - no degradation of biodiversity	Biodiversity maintained/ enhanced	Reduced disturbance / extinction of species
Genetic resources	Conservation of genetic diversity for resilient food systems	Genetic potential of crops and farmed animals exploited, not only in terms of productivity but also in terms of robustness and nutritional quality	
Marine resources	Conservation / no depletion of fish stocks – no disturbance of marine environment	Avoidance of by-catch, proper use of by-catch	Limited disturbance of marine environment
Non-renewable resources			
Minerals	-	High nutrient efficiency along the food chain *Low total amount of 'new' minerals for food systems*	Reduced pollution by minerals
Fossil fuel	-	High energy efficiency / renewable energy sources *Low total amount of fossil fuels for food systems*	Reduced burning fossil fuels / clean burning methods *(GHG emissions, air pollution)*
Use of agents / synthetic components	-	Minimized use	Reduced pollution and contamination *(soil, air and water quality)*

(1) The columns 'sustainable use' and 'efficient use' are not meant to indicate a contradiction; in most cases both are needed simultaneously. See for example the SAFA guidelines for implementation at enterprise level (FAO, 2013c).
(2) For reasons of simplicity, this is defined in physical terms. Farmers might be more interested in outputs related to revenue or employment.

7.3 Overview of options

The underlying principles of resource-efficient food systems were presented in Section 7.2, while a number of resource-specific options were presented in Chapter 5 that make the use of the various natural resources more sustainable and efficient and reduce the environmental effects. These options were resource-specific, implying that synergies and trade-offs were not discussed. Neither were options in the whole food system presented, such as options on the consumption side.

A large number of options are available to make food systems more sustainable in terms of resource use and environmental impacts. Some of these options not only result in a positive effect on the resource that is targeted, but could also have a positive effect on other resources or environmental impacts. For example, better nitrogen management will not only lead to improved resource efficiency, it might also lead to better water quality and lower greenhouse gas emissions. Reduced food waste will reduce overall demand thereby reducing all

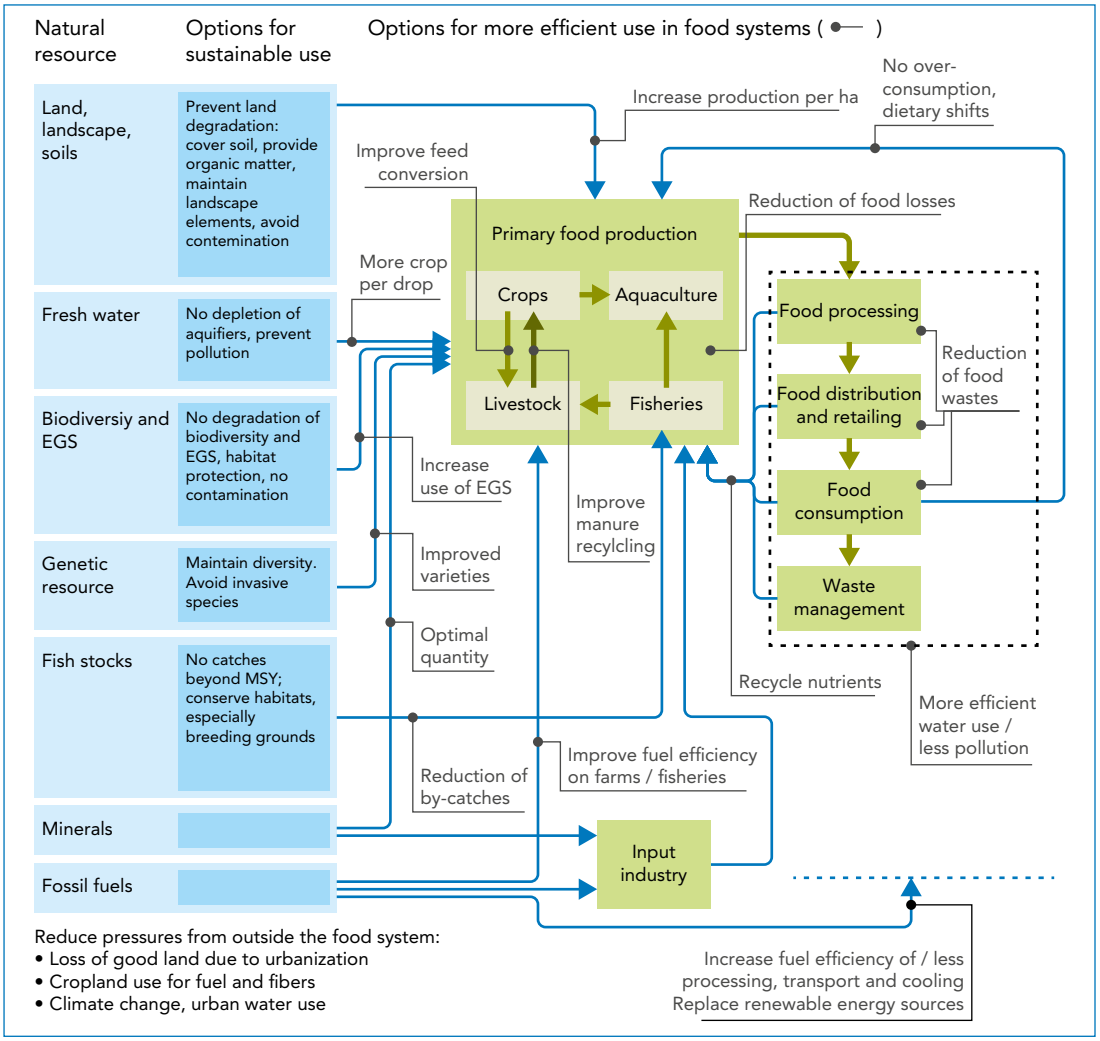
environmental food system impacts. Conversely, trade-offs are also possible. Some of the options can be implemented 'downstream' in the food system including the reduction of food waste at the retail, food service or household level.

There are many options for sustainable and efficient use of natural resources and reduced environmental impacts in food systems. For analytical purposes, the authors propose four main option categories: options to reach a sustainable use of natural resources, options to increase resource efficiency in primary food production, options along the supply chain to increase resource efficiency (including recycling) and options outside the food system. A number of possible measures within each one of these categories are presented in Figure 26.

Table 12 shows, in a very general manner, a few examples of options to reduce the impact of food system activities on resources and the environment. A number of points should be noted:

- Many of the options mentioned cannot be directly achieved but require more specific actions (these are included in the column 'Examples'). For instance, 'increasing crop yields' is an outcome of actions such as improved seeds, better weed control, better fertilization, and so on. This may however lead to certain trade-offs such as loss of biodiversity.

Figure 26 Options for sustainable and efficient use of natural resources and reduced environmental impacts in food systems



The assessment of the environmental effects of the various options is an indication, and only valid in the case of a judicious application.

- The biophysical options are regarded as variable and location-specific with regard to technology and farm scale; for example 'precision farming techniques' may be executed with high-tech equipment and sensors, or with manual labor and human observations.
- A tentative estimate has been made of the impact of each option on food availability.

The fact that a better management of natural resources can truly support better livelihoods is illustrated by a case study from Ethiopia (see Box 9). Rehabilitation of degraded lands and better use of environmental goods and services led to significant improvement in livelihoods of the communities concerned.

Table 12 and Figure 26 contain a large number of 'resource-specific' options, largely aimed at the sustainable or more efficient use of an individual resource. These resource specific options are mainly aimed at the primary production. As the options are not new, and much work already has been done in developing and implanting these options, this report will not focus on these. Still, these are very important and relevant options, especially when implemented in combination. Annex A to this report provides a brief overview of these options, but much more information can be found in the underlying literature.

A number of important lessons can be learned from Figure 26 and Table 12:

- There are many options to move towards the sustainable use of renewable resources, enhance the efficient use of natural resources and reduce the environmental impacts of food systems.
- As the direct use of most renewable resources is related to primary food production (agriculture and fisheries), the practices at this stage largely determine whether the resources are managed sustainably. In the rest of the food system most of the available options target a more efficient use of resources (including recycling). Reduction of pollution is still an important option, in and outside the food system, to guarantee a sustainable use of natural resources.
- A number of options are suggested along the food system, such as a reduction of food waste and dietary changes, which have an effect on the total demand of food production and, therefore, could reduce the pressure on natural resources as well as the environmental impacts.
- Several options proposed at the farm level have simultaneous positive effects on the efficient use of a number of resources, such as improving feed conversion and increasing crop yields.
- Many resource-specific efficiency options have a positive effect on other resources or environmental impacts.
- Figure 26 and Table 12 are comprehensive as they should in principle cover all the points of intervention; however, behind each point of intervention there are many ways of achieving the indicated objective. For example, 'increased crop yields' or 'increased feed efficiency' could be reached by dozens of different measures, often also influencing the use of other resources.

Table 12. Example of options to reduce the impact of food system activities on resources and the environment (including synergies and trade-offs)

	Natural Resources						Environmental Impacts			
Points of intervention	Land, land-scape soils	Fresh water	Bio-diversity	Genetic resour-ces	Minerals	Fossil fuels	GHG emissions	Water, soil, air quality	Food availa-bility / health	Examples
Sustainable use										
Land, landscape soils	+	0	+	0			+	+	+	Soil conservation practices
Fresh water	0	+					0	+	+	No depletion of aquifers
Biodiversity	+	0	+	+			0	+	+	Biodiversity conservation at landscape level
Genetic resources	0	0	+	+			0	0	+	Maintenance of genetic diversity
Efficient use in primary food production										
Increase crop yields	+	+	+	0	+	+	+	-?	+	Sustainable intensification
Improve water efficiency on farms	+	+	0	0	+	+?	0	+?	+	Drip irrigation, reduced leakages
Enhance use of ecosystem services	+	0	+	0	0	0	0	+	+?	Biological pest control
Seeds with more genetic potential	+	?	?	+	+	+	+	0?	+	High yielding varieties
Improve soil fertility, improve efficiency	+	+	+/-	0	+	+?	+	-?	+	Fertilization, better placement
Improve fuel efficiency on farms	0	0	0	0	0	+	+	0	0	No-tillage farming, fuel efficient equipment
Increase feed efficiency livestock	+	+	+	0	+	+	+	+?	+	Better feeding techniques
Improve grassland use / feed efficiency for beef and dairy	+	+?	+	0	+	+	+	0	+	Controlled grazing
Improve manure recycling	+	+	+	0	+	0	+	+	0	Coupling crop and livestock production
Reduce post-harvest losses	+	+	0	0	+	0	0	+?	+	Better storage
Integrated pest management	+?	+?	+	+?	0	0	0	+	+	Application based on pest monitoring
Reduce use of pesticides, antibiotics, etc.	+?	+	+	+	0	0	0	+	+	
Efficient use in food chain										
Improve recycling minerals, including reduction of emissions	+	0?	+	0	+	+?	+	+	+?	Improved integration of animal manure in crop production
Improve water efficiency in food chain	+	+	0		+?		0?	+?		Reduce water use in processing
More efficient fossil fuel use	0?	0?	+		0?	+	+	+		More efficient transport and cooling
Reduction food wastes	+	+	+		+		+	+	+	Reduce post-harvest losses
Less resource-intensive ('sustainable') diets	+	+	+	0	+	+?	+	+	+	Reduce overconsumption, moderate meat intake
Outside the food system										
Reduction use of biofuels and natural fibres	+	+	+	0	+	+	+	+		Less biofuels and fibres from croplands
Reduce pollutants	+	+	+	+	0	0	0	0	+	Control industrial air pollution

(1) + = positive effect /intended or large positive effect; 0 = neutral effect; - = negative effect; ? = effect uncertain. Green shading means directly intended effect. Marine activities are excluded from this overview.

(2) The scores are generally based on expert judgement and indicate a general direction. Large variations may occur in individual cases.

7.4 Brief description of options

This section provides a brief description of the various options, in particular a number of 'overarching' options both on the production side and the consumption side. A number of resource-specific options were already discussed in Chapter 5. It is not possible to give a full description of all options within the framework of this report, partly because of the need for succinctness, but more importantly because almost all options are very context-specific. Therefore, information would need to be available at the national (or in many cases even local) level to obtain consistent information, which is not feasible within the framework of this report.

7.4.1 Options to increase resource efficiency in primary food production

Options to improve the use of natural resources can be divided in options which aim at the improved use of individual resources ('resource-specific' options), while other options (for example improved feed efficiency) have a positive effect on several or even all natural resources. These resource-specific options are essential, and in many situations these options have already be implemented. Nevertheless, there are also ample opportunities to improve the use of various resources. A brief overview of these options is given in Annex 1. For most natural resources there is much literature available on good management practices and options to improve the use of the individual resources. Given the fact that many of these resource-specific options are well-known in a technical sense, this report will focus on their implementation (Chapter 8) as well as on cross-cutting options, such as sustainable intensification and increasing feed efficiency.

Sustainable intensification of crop production

Sustainable intensification can be defined as simultaneously improving the productivity and sustainable management of natural resources, although various, overlapping definitions exist (Buckwell *et al.*, 2014, Garnett *et al.*, 2013, Pretty *et al.*, 2011). Sustainable intensification of crop production is a strategic objective of the FAO. The core idea of sustainable intensification is making better use of existing resources (e.g. land, water, biodiversity), while not undermining the capacity to produce food in the future (Pretty, 2007). Especially for regions with a large yield gap for crops, sustainable intensification is seen as the most important route to increase crop production (both per hectare as well as for a whole region), while minimizing resource use and environmental impacts (AGRA, 2013, FAO, 2011d). For many it is also seen as an important economic opportunity[37].

Although promoted by many, the concept, or at least the actual implementation of sustainable intensification, is also criticized. Some see sustainable intensification as a pretext for the introduction of GM crops, pesticides or free trade (Friends of the Earth International, 2012). Critics fear not only the environmental consequences of these inputs, but also that they would make farmers more dependent on large companies. It should be stressed that sustainable intensification rather denotes a goal, without specifying with which agricultural approach this could be attained (Garnett *et al.*, 2013). The concept does not require certain technologies or the use of certain inputs such as GM seeds or pesticides. It should also be stressed that sustainable intensification does certainly not imply the mechanization of farming by means of farm machinery, nor does it necessarily imply certain inputs or upscaling of farms. Especially for smallholder farms, sustainable intensification might even be a promising route to increase crop or monetary output per hectare, thus obtaining more income from the same area of land (FAO, 2011d).

From a biophysical perspective, there are many ways in which crop yields could increase. These include higher soil fertility (integrated

37. The latest report from TEEB for Agriculture and Food found that "if Senegal was to change all of its irrigated lowland systems from conventional management to SRI (System of Rice Intensification), about US$11 million of savings in water consumption related health and environmental costs would be generated. At the same time, the rice producer community would gain a total of US$17 million through yield increases." (TEEB, 2015).

nutrient management), improved crop varieties, better water supply or utilization of rainwater and improved pest and weed management (for example by biological or integrated pest management). The identification of the most effective measures is very site-specific and no blanket recommendation can be given. In many cases (but certainly not in all) increasing crop yields by taking away the most limiting factor (for example water availability) might not only increase crop yields (thus land productivity), but also the efficient use of other resources such as minerals (fertilizers), fossil fuels and human labor (Ittersum van & Rabbinge, 1997, Rabbinge *et al.*, 1994).

Increase feed efficiency of livestock and improve grassland use

Farmed animals consume around 35% of the total crop production on arable land (Steinfeld *et al.*, 2006). In addition, grassland and other forages are being used, as well as large amounts of co-products (such as oil meals) and by-products (such as molasses). An increase in feed efficiency could lead to a reduced demand for feed crops and thus to a reduced pressure on all natural resources needed for crop production (land, minerals and water). Globally, there are still large differences in feed efficiency (Gerber *et al.*, 2013). 'Closing the feed efficiency gap' is therefore identified as one of the three focus areas of the Global Agenda for Sustainable Livestock[38].

Efforts to increase feed efficiency should certainly not be restricted to confined animals, as it is also relevant for grazing animals. Improved grassland and ranging management has a large potential, given the fact that more than 75% of all agricultural land use is in the form of grasslands.

Concrete measures to increase the overall feed efficiency include improving feed composition, reducing feed losses, better storage of feed, and improving animal health. 'Overall feed efficiency' indicates that it is not only about the individual animal's performance, but that aspects such as mortality, reproductive performance and longevity are important too. Furthermore, feed efficiency should be analyzed in a broader context: if livestock farmers were to shift from by-products and crop residues to crop products with a high nutritional value, the feed efficiency expressed as kg dry matter per kg meat (or weight gain) might improve, but the agricultural system as a whole would become less resource efficient.

However, a very narrow focus on high feed efficiency might compromise animal welfare, animal health or human health. It is well-known that free-range animals have a lower feed efficiency than animals in a restricted environment (De Vries & De Boer, 2010). Fast-growing broilers have a high feed efficiency, but there are also trade-offs with the chicken's welfare and health. Some heavy metals (copper and zinc) and antibiotics promote a high feed efficiency, but have clear environmental impacts or consequences for human health (development of antibiotic resistance).

Reduction of food losses

A final overarching option at the farm level is the reduction of pre- and post-harvest food losses. Improving crop protection worldwide helps reduce losses to pests, disease and weeds, thereby increasing input use efficiency of production. Substantial losses also occur post-harvest, i.e. in drying and storage. The losses can be both physical losses caused by rodents, insects or infestations, and loss of quality and value of crops. The extent of these losses is globally substantial, but hard data are lacking. Estimates range from 5–30% or more. This represents a vast amount of food, along with the wasted cost and effort of producing it. In Sub-Saharan Africa, the post-harvest grain losses are estimated to have a value of USD 4 billion per year (World Bank & FAO, 2011). Food losses can be reduced by better storage techniques (including cooling by natural techniques), on-farm processing and better transport from rural areas to urban areas. In Chapter 7 a brief analysis of the causes of food losses will be presented.

38. http://www.livestockdialogue.org/en/

7.4.2 Options to increase resource efficiency along food systems

Reducing food waste

Reducing food waste is a very important option to increase the total resource efficiency of the food system. Although there is still discussion about the exact extent of food waste, it is clear that reducing waste could have a significant effect on reducing resource use as well as on food availability. Around the globe, many actors are already actively working to reduce food waste (see Box 7).

Food waste does not have to be completely lost for the food sector. Some food 'waste' could even still be used for human consumption, as for example certain vegetables that do not match specifications set for appearance (size, shape and color). Food waste (as well as by-products) can also be used as feed and thus converted into high-value products such as meat and dairy. Finally, food waste can also be used as bio-energy or (in the form of compost) as a soil amendment. From the perspective of minerals, it is important that the minerals contained in food waste are recycled.

Recycling of nutrients along food systems

Minerals, such as phosphorus, potassium, zinc and many others (See Chapter 5) are transported through the food chain, ending up in waste and human excrements. Recycling nutrients can both reduce the need for new input of these minerals, while simultaneously reducing nutrient losses. An example is the collection and composting of organic urban waste in Surabaya (see Box 8).

Less resource-intensive (more 'sustainable') diets

A shift towards less resource-intensive diets would contribute to a significant reduction in resource use and environmental impacts of food production. In some cases there could be synergies between healthier diets and less-resource intensive diets. This option is not only relevant for affluent countries, but certainly also for emerging and developing countries, where the share of people who are overweight or obese has increased rapidly in recent years.

Main components of such a shift are:

- Reducing the total food (energy) intake: overweight and obesity are related to an excessive intake of total energy. Lowering this intake will not only be beneficial for human health, it also reduces the total food demand.
- In regions with currently high consumption rates of meat, dairy and eggs: reducing the consumption of these products to a 'moderate level'. This would lead to considerable reduction in natural resource use as the production of these foods generally requires much more resources (and leads to higher

Box 7 'THINK EAT SAVE' – Global engagement for the zero hunger challenge

The United Nations Sustainable Development Goals include a 50% reduction target for global food waste by 2030. The UN Secretary-General launched the Zero Hunger Challenge, presenting an aspiration goal for zero food loss and waste.

To work towards this vision, UNEP launched the Think Eat Save initiative in 2013 as a public awareness-raising and engagement activity to catalyze global action. In May 2014, UNEP, FAO and WRAP, launched the Think Eat Save guidance for governments and businesses on mapping, planning and delivering an effective food waste prevention strategy (FAO, 2011b). UNEP is currently developing pilot studies to support countries, cities and businesses in implementing this step-by-step methodology. Benefits of piloting the guidance include the development of a local action plan with concrete socio-economic and environmental benefits with the support of a globally-recognized UN initiative and its expert team, enabling participants to build on existing activities and experiences to accelerate change.

Box 8 Reducing waste in Surabaya through composting and multi-stakeholder collaboration

With three million inhabitants, Surabaya is the second largest city in Indonesia. Waste is a major environmental concern and solid waste management a huge burden on the city's budget. In the framework of a city-to-city cooperation with Kitakyushu (Japan), Surabaya authorities were able to reduce daily waste by more than 20% from 1500 to 1000 tonnes a day. The process was organized as a multi-stakeholder cooperation. The focus was on organic waste, which accounts for 55% of the city's total solid waste. Between 2005 and 2009, Surabaya authorities intensively promoted composting practices among households and established composting centers for public operation.

Pusdakota's community-based composting centre (Photo courtesy of KITA)

Surabaya City's market-waste composting centres

Composting centres in Surabaya

The initiative started in 2004 as a pilot model for efficient solid waste management in a community run by KITA (techno-cooperative association) from Japan and a local NGO (Pusdakota). After a period of testing composting methodologies, training households and distributing composting baskets, Pusdakota started to operate as a community waste station and collected organic and inorganic waste separately from households to produce high quality compost. After initial success, the city authorities started to scale-up this initiative, in close cooperation with KITA, civil society organizations, media and private companies. Between 2005 and 2011 over 80,000 households were trained on composting. Composting baskets were distributed freely to 19,000 households, local campaigns were carried out and additional composting centers were established, 14 of which are operated by the city. The city purchased baskets from Pusdakota and outsourced the distribution to a local women's group and NGOs.

Eventually these composting centers proved to be profitable, and the rate of return of investments has been estimated to be just over two years. Another interesting finding has been that every kg reduction in organic waste leads to 1–2 kg reduction of other types of solid waste, probably because organic waste separation encourages the reuse and recycling of other dry waste materials.

Similar projects have started in other cities in Indonesia, and the approach has been disseminated to the Philippines and Thailand. An important lesson from these initiatives is that financial and political support from local governments is essential for local groups to start up the operation of composting centers, as they are not able to bring up the investment costs and the demand for compost may fluctuate. Another lesson is that NGOs and community groups have also played an essential role as mediators in the process of the scaling-up and cross-sharing of experiences and good practices.

Source: (IGES, 2009)

GHG emissions) than plant-based alternatives such as cereals and pulses. As many livestock products contain saturated fats, a reduction in their consumption will also have health benefits. In many developing and emerging countries too, certain groups (notably in cities) have also geared towards high consumption rates of animal products.

- Reducing the intake of certain beverages such as soft drinks, alcoholic beverages and bottled water as these have generally low nutritional value but a high resource use (especially for transport, packaging and cooling).

There is not always a synergy between 'healthier' and 'sustainable'. Examples where there are trade-offs are a higher consumption of fatty fish, fruits and vegetables. In regions with diets that are low in nutritional value, an increase in meat and dairy consumption (to a moderate level) could have positive health outcomes as meat and fish contain essential nutrients and minerals.

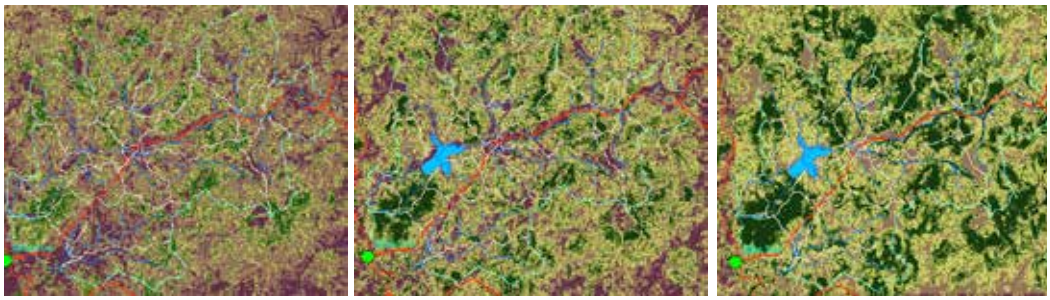
Box 9 Case Study: Impacts of MERET Project on environment and livelihoods

MERET (Managing Environmental Resources to Enable Transitions to sustainable livelihoods) is a community-based and people-centered land rehabilitation and livelihood improvement project of the Government of Ethiopia that has been supported by WFP-Ethiopia since the mid-1980s (FAO, 2015d).

Rehabilitation of degraded lands and enhancement of environmental goods and services constitutes the core component of MERET. Land degradation and associated poverty was a major challenge in many parts of Ethiopia resulting in extreme food insecurity. Reform of government policy towards addressing environmental degradation through participation of communities and aligning resources from development partners were the major driving force of the initiation of this project. After its success in improving the lives of local communities, the market became a major driver for its continuation. .

The on-site and off-site benefits of MERET are noticeable features of the treated watersheds. Taking a few key biophysical impact indicators, it was observed that MERET was able to induce significant positive changes in the overall vegetation cover, reduction of current rate of soil erosion, improve in soil productivity, improve hydrologic regime and overall change in the micro-climate of the watersheds and their surroundings (Figure B.4).

Figure B.4 Changes in environmental services and goods of watershed treated by MERET Project



Enemerid/M.Shewito (Adwa) in 1986 Enemerid/M.Shewito (Adwa) in 2000 Enemerid/M.Shewito (Adwa) in 2010

(Source, WLRC, 2013)

The outcomes achieved in the domain of watershed rehabilitation combined with homestead development interventions and other income generating activities have brought about enhanced food security and positive livelihood impacts to beneficiary households in the sub-watersheds. The observed impacts include (i) increased crop production and productivity, (ii) increased livestock productivity, (iii) incomes from sale of grass and wood from closed areas, and (iv) increased household incomes from homestead development and income generating activities (See Figure B.5).

Figure B.5 Changes in asset at HH level due to integrated homestead development in Ana Belesa watershed, Lemu, Ethiopia

Source, WLRC 2013

(a) house before project intervention, (b) mid-project and (c) end of project. The picture in the left shows a combination of interventions around the homestead including water harvesting.

Box 9

In terms of adaptation to and mitigation of climate change, MERET has constituted a range of local level adaptation responses which are already responding to climate variability and are vital to enhance resilience to future impacts of climate change. In more specific terms, the achievements of MERET include: (i) unproductive and degraded wastelands have been turned into productive lands for crop production, forage production or woodlands; (ii) integrated application of erosion control and moisture retention measures with soil fertility treatment, mainly compost, has led to increased productivity and yields from cultivated lands; (iii) soil and water conservation has, in some cases, made possible the use of chemical fertilizers and improved crop varieties in areas where this had become impossible due to moisture stress, (iv) rainwater retention within catchments has increased surface and underground water availability and created opportunities for small scale irrigation in downstream areas and reduced flood damage to downstream areas; and (v) household level rainwater harvesting efforts have enabled introduction and production of a wide variety of fruit trees and vegetables formerly unknown to the communities which diversifies income and nutrition at the household level.

MERET communities have become more resilient to climate change, and their livelihoods has significantly improved going from being highly dependent on food aid to becoming self-sufficient and connected to the market.

7.4.3 Options outside the food system

Reduce the use of biofuels and natural fibers

Reducing the use of biofuels and natural fibers is an option largely beyond current food systems, but as their production requires similar resources as food (land, water and minerals) they should be briefly mentioned here. Biofuels (mainly produced from maize, sugar cane and oil seeds) now occupy around 4–5% of the global cropland area (OECD & FAO, 2014). Their production and use is often stimulated by legislation as mandatory. A lower production of biofuels would in principle make more land available for food production and reduce the need for new cropland (UNEP, 2014). Also the production of natural fibers (such as cotton) requires significant amount of resources, such as land and water.

7.5 Potential effects of options

What could various options achieve in terms of a more sustainable and efficient use of natural resources and reducing environmental impacts? In various studies, the potential effect of a number of the options (as mentioned in Table 12) has been assessed. These studies are very diverse in character: they vary in geographical scope (from national to global), the ways in which options are modelled (individual options versus combination of options) and results (ranging from effects on GHG or nutrient emissions to food security). A common issue is that few studies are able to model the effect on the sustainable use of natural resources and most models struggle to incorporate feedback loops (unsustainable use of natural resources leading to degradation of resources which leads to a lower potential in crop yields, water availability, biodiversity, fish stocks).

There are several useful examples:

- A recent IFPRI publication assessed the potential effect of a number of technologies (such as no-till, precision agriculture, drip irrigation and nitrogen-use efficiency) on crop yields, prices and food security. The technologies that lead to the highest yield increase (15–32%) are no-till (for maize and wheat), nitrogen-use efficiency (maize and rice), heat-tolerant maize varieties and precision agriculture (rice and wheat) (Rosegrant *et al.*, 2014). Many of the technologies also lead to lower nitrogen losses, lower water use and higher water productivity (especially drip irrigation). Many technologies lead to a lower harvested area (0–10%). Projected kilocalorie availability improves, while the number of malnourished children decreases by up to 9% in certain regions.
- A number of pathways are analyzed in the *Roads from Rio+20* study (PBL, 2012). All of these pathways (apart from the Trend scenario) assume that undernutrition is eradicated, thus more calories are needed. The Global Technology Pathway addresses most of the issues through production increase. In the Consumption Change pathway, an assumed

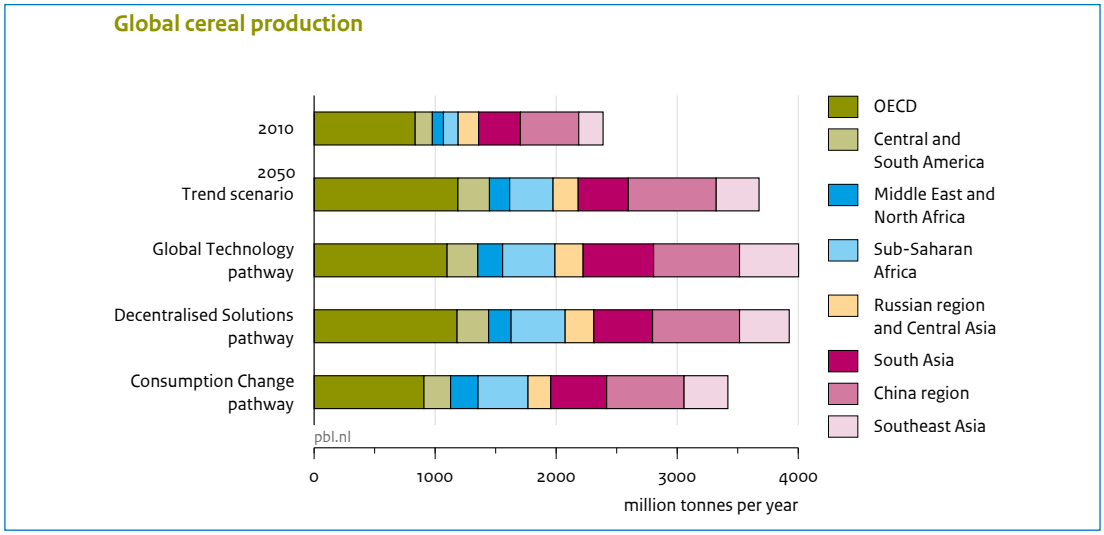
reduction of food wastes and losses and levelling off of meat consumption in richer countries will result in 15% less cereal demand compared to the Global Technology pathway (Figure 27). This shows the huge potential of reducing food demand through dietary changes and reducing food wastes and losses to reduce the pressure on natural resources and reduce environmental impacts.

- Over the last five years, many studies have looked into the effects of dietary changes. For example, (Tilman & Clark, 2014) reported that per capita GHG emissions of the projected 2050 diet would be reduced by 30%, 45% and 55% if people were to change to a Mediterranean, pescetarian and vegetarian diet respectively (Tilman & Clark, 2014). All the alternative diets would also have significant health benefits, and global land use would also be significantly lower. Similar results have been found by (Stehfest *et al.*, 2009).
- A recent study showed that halving the amount of meat, dairy products and eggs eaten in the EU would result in a 40% reduction in nitrogen emissions, a 25–40% reduction in greenhouse gas emissions, and 23% per capita less use of cropland for food production (Westhoek *et al.*, 2014). In a case study for three European countries, it was found that a change towards healthy and sustainable diets would lead to a reduction of GHG emissions from food production by 25% (Macdiarmid *et al.*, 2011).
- Although good integrated assessments of the combined potential of various options are lacking, findings from studies looking at individual options indicate that these could lead to an estimated 5–20% improvement in efficiency; when combined, the increase could be up to 20–30% for certain resources and impacts, assuming limited rebound effects.

7.6 Summary and conclusions

There are many options to enhance the sustainable management and efficient use of natural resources, in all food system activities. In most cases, this will also lead to lower environmental impacts, for example by reducing nutrient losses (in the case of the more efficient use of fertilizers), GHG emissions (in the case of a more efficient use of fossil fuels) and water use (in the case of more efficient food processing).

Figure 27 Effect of various scenarios on cereal demand



Source: (PBL, 2012)

(1) By 2050, global cereal production would increase by 54% under the Trend scenario, compared to 2010. Production in the Decentralized Solution pathway is lower than in the Global Technology pathway because policies especially target access to food for poor people, whereas the Global Technology pathway focuses on low food prices for all. The lower cereal production especially in OECD countries in the Consumption Change pathway is caused by the particularly large reduction in the consumption of meat and egg products.

Options to attain a sustainable use of renewable resources (land, soils, water, and ecosystem services) are largely connected to farmers (including aquaculture) and fishermen, as they are typically the main users of these resources. Potential biophysical options are the prevention of land degradation (e.g. by keeping the soil covered and by using soil amendments as compost), limited water use to prevent depletion of aquifers and the inclusion or conservation of biodiversity in agricultural landscapes. An important measure for *fisheries* is balancing fish catches with their ecological carrying capacity.

There are many **options to improve the efficient use of natural resources** in agricultural systems. *Sustainable intensification* is an important route, mainly increasing crop yields with no negative effects on other resources and no additional environmental impacts. Other important ways to improve resource efficiency are better water management (both of rainwater and irrigation water), a more effective use of ecosystem services (for example for pest and disease management, which could reduce the use of pesticides), and better nutrient management. An important route to improve nutrient efficiency is the closing of the crop-feed-manure loop. This loop is now often broken due to a spatial segregation of crop and livestock production. There are good opportunities in pastoral livestock systems to increase production while using the same amount of natural resources (mainly land, including ecosystem services and genetic material). In pig and poultry production, opportunities exist to increase feed efficiencies.

On the demand side, the reduction of food losses and waste is a crucial route to improving the resource efficiency of food systems. The main causes of food losses in the field are pests and diseases. Post-harvest losses are often due to inadequate storage allowing rodent and insect damage, insufficient processing capacity at the farm or local level and other logistical issues. Food availability in rural areas in developing countries will generally benefit from a reduction in past-harvest food losses. There is no simple, single solution to the reduction of food losses and waste. In many cases, systemic solutions are needed, such as improving rural infrastructure or changes in the institutional configuration. Food waste and residues from food processing still contain valuable minerals and organic substances which could be recycled to farms, for example in the form of feed or compost. Food waste might also be used for energy production, for example through industrial digesting.

Changes in food consumption patterns have a significant potential to reduce the use of natural resources and environmental impacts. In affluent societies, people currently consume relatively high amounts of various animal products (meat, eggs, dairy and fish). In general, a shift to a more plant-based diet would lead to lower resource use as well as to healthier diets, because of the lower intake rate of saturated fats as well as of red and processed meat. For hungry and undernourished people the situation is obviously different.

There are thus significant opportunities to reduce resource use on the consumption side. A reduction in food loss and waste, and a levelling off of meat and dairy consumption in richer societies could for example result in a 15% lower global cereal demand compared to a baseline scenario.

Credit: Marco Alhelm, Shutterstock.com

Chapter 8

Opportunities for a transition towards sustainable food systems

8.1 Introduction

A sustainable food system is defined as '*a food system that ensures food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition of future generations are not compromised*' (HLPE, 2014a). Chapter 4 of this report demonstrated that current food systems do not result in proper nutrition for many people in different world regions. Chapter 5 established that, in many cases, natural resources are not managed sustainably or efficiently throughout food systems, leading to risks for future food supply as well as high and increasing environmental impacts. Chapter 6 analyzed the contexts in which food systems operate, many of which lead to an unsustainable or inefficient use of natural resources. Chapter 7 demonstrated that there is a large range of biophysical options to improve the use of natural resources in food systems.

This chapter presents the institutional options to move towards environmentally-sustainable food systems, exploring how a transition in this direction could be stimulated. It provides a thinking framework illustrated by some exemplar actions currently taking place within food systems.

8.2 Limitations and the need for realism

First, it should be stressed that the necessary transition will mainly involve adaptations *within* a given food system (as described in Chapter 3). The type (or types) of food systems in a certain region is mainly the result of the prevailing socio-economic and biophysical contexts, and the transition pathway needs to be developed within those contexts.

When trying to identify pathways towards sustainable food systems a number of factors mean that some realism should be observed:

- Food systems are globally very diverse as well as complex and dynamic (Chapter 3). This implies that there are no 'universal' solutions,
- Moreover, such a transition has many features of a 'wicked' problem (Allen *et al.*, 2011, Ludwig, 2001). Food systems are not only complex; there are many differences in perception in society on the critical issues and challenges, as well as on pathways forward. There is also considerable disagreement on the role governments could (or should) play.
- Food systems are more and more governed by private actors (Schilpzand *et al.*, 2010a), acting across national borders, making it harder for governments to exert influence (Schilpzand *et al.*, 2010b). Due to urbanization and globalization the spatial, and –although harder to prove – mental disconnect between food production and food consumption is growing. This makes it harder for consumers to influence production practices, but certainly not impossible.
- There is a significant lack of information concerning both the current state of natural resources for, and the environmental impacts of, food systems (Chapter 5);

These factors do not mean nothing is possible, as will be shown in the rest of this chapter. It is however important to make the point that, given different interests and the huge complexity, no 'blue-prints' or general recommendations can be provided. Making progress towards sustainable food systems will imply 'muddling through' (Sayer *et al.*, 2013). Incremental improvements are therefore important to make progress. The massive challenges do however justify *radical incrementalism* (Hajer, 2011). In most cases, it will require learning-by-doing and adaptive approaches (Allen *et al.*, 2011, Ludwig, 2001, Sayer *et al.*, 2013). Given the large global variation in food systems, this report can only be generic and provide a framework of thinking, underlining that actual actors on the ground have to cooperate to make food systems more sustainable and healthier.

8.3 'Principles' and importance of the 'food system lens'

The motivation to apply a 'food system lens' has been provided in Chapter 2 and the following chapters have supported the value of such an approach: using a food systems approach is an important method to identify and analyze issues around food systems and natural resources, as well as to identify concrete options and opportunities for change. Governments, researchers and private actors often focus on farmers and fishermen to attain a more efficient and sustainable use of natural resources, or on one issue ('carbon footprints'), or on one commodity. Some examples are:

- resource-oriented policies and actions, for example targeting sustainable land use (Sayer *et al.*, 2013, Scherr & McNeely, 2008, Verburg *et al.*, 2013), efficient use of nutrients (Oenema *et al.*, 2007, Sutton *et al.*, 2013, Sutton *et al.*, 2011b), and water use (De Fraiture *et al.*, 2014, FAO, 2011e, HLPE, 2015, Hoekstra & Mekonnen, 2012, WWAP, 2015).
- commodity-oriented policies, for example around soy beans (Nepstad *et al.*, 2014, RTRS, 2010) and palm oil (Oosterveer *et al.*, 2014, RSPO, 2013), or in general production chain oriented (Oorschot van *et al.*, 2014).
- issue-oriented policies, for example reduction of food waste (Gustavsson *et al.*, 2011, HLPE, 2014a), climate-smart agriculture or dietary changes (FAO, 2010, Tilman & Clark, 2014, Westhoek *et al.*, 2011).

All these approaches certainly have their merits and should be mainly continued, as in a many cases an approach that targets one commodity or one resource might be very effective. In other cases, a food system lens has added value, as it looks systematically at both mechanisms and actors in the food system, and not only at the level of primary production, but along the food chain. The approach also looks at aspects of food consumption, food loss and waste. The food system lens can thus facilitate reframing the thinking in terms of '*resource-smart food systems*'.

In a food system approach one actor can stimulate another to take action, as in the case of MSC fisheries where food companies and supermarkets enable fishermen to adopt better fishing techniques (see Box 11). Or governmental programs for school lunches lead to better nutrition but can also stimulate local farmers' choices (see Box 12).

Finally, it has to be acknowledged that the food system approach is based on a 'vertical' food chain concept, identifying where food systems activities interact with natural resources. There are many other factors besides food system activities involved in natural resource management warranting a more 'horizontal' landscape approach, which also addresses other activities in landscapes. These landscape-level considerations need to be seen as complementary to the integrated food system approach.

8.4 Analysis of national or regional food systems and impact on national resources

Given the limitations of a general, global approach, it is suggested that governments and other actors operating at a national level (or at city level) start with a comprehensive analysis of the national food system. This can assist in the identification of the most important issues regarding natural resources as used in national food systems, as well as effective opportunities for intervention. The level or type of analysis (country, regional; local, urban) depends on the goal. As a first step, it is good to realize (see also Chapter 2 and 3) that the 'food production system' (including agriculture, fisheries and related food processing) generally does not geographically coincide with the 'food consumption system' (see Figure 28), and hence the importance of

trade and transport infrastructure. Part of the national (or local) production is usually exported to other regions, and part of the consumed food is imported. The share of imported or exported food in the total food production and consumption does not only depend on the share of food that is produced at the given level, but also on the related socioeconomic and political contexts. The difference between nationally- (or locally-) produced food and imported food is relevant as national governments generally have more influence over national natural resources as needed to support the food system, then they have over those used to produce food elsewhere in the world. The growing urban populations are a special case as almost all of the food will come from outside the city's boundaries. In this case, a food systems approach is particularly useful. There are many opportunities to improve national resource efficiency by actions at city level, for example by promoting small-scale horticulture (which significantly helps nutrition and livelihoods), reducing food waste, promoting different diets and by recycling food residues and nutrients back to the rural areas. To assist in this analysis, a draft framework has been developed, but this should be seen as a first step, which should be further developed and improved (see Box 10). The FAO has also developed a set of indicators on good governance, natural use and social well-being (FAO, 2013c).

Box 10 Draft framework for analyzing national food systems, with focus on national resources

On the present prevailing food systems

1. What is the prevalent type of food system? Who are the principal actors? What is the relation between national food production and food consumption?
2. How is food production (farming, fishing) organized? What farms and fishery types are dominant? What is the size and nature of livestock and aquaculture production?
3. Where is primary and secondary processing done and by whom?
4. Where is food being transported from and how?
5. How is food consumption being organized? What is the share of supermarkets and out-of-home consumption in total expenditures?

On natural resources:

1. What is the nature and extent of land use: is there expansion or contraction of the agricultural area? What is the situation regarding land degradation? How are crop yields compared to similar regions / potentially attainable yields? How is pasture land being used?
2. How are fisheries managed? What is the status of fish stocks? Is there aquaculture, and what are the related environmental impacts?
3. What is the situation regarding plant and animal breeds: availability, diversity, quality, genetic potential?
4. What is the nutrient use efficiency, amount of nutrients (minerals) being used, nutrient losses?
5. Is water being used sustainably and efficiently in irrigation and food processing? Are groundwater levels being monitored? Is there potential for expansion of irrigated area?
6. What are the amounts and proportions of fossil and biomass fuel used in which food system activities?
7. What are the overall environmental impacts: GHG emissions, nutrient losses, pesticide emissions, soil and water quality?
8. How are property rights and land tenure organized?

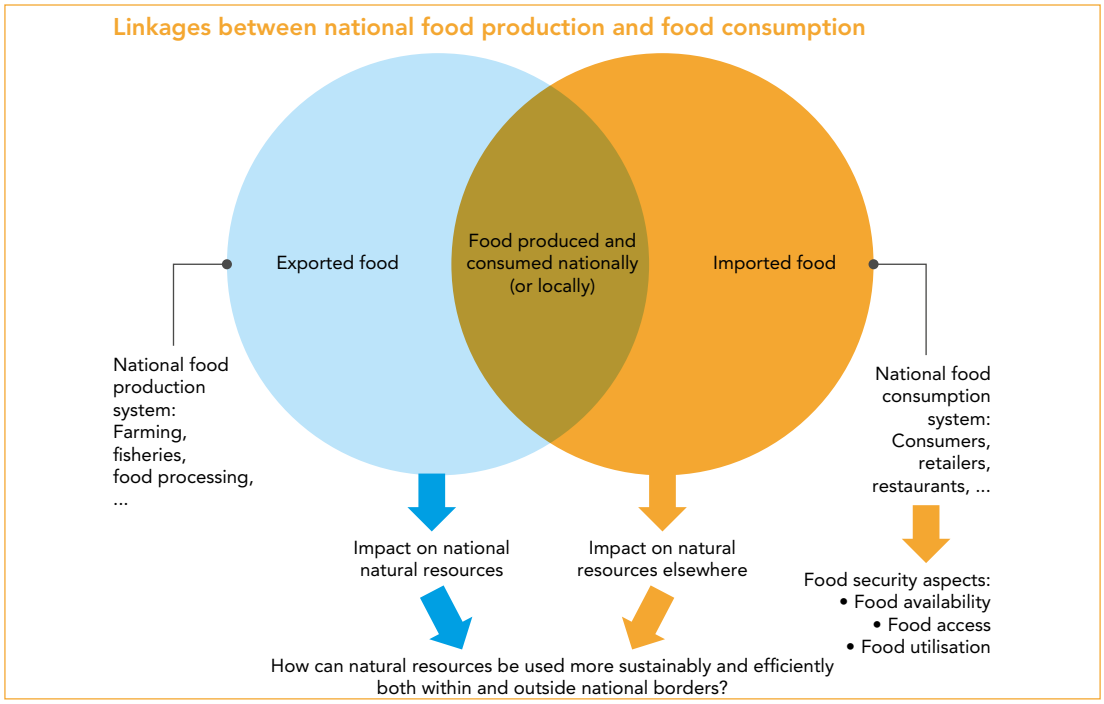
With respect to food demand:

1. What is the food security situation (stability of food availability, food access, food utilization)?
2. What is the nutritional security situation (prevalence of undernutrition, overnutrition, other forms of malnutrition? What is the trend in diets over the last 10 – 20 years? What are the expectations for the future? What is the share of livestock products in diets?
3. How much fossil fuels and packaging are used in food consumption?
4. How much food waste occurs? What is happening to food waste, food residues and human excreta?
5. What is the fate of nutrients entering urban food systems?

With respect to actors, institutions, regulation:

1. What kinds of regulation are in place to regulate food system activities, and the use of and access to natural resources?
2. What kinds of environmental regulation are in place? How are they implemented and enforced?
3. Which subsidies are installed? What is the tax regime? Are there import and export tariffs?

Figure 28 Schematic representation of a national (or regional) food system, disaggregated into a food production and consumption system



8.5 Three pathways towards environmentally-sustainable food systems

Drawing from the transition theory (Haan de & Rotmans, 2011) three *governance dynamics* or 'pathways' can be distinguished that have the power to reshape current food systems, and hence their interactions with natural resources. These governance dynamics are (i) reforms by governments and international institutions; (ii) adaptations by food system actors; and (iii) alternative (niche) innovators. The question of how these three pathways interact and co-evolve largely depends on the context and the type of food system.

8.5.1 Reforms by governments and international institutions

National and local governments play an important role in pursuing public goals like human health, education, the sustainable use of natural resources and the mitigation of environmental impacts by human actions. States are often the legitimate authority to establish legal frameworks and their decisions give direction to societal change. Aside from national governments, international institutions play an important role for similar reasons. International trade agreements (either in the framework of the WTO or bilateral agreements) have an influence on a country's agricultural and fisheries sectors. Governments can intervene in the functioning of food systems by creating positive and negative pressures and incentives, by initiating public debates and by triggering people and businesses to think in new directions. An overview is given in Table 13 of existing regulations and entry points that states, local authorities, international institutions and other actors could use to initiate change in food systems to promote the sustainable use of natural resources and reduce environmental impacts.

One of the priority areas for government reforms, particularly in lower income countries, is to establish clear property and tenure rights regimes for natural resources (see Chapter 6). It must be

noted that decentralized government units often lack the financial and administrative capacity for the allocation of resources and are often unable to solve natural resource-related conflicts. At the international level, global guidance is useful for national governments in setting up land use and land tenure laws and ensuring their local implementation and enforcement, as for example is done in the Voluntary Guidelines on Responsible Governance of Tenure of Land and other natural resources by the Committee on World Food Security (CFS, 2012b). Another priority issue for government reform especially in low income countries is the need for investments in rural infrastructure including irrigation, water supply, roads and services that enable both local production and 'value-addition' activities such as processing and packaging (HLPE, 2013b, World Bank, 2007).

Incentives for food systems actors, to prevent them from imposing negative externalities can stem from environmental regulations (e.g. environmental standards) or pricing externalities. To be effective it is important that legislation is binding and enforced both at international and national levels. At the national level, governments can initiate *environmental fiscal reforms* that tax and discourage non-sustainable production practices; this could for instance be done through policies that put a price on greenhouse gas emissions, nutrient leakages to groundwater or water use. Another measure that could trigger improved use of resources is the creation of markets for resource 'stocks' such as for water (OECD, 2010), or financial incentives for natural resource users through PES schemes (FAO, 2007).

Another priority area is the removal of subsidies that encourage unsustainable or inefficient production or practices like the subsidies for fossil fuels that stimulate for example water extraction for irrigation or unsustainable fishery practices (see examples in Chapter 5 for both). Price subsidies for agricultural commodities (for example for rice and sugar), which are generally distorting and lead to overproduction and inefficient practices (see also Chapter 3), could also be revisited by national governments (OECD, 2013c). Other policies that could be revised are targets and subsidies related to biofuels. Countries could reverse the demand for biofuels by eliminating the direct and indirect subsidies to produce fuel crops and by phasing out biofuel quotas (HLPE, 2013a, UNEP, 2009, UNEP, 2014). There are already various examples of environmental policies in the form of environmental regulations or taxations of pollution, for instance the EU Nitrates Directive (Velthof *et al.*, 2014) and EU pesticides measures. It should however also be noted that, in many countries, such measures have often met with resistance. Reporting on the implementation of such regulations in the EU, US and Canada, (Grossman, 2006) shows the difficulty of applying the polluter pays principle to agriculture, as it is complex both to control diffuse emissions from agriculture and to allocate responsibility for the remaining emissions.

Aside from regulation and financial policies, policy interventions could include the development of physical infrastructure (especially focused at rural infrastructure), capacity building for best farming practices, and measures to improve a better functioning of markets (with special attention to the position of smallholders and consumers). Evidence from Asia and Africa has proven that investments in rural infrastructure, agricultural research and extension have large impacts on agricultural productivity and poverty reduction (Fan, 2010, HLPE, 2013b). Rural Areas are critical points of intervention in the food system considering most of the poor populations in the world depend directly or indirectly on agriculture to produce their own food and generate their income. With improved rural infrastructure and relatively simple technologies, some quick and significant gains can be made in terms of reducing pre- and post-harvest losses in low income regions (HLPE, 2014a, Lipinski *et al.*, 2013). Governments in many low income countries however often lack sufficient capital and infrastructural development often does not materialize. Considering the magnitude of the need and the potential benefits to food systems as a whole, it is in the interest of many to pool resources and invest in rural infrastructure and services.

Table 13. Non-exhaustive overview of current policies influencing directly or indirectly food systems and the use of natural resources

Aspects	International institutions	National governments	Local authorities
Agriculture	Trade policies and agreements Common principles for agricultural practices Research and innovations relevant for vulnerable groups and environments	Agricultural policies Sustainable Public Procurement Policies Mainstream (private) standards and certification schemes Rural investments (infrastructure, rural services)	Iterative technology development with farmers Institutional strengthening of local groups and farmers (cooperatives, water groups, farmer field schools, etc.) Local extension services
Fisheries	Treaties on fisheries (200 miles zone, UN Fish Stocks Agreement) in High Seas, Code of Conduct for Responsible Fisheries for fisheries;	Standards for fish stocks, genetic diversity, rules and guidelines for aquaculture Standards for sustainable fishing	Formal and informal arrangements on fishing rights, quotas, etc.
Resources	International Treaty on Plant Genetic Resources for Food and Agriculture; (Voluntary) Guidelines on Responsible Governance of Tenure of Land and other natural resources (CFS and FAO); UNCCD	Property rights regimes, legal frameworks Markets for resource stocks (water, fish) PES schemes Laws for genetic resources	Resource allocation and (integrated) resource use plans Monitoring quality and quantity of resources Local breeding programmes and seed banks Urban infrastructure (waste, sewage, water reuse)
Environmental impacts	Various conventions and processes (UNFCC, CBD, IPCC) UN – System of Environmental-Economic Accounting 2012 / Experimental Ecosystem Accounting (SEEA)	Environmental regulation (pesticides, fertilizer, water quality, waste disposal) Eliminate harmful policies and subsidies (biofuels, water use, pesticides, etc.)	Monitoring/taxing environmental standards Waste management (and reuse)
Food safety	SPS (The Agreement on the Application of Sanitary and Phytosanitary Measures); Codex Alimentarius (International food standards)	Food security policies (for example minimum stocks of notably cereals)	
Food and health	International guidelines (WHO)	Regulating the food environment (stricter rules on marketing, promotion, labelling, etc.) Dietary guidelines National campaigns to promote diets.	Local regulation of the food environment Cooperation with retailers to establish codes of conduct
Food security	SDGs, Zero Hunger Challenge, etc. Committee on World Food Security (CFS)	Food programmes Price support to farmers National food stocks	Local food stocks
Economic and fiscal policies	Treaties and Voluntary Agreements on investments and business practices (e.g. UN Global Compact, FAO / OECD guidelines). Principles for responsible investments in agriculture and food systems (CFS 2014)	Regulations for sustainable sourcing (adopt and mainstream standards, certification schemes) Environmental regulations and fiscal reforms (tax on using inputs or related pollution) Subsidies (water, fertilizers) Changes in anti-trust laws	Monitor contractual agreements farmers-buyers Rules and regulations for retailers/food industry to source locally Pool private investments for rural development
Food and waste (including recycling of nutrients)	Establish guidelines, indicators and international targets for waste reduction and monitoring	National Waste Reduction strategies and targets Regulations and taxes on waste disposal Subsidies for new technologies Facilitating of multi-stakeholder platforms	Local wet markets Urban infrastructure (waste, sewage, water reuse) Municipal waste management and reuse Local strategies to prevent and reduce food waste
Food and education	Global Food Education campaigns (e.g. Think, Eat, Save)	Inclusion of food in primary and secondary school curriculums Regulations on labelling Information campaigns Institutions for consumer and health protection	Educational programmes and campaigns School gardens Composition of school meals Local information campaigns

8.5.2 Private actors

In the past few decades, a shift has occurred in the governance of food systems from public to private actors, which is largely related to the 'rolling back' of the state as outlined in Sections 3.4.1 and 3.4.2. Many businesses recognize the pressures on natural resources and food systems and have started to perceive these as threats to their – possibly long-term – operations. Consequently, many businesses are experimenting with innovative business models and adapting their strategies for more sustainability (KPMG, 2012). These dynamics can be referred to as the adaptation pathway in which change is initiated from within the prevailing system and by actors that already determine its current functioning. Forerunners in the food system thus act as main agents of change on a voluntary basis and apply self-steering mechanisms.

Businesses increasingly recognize the need to take steps towards sustainability and act individually or collaborate around technological innovations with other businesses, civil society organizations and governments at a pre-competitive stage. Several examples of ongoing private initiatives are given in Table 14. The Sustainable Agriculture Initiative Platform (SAI) is an example of a private initiative that brings around 50 leading businesses together to cooperate on a joint agenda. These businesses jointly analyze problems, formulate shared values, goals and standards and monitor and support each other in the implementation of agreed sustainability measures. Multi-stakeholder platforms are another form of collaboration with a diverse and flexible membership base that attempt to tackle issues at a sector or supply-chain level and over a longer period of time. Examples are The Roundtable on Responsible Soy (RTRS), the Roundtable on Sustainable Palm Oil (RSPO) and The Global Roundtable for Sustainable Beef (GRSB). These initiatives thus can potentially lead to shifts towards sustainable production in some sectors. However, it has to be noted that businesses are mainly profit-driven, and that they will only undertake actions to a certain levels of costs. One of the reasons is the fear of 'free-riders', companies who do not take action but who profit from actions taken by others. Another mechanism is 'green-washing', where companies overstate their actions or claims on products, in order to meet consumer demand for environmentally friendly goods and services.

Proactive companies in the food sector, as in other sectors, have essentially three drivers to work for sustainable food systems:

1. Supply risk management: through various sustainability innovations, businesses try to secure continued crop supply, which is fundamental to their business operations.
2. Improve reputation: increasing pressure by consumers in the marketplace, but mostly by civil society opinion steered by pressure groups and NGOs, demand a proactive action by private companies in manufacturing and retail sectors (particularly those facing the consumers, but increasingly also their big suppliers of commodities and raw materials). These companies realize that unless they can prove due diligence in their operations they risk losing consumers who are increasingly aware and informed.
3. Sustainability as a business model: companies that believe in sustainability as the only valid way of doing business and work under the assumption that only proactive companies who do their bit and beyond to ensure sustainability will win in the marketplace.

8.5.3 Alternative (niche) innovators and NGOs

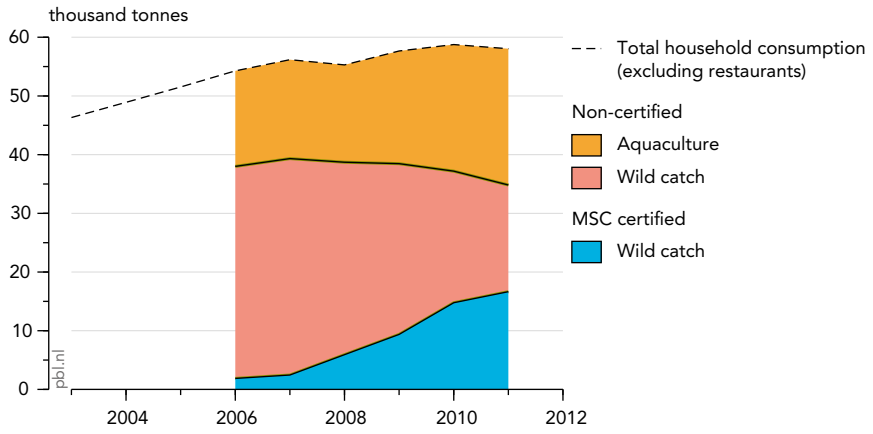
Civil society actors have been another driving force in food system governance. By using information from research and international fora (e.g. IPCC, UNEP, FAO), pilot projects, information channels, local and international networks, these actors play an important role in drawing the public attention to the adverse outcomes of current food systems. Through lobby and advocacy, these actors inform the public and put pressures on companies and governments to address these adverse outcomes (Doh & Guay, 2006, Oosterveer & Spaargaren, 2011, Schilpzand *et al.*, 2010b). These actors experiment with food system innovators, and although some innovators initially emerge as niches, those that prove viable can sustain. The innovators can thus inspire other companies, governments and other more mainstream food system actors.

Box 11 MSC and the Netherlands

The Marine Stewardship Council (MSC) was founded in 1997 as a joint project between the WWF and Unilever. During a two-year process they developed a set of criteria for sustainable and well-managed fisheries, which was used from March 2002 onwards as a label on products (PBL, 2014b). In 2008 Dutch supermarkets set the goal to only sell sustainable fish by 2011, mainly focusing on MSC and ASC (Aquaculture Stewardship Council) certified products. At the end of 2011 around 85% of the supply of fish in supermarkets (fresh fish and frozen fish from private labels (own brands) was MSC-certified (or comparable). No specific targets are set for other brands.

The amount of MSC-certified products consumed has increased considerably: from 6% of the consumption in 2007/2008 to almost 40% of the consumption in 2011/2012 (PBL, 2014b). This is lower than the share in supermarkets as a result of a lower percentage in specialized shops and fresh produce markets. MSC did lead to economic benefits for some fisheries as it provided market access and price advantages (PBL, 2014b). The higher price enabled fishermen to adopt new, less harmful fishing techniques. A positive by-effect is that the new methods require far less fuel. The Dutch government played a facilitating role, partly by subsidizing the cost of the development of certification schemes, partly by fiscal measures which supported investments in new fishing gear.

Figure B.6 Fish consumption in the Netherlands



Source: MSC International, 2012

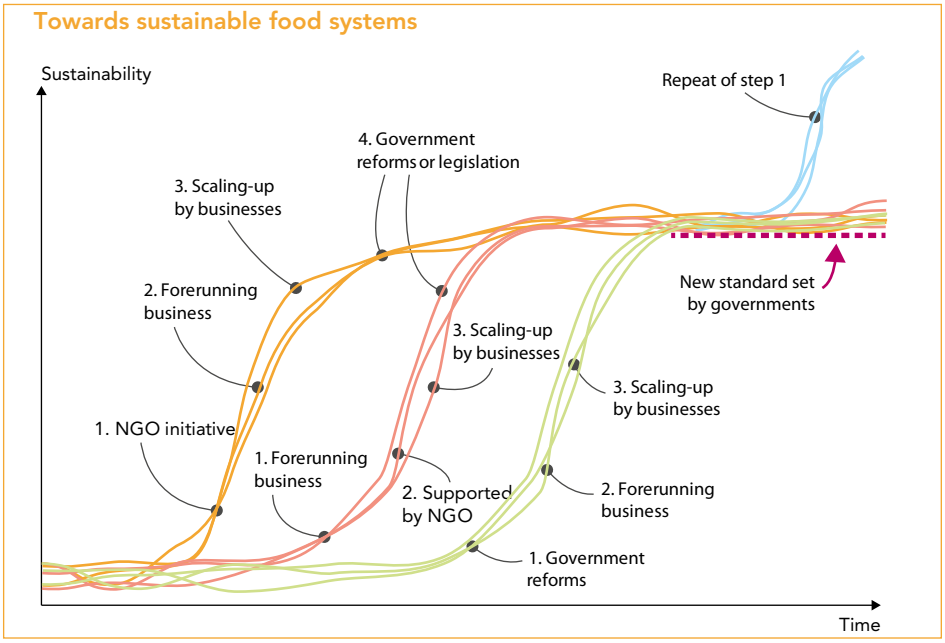
Source: (PBL, 2014b)
(1) The consumption of fish in the Netherlands is increasing, and that is primarily due to the increasing amount of aquaculture. The share of the MSC certification label in the consumption of wild caught fish has risen to 40%.

Table 14. List of illustrations of sustainability-encouraging initiatives by the private sector (non-exhaustive)

Initiative	Initiators	Target	Type of intervention
SAI Platform	Food and drink companies	Farmer	Consensus about farm sustainability requirements
Global GAP	Retail	Farmer	Food safety and farm audit system
UN Global Compact And Global Reporting Initiative	Companies and governments	Whole value chain	Consensus on high level principles
TSC	Retail	Whole value chain	
The Roundtable on Sustainable Soy (RTRS)	Sector and NGOs	One commodity	Certification
The Roundtable on Sustainable Palm Oil (RSPO)	Sector and NGOs	One commodity	Certification

Source: based on (Ywema, 2014)

Figure 29 Spiral movements created by the co-evolution of different pathways



(1) Small actions and innovations are gradually taken over by frontrunners (private actors), governments respond by institutional arrangements to enable scaling up, until the practice is applied by 80–90% of the industry.

8.5.4 Co-evolution of three pathways for an upward spiral movement

The governance dynamics in reform, adaptation and niche-innovations are not mutually exclusive but usually co-evolve alongside each other (see Figure 29). The interplay and synergies among these three pathways could create a culminating effect towards more sustainable food systems. Businesses with international operations could benefit from the expertise, strengths and position of civil society and governments, for instance in expanding their business into new unfamiliar contexts or in making sustainability shifts. In their turn, civil society can utilize the power and capacities of private actors, which is otherwise out of their reach. Civil society organizations could also play a watchdog role to ensure that private actors comply with public norms and standards as established by governments and international institutions.

Finally, civil society actors and governments could align with existing multi-stakeholder roundtables to ensure that public values and interests are well represented. At this point, the practice becomes the new norm, either set by governmental reforms or industry standards. To realize the upward spiral movements, both governments and the private sector need to reconsider their roles and approaches. An example of such an approach is the development of the Marine Stewardship Council (see Box 11). In this example, governments have mainly played a facilitating role, although it has not resulted yet in new standards.

8.5.5. Flexible, participative governance and co-opting with private actors that integrate sustainability as the core of their business

In a context of rapidly changing socio-economic environments and the shift of power to private actors, governments have come to a point where they need to rethink their roles, responsibilities and approaches to public governance. With regard to food systems, governments' role and influence has been diminishing, while the complexity of food systems has been growing. Contrary to traditional societies, the connection between food and consumption no longer takes place within clear boundaries, making it more difficult for governments to regulate and

Box 12 The School Lunch Programme in Brazil: The case of Paragominas

In Brazil, eating at school is considered a right of students in public elementary school and a state duty. For practical reasons, many schools purchase their meals from large companies, while one of the great challenges of the local administration is to improve the quality of school meals and at the same time improve local food production.

Against this background, in 2009 the Brazilian government passed a law that required at least 30% of the total funds allocated in the National School Feeding Programme (PNAE) to be used to purchase food directly from family farms. This requires special attention to guarantee that the producers are able to produce the required quantity, quality and regularity, which is challenging because in general the local production is irregular and below quality standards. However, some cities have achieved good results, as in the case of Paragominas, in the Pará State of Northern Brazil.

The city of Paragominas (with around 100.000 inhabitants) had already started to enable the purchase of food from family farms since 2005, planning a balanced menu, controlling the quality of products and monitoring food handling. Most of the vegetable production from family farms was targeted at school lunches, through a partnership agreed with the city. The introduction of local production using vegetables rich in iron and regional fruits like açai ensured that the nutritional needs of students were met and, in fact, contributed to the improvement in education indicators of the municipalities. Beyond this benefit, the relationship between school meals and local family farm production stimulated production, the organization and strengthening of associations of farmers and the value of household production. This promoted increased investment to diversify production, introduction of gardens with greenhouses, irrigation water, artesian wells, fish farming and added value to products, among other things. All this contributed to boosting the local economy, improving the supply of food, ensuring food security and simultaneously providing healthy food for school students.

(1) Law no 11.947; http://www.planalto.gov.br/ccivil_03/_ato2007-2010/2009/lei/l11947.htm)
(2) School lunch programmes can help reconnect urban demand and regional production (pictures are not from the Paragominas region) http://www.agriculturesnetwork.org/magazines/global/regional-food-systems/brazil-paa

control. Therefore, to realize ambitions towards sustainable food systems, governments need to co-opt with private actors and civil society, and use their positive energies and power as a vehicle for change. Regardless of how effective these are, the existence of so many initiatives proves that there is some form of awareness and willingness to change among private businesses. It is argued that governments lag behind businesses and civil society in sustainability innovations (Lang & Heasman, 2004, WWF, 2014). Co-opting with private actors requires governments to adopt institutional frameworks that are flexible and participative and which facilitate these new types of alliances to collaborate, experiment, and learn.

Governments could pay attention to the following to create a more enabling environment for private actors to scale up their innovations:

- Creating a *level playing field* through regulatory pressures for sustainability.
- Deal with the *distrust* among businesses. In a context of high competition, cooperation can be counterintuitive or jeopardize corporate interests, which may withhold businesses from cooperating. Governments could initiate multi-stakeholder platforms and play the role of a 'third party' that facilitates and mediates between different stakeholders. Civil society organizations (NGOs) could also take on this role of third party.

- Actively *address institutional constrains*. A barrier for private actors to cooperate is the fear that this could be illegitimate and against existing competition laws and anti-trust agreements. To create space for cooperation, governments could make exceptions in competition law that makes cooperation possible. Governments need to be in continuous dialogue with businesses and platforms to learn about the institutional barriers private actors face in scaling up innovations, and try to address these barriers, for instance through cross ministerial dialogue for institutional adaptation.
- Financial support for innovation and scaling up. Both governments and businesses can pool resources to invest in sustainability innovations and collaborate to manage and spread risks associated with new technologies.

Obviously, the interaction between administration, private partners and NGOs can materialize at different levels: global, national and locally. Examples at the global level are the UN Global Compact (UN Forum for Sustainability Standards) as well as the Sustainability Assessment of Food and Agriculture systems (FAO).

8.6 Nodes of action

Chapter 6 and the previous paragraphs have provided a broad overview of the role and processes through which governments, private actors and civil society could move towards sustainable food systems. This section presents several 'nodes' as areas for concrete action. Although many more nodes exist, the identified nodes are areas where cooperation between governments, private sector and civil society could have significant potential for a transition towards sustainable food systems.

8.6.1 Cities and reconnecting urban – rural relationships

Cities are, for a number of reasons, very important nodes in food systems, both in industrialized countries, as well as in low income regions (Garnett *et al.*, 2015). Globally, more than 50% of the population now lives in cities, implying that at least 50% of the food is consumed in cities, and that large quantities of nutrients are transported to cities. Cities can therefore be the node where a transformation towards more sustainable food systems might start.

Urbanization, which is currently occurring very rapidly in many developing countries (Chapter 4) has a large impact on food systems and therefore on the use of natural resources (Chapter 4 and 5). Examples of transformations are supermarketization and changing food preferences: more ultra-processed food, meat, rice and wheat, less tubers and coarse grains. These transformations can have a large effect on smallholder farms in the region, for example because they are often not able to match the requirements or product quality standards set by procurers, or because they are trapped in a price-cost squeeze (HLPE, 2013b). In response, large buyers often prefer imported food products in order to meet the demand, implying that local farmers hardly profit from the increased buying power from cities. If smallholder farms would be better connected to the urban markets in their region, this could lead to investments and increase in local production capacity. Provided that these investments are directed in the right way (for example to support sustainable intensification or sustainable fisheries practices) this could lead to a more efficient and sustainable use of natural resources. This is of course only possible if there is enough potential to increase in a sustainable manner the agricultural production around the involved cities. Locally or regionally produced food is certainly not by definition more environmentally friendly (Edwards-Jones *et al.*, 2008).

Re-linking urban demand with regional production can also provide important economic opportunities for farmers, only if the necessary regulatory instruments are established to bridge the significant gap in economic and political power between smallholders and their organizations on the one side, and the other contracting organizations (such as supermarkets and large

food companies) on the other side (HLPE, 2013b). Contract farming is not a priori beneficial for smallholders; it needs certain supports and policies to be successful (ibid.). Re-linking also offers many opportunities for new enterprises such as packaging, transporting and trading to emerge. A concrete example of re-linking urban demand with regional production is the case of School Lunches in Paragominas (see Box 12).

Urbanization also causes a mental disconnect between food consumption and food production. An increasing number of people do not know how food is being produced, and how much effort it takes to produce food. This could lead to unhealthier diets and higher food wastes. However, cities are also the breeding places of new initiatives, as well as social and cultural movements. Although city dwellers are sometimes not well informed or have romantic ideas about the reality on the ground, as well as on the potential of certain 'solutions', this kind of initiatives could be an important starting point for innovations. Various resourceful studies have explored opportunities that cities offer to drive society towards a green economy, such as the *Green Economy* report by (UNEP, 2011c) and *City-level decoupling* report (UNEP, 2013) that zoomed into resource flows and infrastructural re-configurations that would contribute to a green economy.

In many cities, initiatives have started around urban agriculture (or actually mostly horticulture). Although globally urban agriculture can only play a limited role in food production (UNEP, 2014), it can have many other benefits. These range from improvements in the social and physical climate in cities to more awareness among city-dwellers on the importance of food and food choices by reconnecting people in cities to the origins of their food.

Closing nutrient cycles is another import element of re-linking urban food systems with food producing regions. Currently, only a small fraction (estimated to be around 5%) of all the nutrients transported to cities is recycled to rural areas (Morée *et al.*, 2013), not only creating pollution issues in and around cities, but also leading to soil depletion (Chapter 5). Options for better recycling include the collection and composting of food residues and recycling of residues from the food processing industry (see Box 8 for an example). An important requirement is that the composted material is free from contamination (for example in the form of heavy metals, harmful microorganisms or residues from medicines and pesticides).

8.6.2 Changing food consumption patterns, using health as a point of entry to improve natural resource management

A reorientation to healthier and more sustainable diets[39] could contribute to a lower resource use in food systems with the added benefit of a significant reduction in the global burden of diet-related disease (Section 6.4.2). (Swinburn *et al.*, 2011) suggest that over-consumption and obesity are a predictable outcome of non-regulated and liberalized market economies that are based on consumption growth. The same authors conclude that governments need to take responsibility in guiding private actors and civil society in a new direction. This recommendation is in line with (Lang & Heasman, 2004), who argue that health has been marginalized in the food economy not seen as the prime responsibility of any one group in the food supply chain, and that public policies integrating food and health are still missing. Governments could combine long-term strategies with short-term pragmatic actions for dietary change (see for example (FAO, 2015e, McKinsey, 2014). While the type of effective intervention is highly context depended, and more research is needed, the following are some possible interventions:

- Formulating national policies, behavior change strategies and programmes based on insights in the determinants of consumption behavior (such as people's values, knowledge and motives).
- Stricter regulations on selling food items that are high in saturated fats and sugars or highly resource-intensive, or the introduction of certain price incentives.
- Informing consumers about potential health risks, as done by the Good Guide for cosmetics.
- Restricting promotional activities like

39. It should be stressed that healthy food items are certainly not always more sustainable

advertisement and other forms of marketing, especially if these are targeted to vulnerable groups like children.

- Regulating and planning the amount and location of food 'outlets' like fast food restaurants, small shops and supermarkets (local authorities could play a particularly important role in this).
- Encouraging retailers and food outlet chains in establishing codes of conduct around marketing.
- Introducing measures for labelling to ensure that citizens have access to correct and uniform flows of environmentally related information. Labels could also be used as a way to increase people's awareness of the farmers' share in the price and profits and the share in price that consumers pay for advertising and marketing costs.
- Launching national information campaigns and initiating dialogues on consumption patterns to challenge people's perceptions and values around food.

The first four actions are especially aimed at rethinking and redesigning the 'food environment', being the physical and social surroundings that influence what people eat, which is especially relevant in urbanized food systems. Although governments could take a leading and guiding role in the above-mentioned interventions, they can only realize these through close cooperation with private sector and civil society actors (see also Section 8.5.4). Governments could, for example, make use of existing dynamics in society, such as alternative food movements and networks or cooperate with civil society actors around national behavioral change campaigns. One example of the latter is the LiveWell project in which the WWF cooperates with European governments in formulating and promoting healthier and more sustainable diets, as well as tools for people to assess their own habits (WWF, 2014).

8.6.3 Nutrients flows as indicator for food system functioning

Non-renewable nutrients (minerals) such as phosphorus, potassium, zinc and many others (See Chapter 5) are transported through the food chain, ending up in waste and human excrements. The global nutrient efficiency for nitrogen and phosphorus is around 15-20%, implying large nutrient losses to the environment. Historically, and still in traditional food systems, most of the minerals in waste were recycled. This was also a necessity as fresh inputs of minerals (in the form of fertilizer) were scarce not only unavailable. Since the discovery of the role of minerals in the nineteenth century, minerals were mined to fertilize soils. Ever since the invention of the chemical binding of nitrogen from the air, a still growing amount of reactive nitrogen is synthesized and used as fertilizer. As in many cases these fresh inputs can replace the extracted minerals, the nutrient cycle has become a one-way street: globally only an estimated 4% of the minerals exported to urban areas is recycled (Chapter 5). Within the agricultural system the circle has also been broken. This is more visible in the livestock sector, were due to the spatial concentration of animal production, manure has become 'waste', leading to pollution, instead of being a valuable source of nutrients. This spatial concentration is possible due to the massive transport of feed (containing minerals), often even between countries.

Nutrient flows and efficiencies along food systems can thus be seen as an indicator of how nutrient flows are organized in these systems. There are many advantages of better nutrient management, ranging from lower depletion rates of mines, to environmental benefits (less water pollution) and human health benefits (more nutrient rich food, especially regarding micronutrients).

As demonstrated in Chapters 5 and 6, there are many ways to improve the recycling of nutrients, and reduce nutrient losses to the environment. These range from better fertilizing practices, to re-establishing the spatial reconnection of crop and livestock production or recovering and recycling nutrients from urban waste and sewages. The actual implementation of these technical solutions could be stimulated by regulation (for example on farming practices and on the prevention of spatial concentration of livestock). Another route could be that private partners (including feed companies,

large food companies and waste processors) adopt more stewardship for mineral flows. The closing of nutrient cycles could be facilitated by innovations, ranging from precision farming techniques to mineral extraction techniques from sewage systems.

8.7 Summary and conclusions

This chapter provided a framework of thinking on how food systems can move towards more sustainable food systems. A first important step in this framework is the use a food systems lens. Using a food system approach is an important method to identify concrete options and levers. Governments, researchers and private actors often focus on farmers and fishermen to attain a more efficient and sustainable use of resources. This report includes a draft for a framework to make a systematic analysis of national (or local) food systems and their impacts on national resources.

Three governance dynamics or 'pathways' can be distinguished that have the power to reshape current food systems. These three pathways are: reforms by governments and international institutions; adaptive food system actors (notably private actors); and alternative (niche) innovators. These pathways are not exclusive, but could motivate each other and create positive feedback loops. An initiative could start from civil society, be taken over by companies and finally be embedded as standard through legislation. Next to government-led interventions, the potential of softer 'governance' regimes could be explored as well, as dedicated actions from the private sector (food companies, retailers) and civil society. The logic of the 'quadruple helix' between governments, business, science and civil society aimed at continuous improvement could be applied here.

Private actors are crucial, but need to be encouraged and steered. In general, due to the 'rolling back' of the state and consolidation process in downstream industries, much of the power is now concentrated in the private actors of the food industry. Some of these private actors, particularly the larger businesses, play a leading role in the transition towards more sustainable production practices. They either take individual actions or create their own platforms to cooperate. Governments can play an active role by providing an overarching framework of vision, goals, and regulations for sustainable production and consumption. This would give leading businesses the confidence to expand the level and scope of their individual and joint activities. Secondly, as private actors operate in a context of competition and uncertainty, they often need a third party that can bring different actors together and play a neutral role in mediating different interests. Governments could take up this role or ensure that another third party is established to play this intermediary role.

Civil society actors (such as NGOs) have been an important driving force in drawing attention to the adverse outcomes of current food systems and in offering alternative solutions. By using research, pilot projects, information channels and networks, these actors put pressure on governments and businesses to change and put innovative solutions on the political and business agenda.

Niche innovators have the ability to experiment with innovative business models and solutions that large businesses might not be able to realize due to their vested interests. These niche innovations can serve as a source of information and inspire larger businesses or governments. Governments and businesses could in turn pay systematic attention to supporting, cooperating with and learning from alternative movements.

References

AGRA (2013) *Africa agriculture status report. Focus on staple crops,* Nairobi, The Alliance for a Green Revolution in Africa

Agropoly (2013) *A handful of corporations control world food production,* Zürich, Berne Declaration (DB) & EcoNexus.

Alexandratos N., Bruinsma J. (2012) *World agriculture: towards 2015/2030. The 2012 Revision,* Rome, Food and Agriculture Organization of the United Nations

Alkemade R., Reid R.S., van den Berg M., de Leeuw J., Jeuken M. (2012) Assessing the impacts of livestock production on biodiversity in rangeland ecosystems. *Proceedings of the National Academy of Sciences*. DOI: 10.1073/pnas.1011013108.

Alkemade R., Van Oorschot M., Miles L., Nellemann C., Bakkenes M., Ten Brink B. (2009) GLOBIO3: A framework to investigate options for reducing global terrestrial biodiversity loss. *Ecosystems,* 12: 374-390. DOI: 10.1007/s10021-009-9229-5.

Allen C.R., Fontaine J.J., Pope K.L., Garmestani A.S. (2011) Adaptive management for a turbulent future. *Journal of Environmental Management,* 92: 1339-1345. DOI: 10.1016/j.jenvman.2010.11.019.

Ango T.G., Börjeson L., Senbeta F., Hylander K. (2014) Balancing Ecosystem Services and Disservices: Smallholder Farmers' Use and Management of Forest and Trees in an Agricultural Landscape in Southwestern Ethiopia. *Ecology and Society,* 19: 30. DOI: 10.5751/ES-06279-190130.

Arets E.J.M.M., Van Berkum S., Van Oosten C., Bindraban P.S., Jongschaap R.E.E., Van Bodegom A.J., Stehfest E., Rozemeijer N., Geissen V., Hessel R., Van der Valk O.M.C., De Jager A.J. (2011) *Competing claims on natural resources. Global trends and local case studies,* Wageningen, Alterra Wageningen UR.

Asfaw S., Lipper L. (2011) *Economics of PGRFA Management for Adaptation to Climate Change: A Review of Selected Literature,* Rome, FAO.

Azadi H., Samiee A., Mahmoudi H., Jouzi Z., Rafiaani Khachak P., De Maeyer P., Witlox F. (2015) Genetically modified crops and small-scale farmers: main opportunities and challenges. *Critical Reviews in Biotechnology*: 1-13. DOI: 10.3109/07388551.2014.990413.

Bai Z., Dent D., Olsson L., Schaepman M. (2008) *Global assessment of land degradation and improvement. 1. Identification by remote sensing,* Wageningen, International Soil Reference and Information Centre (ISRIC).

Beekman G., Meijerink G. (2010) *Reducing food price variability in Sub-Saharan Africa,* The Hague, LEI Wageningen UR.

Berdegué J.A., Balsevich F., Flores L., Reardon T. (2005) Central American supermarkets' private standards of quality and safety in procurement of fresh fruits and vegetables. *Food Policy,* 30: 254-269. DOI: 10.1016/j.foodpol.2005.05.003.

Beveridge M.C.M., Phillips M., Dugan P., Brummet R., Center W. (2010) *Barriers to aquaculture development as a pathway to poverty alleviation and food security.* Advancing the Aquaculture Agenda: Workshop Proceedings, Organization for Economic Cooperation and Development, Paris. pp. 345-359

Bhujel R.C. (2012) *Small-scale aquaculture: Global and national perspectives.* Small-scale aquaculture for rural livelihoods: Proceedings of the Symposium on Small-scale aquaculture for increasing resilience of Rural Livelihoods in Nepal. 5-6 Feb 2009. Kathmandu, Nepal. pp.

Biemans H. (2012) Water constraints on future food production. Dissertation Wageningen University, Wageningen.

Bleeker A., Hicks W., Dentener F., Galloway J., Erisman J. (2011) N deposition as a threat to the World's protected areas under the Convention on Biological Diversity. *Environmental Pollution,* 159: 2280-2288. DOI: 10.1016/j.envpol.2010.10.036.

Bobbink R., Hicks K., Galloway J., Spranger T., Alkemade R., Ashmore M., Bustamante M., Cinderby S., Davidson E., Dentener F., Emmett B., Erisman J.W., Fenn M., Gilliam F., Nordin A., Pardo L., De Vries W. (2010) Global assessment of nitrogen deposition effects on terrestrial plant diversity: a synthesis. *Ecological Applications,* 20: 30-59. DOI: doi:10.1890/08-1140.1.

Bommarco R., Kleijn D., Potts S.G. (2013) Ecological intensification: harnessing ecosystem services for food security. *Trends in Ecology & Evolution,* 28: 230-238. DOI: doi:10.1016/j.tree.2012.10.012.

Bouwman A.F., Beusen A.H.W., Billen G. (2009) Human alteration of the global nitrogen and phosphorus soil balances for the period 1970-2050. *Global Biogeochemical Cycles,* 23. DOI: 10.1029/2009GB003576.

Bouwman L., Beusen A., Glibert P.M., Overbeek C., Pawlowski M., Herrera J., Mulsow S., Yu R., Zhou M. (2013a) Mariculture: significant and expanding cause of coastal nutrient enrichment. *Environmental Research Letters,* 8: 044026.

Bouwman L., Goldewijk K.K., Van Der Hoek K.W., Beusen A.H.W., Van Vuuren D.P., Willems J., Rufino M.C., Stehfest E. (2013b) Exploring global changes in nitrogen and phosphorus cycles in agriculture induced by livestock production over the 1900–2050 period. *Proceedings of the National Academy of Sciences,* 110: 20882-20887. DOI: 10.1073/pnas.1012878108.

Buckwell A., Nordang Uhre A., Williams A., Poláková J., Blum W.E.H., Schiefer J., Lair G.J., Heissenhuber A., Peter Schießl P., Krämer C., Haber W. (2014) *Sustainable intensification of European agriculture: A review sponsored by the RISE Foundation,* Brussels, RISE Foundation.

Burke L.M., Reytar K., Spalding M., Perry A. (2011) *Reefs at risk revisited*, World Resources Institute Washington, DC.

Cassman K.G., Dobermann A., Walters D.T. (2002) Agroecosystems, nitrogen use efficiency and nitrogen management. *Ambio,* 31: 132-141.

CFS (2009) *Reform of the CFS, Final version* CFS 35: 2009/2 Rev. 2. October 2009, Rome, Committee on World Food Security.

CFS (2012a) *Coming to terms with terminology,* Rome, Committee on World Food Security.

CFS (2012b) *Voluntary guidelines on the responsible governance of tenure of land, fisheries and forests in the context of national food security,* Rome, Committee on World Food Security.

Chamberlin J., Jayne T., Headey D. (2014) Scarcity amidst abundance? Reassessing the potential for cropland expansion in Africa. *Food Policy,* 48: 51-65. DOI: 10.1016/j.foodpol.2014.05.002.

Chopin T., Cooper J.A., Reid G., Cross S., Moore C. (2012) Open–water integrated multi–trophic aquaculture: environmental biomitigation and economic diversification of fed aquaculture by extractive aquaculture. *Reviews in Aquaculture,* 4: 209-220. DOI: 10.1111/j.1753-5131.2012.01074.x.

Conway G. (2012) *One billion hungry: can we feed the world?,* Cornell, Cornell University Press.

Cordell D., Drangert J.O., White S. (2009) The story of phosphorus: Global food security and food for thought. *Global Environmental Change,* 19: 292-305. DOI: doi:10.1016/j.gloenvcha.2008.10.009.

Cumming G.S., Buerkert A., Hoffmann E.M., Schlecht E., von Cramon-Taubadel S., Tscharntke T. (2014) Implications of agricultural transitions and urbanization for ecosystem services. *Nature,* 515: 50-57. DOI: 10.1038/nature13945.

CWC/MWR (2002) *Water Statistics*, Central Water Commission, Ministry of Water Resources.

Dawkins M., Layton R. (2012) Breeding for better welfare: genetic goals for broiler chickens and their parents. *Animal Welfare-The UFAW Journal,* 21: 147. DOI: 10.7120/09627286.21.2.147

De Fraiture C., Fayrap A., Unver O., Ragab R. (2014) Integrated water management approaches for sustainable food production. *Irrigation and Drainage,* 63: 221-231. DOI: 10.1002/ird.1847.

De Vries M., De Boer I.J.M. (2010) Comparing environmental impacts for livestock products: A review of life cycle assessments. *Livestock Science,* 128: 1-11. DOI: doi:10.1016/j.livsci.2009.11.007.

Deininger K.W., Byerlee D. (2011) *Rising global interest in farmland: can it yield sustainable and equitable benefits?*, World Bank Publications.

Denison R.F. (2012) *Darwinian agriculture: How understanding evolution can improve agriculture,* Princeton NJ, Princeton University Press.

Dixon J. (1999) A cultural economy model for studying food systems. *Journal of the Agriculture, Food, and Human Values Society,* 16: 151-160. DOI: 10.1023/a: 1007531129846.

Doh J.P., Guay T.R. (2006) Corporate social responsibility, public policy, and NGO activism in Europe and the United States: An institutional stakeholder perspective. *Journal of Management Studies,* 43: 47-73. DOI: 10.1111/j.1467-6486.2006.00582.x.

Drent J., Dekker R. (2013) *How different are sublitoral Mytilus edulis communities of natural mussel beds and mussel culture plots in the western Dutch Wadden Sea,* Texel, NIOZ.

Dulvy N.K., Fowler S.L., Musick J.A., Cavanagh R.D., Kyne P.M., Harrison L.R., Carlson J.K., Davidson L.N., Fordham S.V., Francis M.P. (2014) Extinction risk and conservation of the world's sharks and rays. *Elife,* 3. DOI: 10.7554/eLife.00590.002.

Dyck A., Sumaila U. (2009) *Contribution of ocean fish populations to the world economy,* Vancouver, Fisheries Centre, University of British Columbia.

EAA (2014) *Aluminium packaging: Convenient, safe and infinitely recyclable,* Brussels, European Aluminium Association.

Edwards-Jones G., Milà i Canals L., Hounsome N., Truninger M., Koerber G., Hounsome B., Cross P., York E.H., Hospido A., Plassmann K. (2008) Testing the assertion that 'local food is best': the challenges of an evidence-based approach. *Trends in Food Science & Technology,* 19: 265-274. DOI: 10.1016/j.tifs.2008.01.008.

EEA (2010) *Agriculture: nitrogen balance (SEBI 019). Assessment published May 2010,* European Environment Agency www.eea.europa.eu/data-and-maps/indicators/agriculture-nitrogen-balance/agriculture-nitrogen-balance-assessment-published.

Eilers E.J., Kremen C., Smith Greenleaf S., Garber A.K., Klein A.M. (2011) Contribution of Pollinator-Mediated Crops to Nutrients in the Human Food Supply. *PLoS ONE 6(6): e213636(6)* DOI: 10.1371/journal.pone.0021363.

Ellis E.C., Kaplan J.O., Fuller D.Q., Vavrus S., Klein Goldewijk K., Verburg P.H. (2013) Used planet: A global history. *Proceedings of the National Academy of Sciences,* 110: 7978-7985. DOI: 10.1073/pnas.1217241110.

Ericksen P.J. (2008) Conceptualizing food systems for global environmental change research. *Global Environmental Change,* 18: 234-245. DOI: 10.1016/j.gloenvcha.2007.09.002.

Esnouf C., Russel M., Bricas N. (2013) *Food system sustainability: insights from duALIne,* Cambridge, Cambridge University Press.

Eswaran H., Lal R., Reich P.F. (2001) *Land degradation: an overview.* Responses to Land degradation, Proc. 2nd. International Conference on Land Degradation and Desertification. pp. 20-35

EUI (2014) *Global Food Security* Index.The *Economist Intelligence Unit,* http://foodsecurityindex.eiu.com.

Fan S. (2010) *Halving hunger: meeting the first millennium development goal through business as unusual,* Washington D.C, International Food Policy Research Institute.

FAO (2005) *Discards in the world's marine fisheries: an update,* Rome, Food and Agriculture Organization of the United Nations.

FAO (2007) *The State of Food and Agriculture 2007: Paying farmers for environmental services* Rome, Food and Agriculture Organization of the United Nations.

FAO (2010) *Sustainable Diets and Biodiversity. Directions and Solutions for Policy, Research and Action. Proceedings of the International Scientific Symposium 'Biodiversity and Sustainable Diets United Against Hunger' on 3-5 November 2010* Food and Agriculture Organization of the United Nations, Rome.

FAO (2011a) *Energy-smart food for people and climate: issue paper*, Rome, FAO.

FAO (2011b) *Global food losses and food waste. Extend, causes and prevention,* Rome, Italy, Food and Agriculture Organization of the United Nations.

FAO (2011c) *Safeguarding food security in volatile global markets,* Rome, Food and Agriculture Organization of the United Nations.

FAO (2011d) *SAVE and GROW: A policymaker's guide to the sustainable intensification of smallholder crop production,* Rome, Food and Agriculture Organization of the United Nations.

FAO (2011e) *The state of the world's land and water resources for food and agriculture. Managing systems at risk,* Rome, Food and Agriculture Organization of the United Nations.

FAO (2012a) *The State of World Fisheries and Aquaculture 2012,* Rome, Food and Agriculture Organization of the United Nations.

FAO (2012b) *World AgricultureTowards 2030/2050. The 2012 Revision,* Rome, (eds Alexandratos N, Bruinsma J), Global Perspective Studies Team, Food and Agriculture Organization of the United Nations.

FAO (2013a) *Healthy people depend on healthy food systems. Sustainable food systems for food security and nutrition. World Food Day,16 October 2013*, Rome, Food and Agriculture Organization of the United Nations.

FAO (2013b) *Rebuilding West Africa's food potential: policies and market incentives for smallholder-inclusive food value chains,* Rome The Food and Agriculture Organization of the United Nations & The International Fund for Agriculture Development

FAO (2013c) *SAFA Indicators: Sustainability assessment of food and agriculture systems,* Rome, Food and Agriculture Organization of the United Nations

FAO (2014a) *Agriculture, Forestry and Other Land Use emissions by sources and removals by sinks,* Rome, (ed) FAO).

FAO (2014b) *FAO Food Price Index,* Food and Agriculture Organization of the United Nations, http://www.fao.org/worldfoodsituation/foodpricesindex/en/ retrieved on 30-09-2014.

FAO (2014c) *The State of World Fisheries and Aquaculture 2014,* Rome, Food and Agriculture Organization of the United Nations.

FAO (2015a) *FAOstat production data*, FAO.

FAO (2015b) *GLADIS,* Food and Agriculture Organization of the United Nations, www.fao.org/nr/lada/gladis/gladis/.

FAO (2015c) *The Second Report on the State of the World's Animal Genetic Resources for Food and Agriculture, edited by B.D. Scherf & D. Pilling. FAO Commission on Genetic Resources for Food and Agriculture Assessments.* Rome, Food And Agriculture Organization of The United Nations.

FAO (2015d) *Soil is a non-renewable resource (fact sheet),* Rome, Food and Agriculture Organization of the United Nations.

FAO (2015e) *The State of Food Insecurity in the World - Meeting the 2015 international hunger targets: taking stock of uneven progress,* Rome, Food And Agriculture Organization of The United Nations.

FAO, UNEP (2014) *Voluntary standards for sustainable food systems.* Joint FAO/UNEP Workshop on Voluntary Standards for Sustainable Food Systems: Challenges and Opportunities (2013: Rome, Italy). pp.

Fernandez-Cornejo J., Wechsler S., Livingston M., Mitchell L. (2014) *Genetically Engineered Crops in the United States,* Washington DC, US Department of Agriculture Economic Research Service.

Foresight (2011) *The Future of Food and Farming Final Project Report,* London, The Government Office for Science.

Fraser E.D.G., Mabee W., Figge F. (2005) A framework for assessing the vulnerability of food systems to future shocks. *Futures,* 37: 465-479. DOI: 10.1016/j.futures.2004.10.011.

Friends of the Earth International (2012) *Wolf in sheep's clothing? An analysis of the 'sustainable intensification' of agriculture,* Amsterdam, Friends of the Earth International.

Fuglie K., Heisey P., King J.L., Day-Rubenstein K., Schimmelpfennig D., Wang S.L., Pray C.E., Karmarkar-Deshmukh R. (2011) *Research investments and market structure in the food processing, agricultural input, and biofuel industries worldwide,* Washington DC, USDA-Economic Research Service.

Funge-Smith S., Briggs M., Miao W. (2012) *Regional overview of fisheries and aquaculture in Asia and the Pacific 2012. Asia-Pacific Fishery Commission RAP Publication 2012/26*, FAO Regional Office for Asia and the Pacific.

Garcia S.M., Rosenberg A.A. (2010) Food security and marine capture fisheries: characteristics, trends, drivers and future perspectives. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 365: 2869-2880. DOI: 10.1098/rstb.2010.0171.

Garnett T. (2011) Where are the best opportunities for reducing greenhouse gas emissions in the food system (including the food chain)? *Food Policy,* 36: S23-S32. DOI: 10.1016/j.foodpol.2010.10.010.

Garnett T., Appleby M.C., Balmford A., Bateman I.J., Benton T.G., Bloomer P., Burlingame B., Dawkins M., Dolan L., Fraser D., Herrero M., Hoffmann I., Smith P., Thornton P.K., Toulmin C., Vermeulen S.J., Godfray H.C.J. (2013) Sustainable intensification in agriculture: Premises and policies. *Science,* 341: 33-34. DOI: 10.1126/science.1234485.

Garnett T., Mathewson S., Angelides P., Borthwick F. (2015) *Policies and actions to shift eating patterns: What works?,* Oxford and London, Food Climate Research Network. University of Oxford and Chatham House The Royal Institue of International Affairs.

Garnett T., Wilkes A. (2014) *Appetite for change: social, economic and environmental transformations in China's food system,* Oxford, Food Climate Research Network. University of Oxford.

Gerber P.J., Steinfeld H., Henderson B., Mottet A., Opio C., Dijkman J., Falcucci A., Tempio G. (2013) *Tackling climate change through livestock – A global assessment of emissions and mitigation opportunities,* Rome, Food and Agriculture Organization of the United Nations.

Gleeson T., Wada Y., Bierkens M.F., van Beek L.P. (2012) Water balance of global aquifers revealed by groundwater footprint. *Nature,* 488: 197-200. DOI: 10.1038/nature11295

Gleick P.H., Burns W., Chalecki E., Cohen M., Cushing K., Mann A., Reyer R., Wolff G., Wong A. (2002) *The World's Water 2002-2003, The biennial report on freshwater resources,* Washington DC, Island Press.

Grassini P., Eskridge K.M., Cassman K.G. (2013) Distinguishing between yield advances and yield plateaus in historical crop production trends. *Nature communications,* 4. DOI: 10.1038/ncomms3918.

Gregory P.J., Ingram J. (2000) Food and forestry: global change and global challenges. *Agriculture, Ecosystems and Environment,* 82: 1-2. DOI: 10.1016/s0167-8809(00)00211-5.

Grossman M.R. (2006) Agriculture and the polluter pays principle. *Electronic Journal of Comparative Law,* 11.3.

Gustavsson J., Cederberg C., Sonesson U., Van Otterdijk R., Meybeck A. (2011) *Global food losses and food waste. Extent, causes and prevention,* Rome Food and Agriculture Organization of the United Nations and Swedish Institute for Food and Biotechnology (SIK).

Haan de J., Rotmans J. (2011) Patterns in transitions: Understanding complex chains of change. *Technological Forecasting and Social Change,* 78: 90-102. DOI: 10.1016/j.techfore.2010.10.008.

Hajer M. (2011) *The energetic society: In search of a governance philosophy for a clean economy,* The Hague / Bilthoven, Netherlands Environmental Assessment Agency (PBL).

Hall S.J., Delaporte A., Phillips M.J., Beveridge M., O'Keefe M. (2011) *Blue frontiers: managing the environmental costs of aquaculture* Penang, Malaysia, The WorldFish Center.

Heisler J., Glibert P.M., Burkholder J.M., Anderson D.M., Cochlan W., Dennison W.C., Dortch Q., Gobler C.J., Heil C.A., Humphries E. (2008) Eutrophication and harmful algal blooms: a scientific consensus. *Harmful Algae,* 8: 3-13. DOI: 10.1016/j.hal.2008.08.006.

HLPE (2011) *Price volatility and food security, A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security,* Rome, HLPE.

HLPE (2013a) *Biofuels and food security. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security,* Rome, HLEP.

HLPE (2013b) *Investing in smallholder agriculture for food security. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security,* Rome, HLPE.

HLPE (2014a) *Food losses and waste in the context of sustainable food systems. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security,* Rome, HLPE.

HLPE (2014b) *Sustainable fisheries and aquaculture for food security and nutrition. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security,* Rome, HLPE.

HLPE (2015) *Water for food security and nutrition. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security.,* Rome, HLPE.

Hoekstra A.Y., Mekonnen M.M. (2012) The water footprint of humanity. *Proceedings of the National Academy of Sciences,* 109: 3232-3237. DOI: 10.1073/pnas.1109936109.

Holmlund C.M., Hammer M. (1999) Ecosystem services generated by fish populations. *Ecological Economics,* 29: 253-268. DOI: 10.1016/S0921-8009(99)00015-4.

Horton R., Lo, S (2013) Nutrition: a quintessential sustainable development goal. *The Lancet*, 382, Issue 9890. DOI: 10.1016/S0140-6736(13)61100-9

Hutchings J.A., Minto C., Ricard D., Baum J.K., Jensen O.P. (2010) Trends in the abundance of marine fishes. *Canadian Journal of Fisheries and Aquatic Sciences,* 67: 1205-1210. DOI: 10.1139/F10-081.

ICN2 (2014) *Rome Declaration on Nutrition*, Rome, WHO and FAO.

IFA (2009) *Energy Efficiency and CO2 Emissions in Ammonia Production 2008-2009 Summary Report,* Paris, International Fertilizer Association.

IGES (2009) *Reducing waste through the promotion of composting and active involvement of various stakeholders: Replicating Surabaya's solid waste management model. Policy Brief 9,* Hayama, Institute for Global Environmental Strategies.

Ingram J. (2011) A food systems approach to researching food security and its interactions with global environmental change. *Food Security,* 3: 417-431. DOI: 10.1007/s12571-011-0149-9.

Ingram J.S.I., Ericksen P.J., Liverman D.M.e. (2010) *Food security and global environmental change,* London Earthscan.

IPCC (2014a) *Climate Change 2014 Mitigation of Climate Change*, Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

IPCC (2014b) *Climate Change 2014: Impacts, Adaptation, and Vulnerability*, Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Final Draft Accepted on 30 March 2014.

Ittersum van M.K., Rabbinge R. (1997) Concepts in production ecology for analysis and quantification of agricultural input-output combinations. *Field Crops Research,* 52: 197-208. DOI: 10.1016/S0378-4290(97)00037-3.

Jackson J.B., Kirby M.X., Berger W.H., Bjorndal K.A., Botsford L.W., Bourque B.J., Bradbury R.H., Cooke R., Erlandson J., Estes J.A. (2001) Historical overfishing and the recent collapse of coastal ecosystems. *Science,* 293: 629-637. DOI: 10.1126/science.1059199.

Jacobsen S.E., Sørensen M., Pedersen S.M., Weiner J. (2013) Feeding the world: Genetically modified crops versus agricultural biodiversity. *Agronomy for Sustainable Development,* 33: 651-662. DOI: 10.1007/s13593-013-0138-9.

Kearney J. (2010) Food consumption trends and drivers. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 365: 2793-2807. DOI: 10.1098/rstb.2010.0149.

Khoury C.K., Bjorkman A.D., Dempewolf H., Ramirez-Villegas J., Guarino L., Jarvis A., Rieseberg L.H., Struik P.C. (2014) Increasing homogeneity in global food supplies and the implications for food security. *Proceedings of the National Academy of Sciences*. DOI: 10.1073/pnas.1313490111.

Kirsten J.F., Dorward C., Poulton C., Vinck N. (eds) (2009) *Institutional economics perspectives on African agricultural development,* Washington D.C., International Food Policy Research Institute

KPMG (2012) *Expect the unexpected: Building business value in a changing world*, KPMG International.

Lambin E., Gibbs H., Ferreira L., Grau R., Mayaux P., Meyfroidt P., Morton D., Rudel T., Gasparri I., Munger J. (2013) Estimating the world's potentially available cropland using a bottom-up approach. *Global Environmental Change,* 23: 892-901. DOI: 10.1016/j.gloenvcha.2013.05.005.

Lambin E.F., Meyfroidt P., Rueda X., Blackman A., Börner J., Cerutti P.O., Dietsch T., Jungmann L., Lamarque P., Lister J., Walker N.F., Wunder S. (2014) Effectiveness and synergies of policy instruments for land use governance in tropical regions. *Global Environmental Change,* 28: 129-140. DOI: 10.1016/j.gloenvcha.2014.06.007.

Lambin E.F., Turner B.L., Geist H.J. *et al.* (2001) The causes of land-use and land-cover change: Moving beyond the myths. *Global Environmental Change,* 11: 261-269.

Lang T., Barling D., Caraher M. (2009) *Food policy: integrating health, environment and society,* Oxford, Oxford University Press.

Lang T., Heasman M. (2004) *Food wars: the global battle for mouths, minds and markets,* London, Earthscan.

Lawrence G., Burch D. (2007) Understanding supermarkets and agri-food supply chains, in: Burch D, Lawrence G (Eds.), Supermarkets and agri-food supply chains: transformations in the production and consumption of foods, Edward Elgar, Cheltenham and Northampton.

Le Roux X., Barbault R., Baudry J., Burel F., Doussan I., Garnier E., Herzog F., Lavorel S., Lifran R., Roger-Estrade J., Sarthou J.P., Trommetter M. (2008) *Agriculture and biodiversity: benefiting from synergies. Multidisciplinary Scientific Assessment, Synthesis Report,* Paris.

Leip A., Weiss F., Lesschen J.P., Westhoek H. (2014) The nitrogen footprint of food products in the European Union. *The Journal of Agricultural Science,* 152: 20-33. DOI: 10.1017/S0021859613000786.

Licker R., Johnston M., Foley J.A., Barford C., Kucharik C.J., Monfreda C., Ramankutty N. (2010) Mind the gap: how do climate and agricultural management explain the 'yield gap'of croplands around the world? *Global Ecology and Biogeography,* 19: 769-782. DOI: 10.1111/j.1466-8238.2010.00563.x.

Lieshout van P., Went R., Kremer M. (2010) *Less pretension, more ambition: development policy in times of globalization,* Amsterdam, Amsterdam University Press.

Lim S.S., Vos T., Flaxman A.D., Danaei G., Shibuya K., Adair-Rohani H., AlMazroa M.A., Amann M., Anderson H.R., Andrews K.G. (2013) A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *The Lancet,* 380: 2224-2260. DOI: 10.1016/S0140-6736(12)61766-8.

Lipinski B., Hanson C., Lomax J., Kitinoja L., Waite R., Searchinger T. (2013) *Reducing food loss and waste,* Washington D.C., World Resources Institute.

Ludwig D. (2001) The era of management is over. *Ecosystems,* 4: 758-764. DOI: 10.1007/s10021-001-0044-x.

MA (2005a) *Ecosystems and Human Well-being: Scenarios, Volume 2. Millennium Ecosystem Assessment,* Washington DC, Island Press.

MA (2005b) *Synthesis report*, Millennium Ecosystem Assessment.

Ma L., Ma W.Q., Velthof G.L., Wang F.H., Qin W., Zhang F.S., Oenema O. (2010) Modeling nutrient flows in the food chain of China. *Journal of Environmental Quality,* 39: 1279-1289. DOI: 10.2134/jeq2009.0403.

Macdiarmid J., Kyle J., Horgan G., Loe J., Fyfe C., Johnstone A., McNeill G. (2011) *Livewell: a balance of healthy and sustainable food choices,* Godalming, WWF-UK.

Malassis L., Ghersi G. (1996) Économie de la Production et de la Consommation: méthodes et concepts, Paris, Cujas.

Mannion A.M., Morse S. (2012) Biotechnology in agriculture: Agronomic and environmental considerations and reflections based on 15 years of GM crops. *Progress in Physical Geography,* 36: 747-763. DOI: 10.1177/0309133312457109.

Marimpi D.M. (2014) Empirical investigation of the dynamic linkages between crude oil and maize prices: Dating the structural breaks. *Journal of Development and Agricultural Economics,* 6: 193-202. DOI: 10.5897/JDAE2013.0552.

Martin W., Anderson K. (2011) Export restrictions and price insulation during commodity price booms. *American Journal of Agricultural Economics*: aar105. DOI: 10.1596/1813-9450-5645

Martini R. (2008) *Fuel Tax Concessions in the Fisheries Sector,* Paris, OECD Publishing.

McKinsey (2012) *The archipelago economy: Unlashing Indonesia's potential*, McKinsey Global Institute

McKinsey (2014) *Overcoming obesity: an initial economic analysis*, McKinsey Global Institute

McLoughlin D., Bourne S., Shelman M., Bradley F., Connolly A. (2012) Towards a branded food economy in China. Industry speaks. *International Food and Agribusiness Management Review,* 15: 177-184.

McMicheal P. (ed) (1994) *The global restructuring of agro-food systems,* Cornell NY, Cornell University Press.

Meah A., Watson M. (2011) Saints and slackers: challenging discourses about the decline of domestic cooking. *Sociological Research Online,* 16: 6.

Merkuseva N., Rapsomanikis G. (2013) *Non-lineair cointegration in the food-ethanol oil system: evidence from snmooth threshold vector error correction models. Agricultural Market Information System (AMIS)*, Food and Agriculture Organization of the United Nations

Metelerkamp L. (2013) *A sustainability review of the global food system. Food systems series part 1*, Ernst and Young

Middleton N., Thomas D. (1997) *World atlas of desertification - Hodder Arnold Publication,* London, Routledge.

Milder J.C., Garbach K., Declerck F.A.J., Driscoll L., Montenegro M. (2012) *An Assessment of the Multi-Functionality of Agroecological Intensification*, Bill & Melinda Gates Foundation.

Molden D. (2007) *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture,* London and Washington, Earthscan.

Morée A., Beusen A., Bouwman A., Willems W. (2013) Exploring global nitrogen and phosphorus flows in urban wastes during the twentieth century. *Global Biogeochemical Cycles,* 27: 836-846. DOI: 10.1002/gbc.20072.

Nepstad D., McGrath D., Stickler C., Alencar A., Azevedo A., Swette B., Bezerra T., DiGiano M., Shimada J., Seroa da Motta R., Armijo E., Castello L., Brando P., Hansen M.C., McGrath-Horn M., Carvalho O., Hess L. (2014) Slowing Amazon deforestation through public policy and interventions in beef and soy supply chains. *Science,* 344: 1118-23. DOI: 10.1126/science.1248525.

Neset T.S.S., Cordell D. (2012) Global phosphorus scarcity: Identifying synergies for a sustainable future. *Journal of the Science of Food and Agriculture,* 92: 2-6. DOI: 10.1002/jsfa.4650.

Neumann K., Verburg P.H., Stehfest E., Müller C. (2010) The yield gap of global grain production: A spatial analysis. *Agricultural Systems,* 103: 316-326. DOI: 10.1016/j.agsy.2010.02.004.

Ng M., Fleming T., Robinson M., Thomson B., Graetz N., Margono C., Mullany E.C., Biryukov S., Abbafati C., Abera S.F. (2014) Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013: a systematic analysis for the Global Burden of Disease Study 2013. *The Lancet*.

Nijdam D., Rood T., Westhoek H. (2012) The price of protein: Review of land use and carbon footprints from life cycle assessments of animal food products and their substitutes. *Food Policy,* 37: 760-770. DOI: 10.1016/j.foodpol.2012.08.002.

North D.C. (1987) Institutions, transaction costs and economic growth. *Economic inquiry,* 25: 419-428. DOI: 10.1111/j.1465-7295.1987.tb00750.x.

North D.C. (1990) *Institutions, institutional change and economic performance,* Cambridge, Cambridge University Press.

OECD (2002) *Measuring material flows and resource productivity. Volume 1. The OECD Guide Glossary,* Paris, OECD.

OECD (2005) *Subsidies: a Way Towards Sustainable Fisheries? ,* Paris, OECD.

OECD (2008) *Environmental Performance of Agriculture in OECD Countries Since 1990,* Paris, OECD Publishing.

OECD (2010) *Sustainable management of water resources in agriculture,* Paris, OECD.

OECD (2011) *Evaluation of Agricultural Policy Reforms in the European Union,* Paris, OECD.

OECD (2012) *OECD environmental outlook to 2050,* Paris, OECD.

OECD (2013a) *Agricultural Policies in non-OECD countries: monitoring and evaluation,* Paris, OECD.

OECD (2013b) *Competition issues in the food chain industry,* Paris, OECD.

OECD (2013c) *Policy instruments to support green growth in agriculture,* Paris, OECD Publishing.

OECD, FAO (2013) *OECD-FAO Agricultural Outlook 2013-2022,* Paris, OECD.

OECD, FAO (2014) *OECD-FAO Agricultural Outlook 2014-2023,* Paris, OECD Publishing.

Oenema O., Oudendag D., Velthof G.L. (2007) Nutrient losses from manure management in the European Union. *Livestock Science,* 112: 261-272. DOI: 10.1016/j.livsci.2007.09.007.

Oenema O., Witzke H.P., Klimont Z., Lesschen J.P., Velthof G.L. (2009) Integrated assessment of promising measures to decrease nitrogen losses from agriculture in EU-27. *Agriculture, Ecosystems and Environment,* 133: 280-288. DOI: 10.1016/j.agee.2009.04.025.

Oorschot van M., Kok M., van der Esch S., Janse J., Rood T., Vixseboxse E., Wilting H., Vermeulen W. (2014) *Sustainability of international Dutch supply chains: Progress, effects and perspectives,* The Hague / Bilthoven, PBL (Netherlands Environmental Assessment Agency).

Oosterveer P., Adjei B.E., Vellema S., Slingerland M. (2014) Global sustainability standards and food security: Exploring unintended effects of voluntary certification in palm oil. *Global Food Security,* 3: 220-226. DOI: http://dx.doi.org/10.1016/j.gfs.2014.09.006.

Oosterveer P., Spaargaren G. (2011) Organising consumer involvement in the greening of global food flows: the role of environmental NGOs in the case of marine fish. *Environmental Politics,* 20: 97-114. DOI: 10.1080/09644016.2011.538168.

Ostrom E. (1990) *Governing the commons. The evolution of institutions for collective action,* Cambridge, Cambridge University Press.

Ostrom E. (1992) *Crafting institutions for self-governing irrigation systems,* San Francisco, ICS Press.

Pauly D., Christensen V., Dalsgaard J., Froese R., Torres F. (1998) Fishing down marine food webs. *Science,* 279: 860-863. DOI: 10.1126/science.279.5352.860

Pauly D., Watson R., Alder J. (2005) Global trends in world fisheries: impacts on marine ecosystems and food security. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 360: 5-12. DOI: 10.1098/rstb.2004.1574.

PBL (2010) *Rethinking Global Biodiversity Strategies: Exploring structural changes in production and consumption to reduce biodiversity loss,* Den Haag/Bilthoven, PBL Netherlands Environmental Assessment Agency.

PBL (2011) *The protein puzzle. The consumption and production of meat, dairy and fish in the European Union,* The Hague (eds Henk W, Rood T, M. Bvd, Janse J, Nijdam D, Reudink M, Stehfest E), PBL Netherlands Environmental Assessment Agency.

PBL (2012) *Roads from Rio+20*, PBL Netherlands Environmental Assessment Agency

PBL (2014a) *How sectors can contribute to sustainable use and conservation of biodiversity,* The Hague, (eds Kok M, Alkemade R), PBL & CBD.

PBL (2014b) *Sustainability of international Dutch supply chains. Progress, effects and perspectives,* The Hague, PBL.

Phalan B., Green R., Balmford A. (2014) Closing yield gaps: perils and possibilities for biodiversity. *Philosophical Transactions B,* 369. DOI: 10.1098/rstb.2012.0285

Pinstrup-Andersen P. (2002) *Towards a sustainable global food system: What will it take?*, Washington.

Pinstrup-Andersen P., Watson II D.D. (2011) *Food policy for developing countries: The role of government in global, national, and local food systems,* Ithaca and London, Cornell University Press.

Ponisio L.C., M'Gonigle L.K., Mace K.C., Palomino J., de Valpine P., Kremen C. (2015) Diversification practices reduce organic to conventional yield gap. *Proceedings of the Royal Society of London B: Biological Sciences,* 282: 20141396. DOI: 10.1098/rspb.2014.1396.

Pretty J. (2007) Agricultural sustainability: concepts, principles and evidence. *Philosophical Transactions of the Royal Society,* 363: 447-465. DOI: 10.1098/rstb.2007.2163.

Pretty J., Bharucha Z.P. (2014) Sustainable intensification in agricultural systems. *Annals of Botany,* 114: 1571-1596. DOI: 10.1093/aob/mcu205.

Pretty J., Toulmin C., Williams S. (2011) Sustainable intensification in African agriculture. *International Journal of Agricultural Sustainability,* 9: 5-24. DOI: 10.3763/ijas.2010.0583.

Rabbinge R., Van Diepen C.A., Dijsselbloem J., De Koning G.J.H., Van Latesteijn H.C., Woltjer E., Van Zijl J. (1994) *Ground for choices: a scenario study on perspectives for rural areas in the European Community.*

Reardon T., Minten B. (2011) Surprised by supermarkets: diffusion of modern food retail in India. *Journal of Agribusiness in Developing and Emerging Economies,* 1: 134-161. DOI: 10.1108/20440831111167155.

Reardon T., Timmer C.P. (2012) The economics of the food system revolution. *Annual Review of Resource Economics,* 4: 225-264. DOI: 10.1146/annurev.resource.050708.144147.

Reardon T., Timmer C.P., Barrett C.B., Berdegué J. (2003) The rise of supermarkets in Africa, Asia, and Latin America. *American Journal of Agricultural Economics,* 85: 1140-1146. DOI: 10.1111/j.0092-5853.2003.00520.x

Rosegrant M.W., Koo J., Cenacchi N., Ringler C., Robertson R.D., Fisher M., Cox C.M., Garrett K., Perez N.D., Sabbagh P. (2014) *Food security in a world of natural resource scarcity: The role of agricultural technologies,* Washington DC, International Food Policy Research Institute.

RSPO (2013) *Principles and Criteria for the Production of Sustainable Palm Oil,* Kuala Lumpur, RSPO.

RTRS (2010) *Standard for Responsible Soy Production. Version 1.0. ,* Round Table on Responsible Soy Association, http://www.responsiblesoy.org/index.php?option=com_docman&task=cat_view&gid=71&Itemid=40&lang=en.

Saier B. (2002) Subtidal and intertidal mussel beds (Mytilus edulis L.) in the Wadden Sea: diversity differences of associated epifauna. *Helgoland marine research,* 56: 44-50. DOI: 10.1007/s10152-001-0097-4.

Saitone T.L., Sexton R.J. (2012) *Market structure and competition in the US food industries. Implications for the 2012 Farm Bill,* American Enterprise Institute, http://www.aei.org/wp-content/uploads/2012/04/-market-structure-and-competition-in-the-us-food-industries_102234192168.pdf.

Sayer J., Sunderland T., Ghazoul J., Pfund J.-L., Sheil D., Meijaard E., Venter M., Boedhihartono A.K., Day M., Garcia C. (2013) Ten principles for a landscape approach to reconciling agriculture, conservation, and other competing land uses. *Proceedings of the National Academy of Sciences,* 110: 8349-8356. DOI: 10.1073/pnas.1210595110.

Scherr S.J., McNeely J.A. (2008) Biodiversity conservation and agricultural sustainability: towards a new paradigm of 'ecoagriculture' landscapes. *Philosophical Transactions of the Royal Society of London B: Biological Sciences,* 363: 477-494. DOI: 10.1098/rstb.2007.2165

Schilpzand R., Liverman D., Tecklin D., Gordon R., Pereira L., Saxl M., Wiebe K. (2010a) Governance Beyond the State: Non-state Actors and Food Systems, in: Ingram J, Ericksen P, Liverman D (Eds.), Food Security and Global Environmental Change, Earthscan, London.

Schilpzand R., Liverman D., Tecklin D., Gordon R., Pereira L., Saxl M., Wiebe K. (2010b) Governance beyond the state: non-state actors and food systems, in: Ingram JSI, Ericksen PJ, Liverman DM (Eds.), Food Security and Global Environmental Change, Earthscan, London. pp. 272-300.

Schmitz C., van Meijl H., Kyle P., Nelson G.C., Fujimori S., Gurgel A., Havlik P., Heyhoe E., d'Croz D.M., Popp A., Sands R., Tabeau A., van der Mensbrugghe D., von Lampe M., Wise M., Blanc E., Hasegawa T., Kavallari A., Valin H. (2014) Land-use change trajectories up to 2050: insights from a global agro-economic model comparison. *Agricultural Economics,* 45: 69-84. DOI: 10.1111/agec.12090.

Seitzinger S.P., Mayorga E., Bouwman A.F., Kroeze C., Beusen A.H.W., Billen G., Van Drecht G., Dumont E., Fekete B.M., Garnier J., Harrison J.A. (2010) Global river nutrient export: A scenario analysis of past and future trends. *Global Biogeochemical Cycles,* 24. DOI: 10.1029/2009GB003587.

Senauer B., Seltzer J. (2010) The changing face of food retailing. *Choices Magazine,* 25 (4).

Sexton R.J. (2000) Market consolidation poses challenges for food industry. *California Agriculture,* 56 (5).

Sobal J., Kettel Khan L., Bisogni C. (1998) A conceptual model of the food and nutrition system. *Social Science & Medicine,* 47: 853-863. DOI: 10.1016/S0277-9536(98)00104-X.

Stehfest E., Bouwman L., van Vuuren D.P., den Elzen M.G.J., Eickhout B., Kabat P. (2009) Climate benefits of changing diet. *Climatic Change,* 95: 83-102. DOI: 10.1007/s10584-008-9534-6.

Steinfeld H., Gerber H., Wassenaar T., Castel V., Rosales M., Haan de C. (2006) *Livestock's long shadow: environmental issues and options,* Rome, Food and Agriculture Organization of the United Nations.

Story M., Kaphingst K.M., Robinson-O'Brien R., Glanz K. (2008) Creating healthy food and eating environments: policy and environmental approaches. *Annual Review of Public Health,* 29: 253-272. DOI: 10.1146/annurev.publhealth.29.020907.090926.

Sutton M.A., Bleeker A., Howard C.M. *et al.* (2013) *Our nutrient world: the challenge to produce more food and energy with less pollution,* Edinburgh, NERC/Centre for Ecology & Hydrology.

Sutton M.A., Howard C.M., Erisman J.W., Billen G., Bleeker A., Grennfelt P., van Grinsven H., Grizzetti B. (eds) (2011a) *The European Nitrogen Assessment: Sources, Effects and Policy Perspectives,* Cambridge, Cambridge University Press.

Sutton M.A., van Grinsven H., Billen G., Bleeker A., Bouwman A.F., Bull K., Erisman J.W., Grennfelt P., Grizzetti B., Howard C.M., Oenema O., Spranger T., Winiwarter W. (2011b) The European Nitrogen Assessment: Summary for policy makers, in: Sutton MA, Howard CM, Erisman JW, Billen G, Bleeker A, Grennfelt P, van Grinsven H, Grizzetti B (Eds.), The European Nitrogen Assessment: Sources, Effects and Policy Perspectives, Cambridge University Press, Cambridge. pp. xxiv-xxxiv.

Swartz W., Sala E., Tracey S., Watson R., Pauly D. (2010) The spatial expansion and ecological footprint of fisheries (1950 to present). *PloS one,* 5: e15143. DOI: 10.1371/journal.pone.0015143

Swinburn B.A., Sacks G., Hall K.D., McPherson K., Finegood D.T., Moodie M.L., Gortmaker S.L. (2011) The global obesity pandemic: shaped by global drivers and local environments. *The Lancet,* 378: 804-814. DOI: 10.1016/S0140-6736(11)60813-1.

TEEB (2010) *The economics of ecosystems and biodiversity: mainstreaming the economics of nature: a synthesis of the approach, conclusions and recommendations of TEEB*, UNEP.

TEEB (2014) http://www.teebweb.org/.

TEEB (2015) *TEEB for Agriculture & Food: an interim report,* Geneva, United Nations Environment Programme (UNEP).

Teh L.C., Sumaila U. (2013) Contribution of marine fisheries to worldwide employment. *Fish and Fisheries,* 14: 77-88. DOI: 10.1111/j.1467-2979.2011.00450.x.

The Economist (2012). Food for thought. Food companies play an ambivalent part in the fight against flab, *The Economist* Retrieved from http://www.economist.com/news/special-report/21568064-food-companies-play-ambivalent-part-fight-against-flab-food-thought

Thorstad E.B., Fleming I.A., McGinnity P., Soto D., Wennevik V., Whoriskey F. (2008) *Incidence and impacts of escaped farmed Atlantic salmon Salmo salar in nature*, Norwegian Institute for Nature Research (NINA).

Tilman D., Clark M. (2014) Global diets link environmental sustainability and human health. *Nature,* 515: 518-522. DOI: 10.1038/nature13959.

Tittonell P., Giller K.E. (2013) When yield gaps are poverty traps: The paradigm of ecological intensification in African smallholder agriculture. *Field Crops Research,* 143: 76-90. DOI: 10.1016/j.fcr.2012.10.007.

Tovey H. (1997) Food, environmentalism and rural Sociology: On the organic farming movement in Ireland. *Sociologia Ruralis,* 37: 21-37. DOI: 10.1111/1467-9523.00034.

Trujilo P. (2008) *Using a mariculture sustainability index to rank countries performances,* Vancouver, (ed) D.Pauly JAa), The Fisheries centre, University of BC.

Tukker A., Goldbohm R.A., De Koning A., Verheijden M., Kleijn R., Wolf O., Pérez-Domínguez I., Rueda-Cantuche J.M. (2011) Environmental impacts of changes to healthier diets in Europe. *Ecological Economics,* 70: 1776-1788. DOI: 10.1016/j.ecolecon.2011.05.001.

UN (2014) Report of the Secretary-General to the General Assembly 69/279*, Agriculture Development, food security and nutrition*, A/69/279 (7 August 2014), available from undocs.org/A/69/279.

Underwood E., Baldock D., Aiking H., Buckwell A., Dooley E., Frelih-Larsen A., Naumann S., O'Connor C.P., J., Tucker G. (2013) *Technology options for feeding 10 billion people. Synthesis report: Options for sustainable food and agriculture in the EU,* Brussels Science and Technology Options Assessment (STOA), European Parliament

UNDESA (2011) *World Urbanization Prospects: The 2011 Revision,* New York, UN Department of Economic and Social Affairs.

UNDESA (2013) *World population prospects: The 2012 Revision,* New York, UN Department of Economic and Social Affairs.

UNEP (2009) *Assessing biofuels. Towards sustainable production and use of resources. A report by the Working Group on Biofuels of the International Resource Panel,* Paris, (ed) Bringezu S. SH, O´Brien M., Kauppi L., Howarth R.W., McNeely J.), United Nations Environment Programme

UNEP (2010) *Assessing the environmental impacts of consumption and production: priority products and materials,* Nairobi / Paris, International Resource Panel United Nations Environmental Programme.

UNEP (2011a) *Decoupling natural resource use and environmental impacts from economic growth International Resource Panel,* Nairobi / Paris.

UNEP (2011b) *Draft Glossary of Terms Used by the International Resource Panel,* Nairobi / Paris, UNEP International Resource Panel.

UNEP (2011c) *Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication. A Synthesis for Policy Makers,* Paris United Nations Environment Programme

UNEP (2012) *The Fifth Global Environment Outlook (GEO-5). Environment for the future we want,* Nairobi, UNEP.

UNEP (2013) *City-level decoupling: Urban resource flows and the governance of infrastructure transitions. A Report of the Working Group on Cities of the International Resource Panel,* Nairobi / Paris.

UNEP (2014) *Assessing global land use: Balancing consumption with sustainable supply. A Report of the Working Group on Land and Soils of the International Resource Panel,* Nairobi / Paris, (eds Bringezu S, Schütz H, Pengue W, O´ Brien M, Garcia F, Sims R, Howarth R, Kauppi L, Swilling M, Herrick J), United Nations Environment Programme (UNEP).

UNEP (2015) *Policy Coherence of the Sustainable Development Goals: a Natural Resource Perspective. A Report by the International Resource Panel,* Nairobi / Paris, United Nations Environment Programme (UNEP).

UNEP (2016) *Unlocking the Potential of Land Resources: Evaluation Systems, Strategies and Tools for Sustainability. A Report of the Working Group on Land and Soils of the International Resource Panel. Herrick, J.,* Nairobi and Paris, United Nations Environment Programme (UNEP).

USDA (2012) *China retail report*, United States Department of Agriculture, Foreign Agricultural Service.

USGS (2013) *Mineral Commodity Summaries: (various elements)*, Washington, U.S. Geological Survey

Valin H., Sands R., Van der Mensbrugghe D., Nelson G.C., Ahammad H., Blanc E., Bodirsky B., Fujimori S., Hasegawa T., Havlik P., Heyhoe E., Kyle P., Mason-D'Croz D., Paltsev S., Rolinski S., Tabeau A., van Meijl H., von Lampe M., Willenbockel D. (2014) The future of food demand: understanding differences in global economic models. *Agricultural Economics,* 45: 51-67. DOI: 10.1111/agec.12089.

Van Drecht G., Bouwman A., Harrison J., Knoop J. (2009) Global nitrogen and phosphate in urban wastewater for the period 1970 to 2050. *Global Biogeochemical Cycles,* 23. DOI: 10.1029/2009GB003458.

Velthof G.L., Lesschen J.P., Webb J., Pietrzak S., Miatkowski Z., Pinto M., Kros J., Oenema O. (2014) The impact of the Nitrates Directive on nitrogen emissions from agriculture in the EU-27 during 2000–2008. *Science of the Total Environment,* 468–469: 1225-1233. DOI: 10.1016/j.scitotenv.2013.04.058.

Verburg P.H., Mertz O., Erb K.H., Haberl H., Wu W. (2013) Land system change and food security: towards multi-scale land system solutions. *Current Opinion in Environmental Sustainability,* 5: 494-502. DOI: 10.1016/j.cosust.2013.07.003.

Vermeulen S.J., Campbell B.M., Ingram J.S.I. (2012) Climate Change and Food Systems. *Annual Review of Environment and Resources,* 37: 195-222. DOI: 10.1146/annurev-environ-020411-130608.

Waite R., Beveridge M., Brummett R.E., Castine S., Chaiyawannakarn N., Kaushik S., Mungkung R., Nawapakpilai S., Phillips M. (2014) *Improving productivity and environmental performance of aquaculture. Working Paper, Installment 5 of Creating a Sustainable Food Future,* Washington, DC, World Resources Institute.

Wallace B.P., Lewison R.L., McDonald S.L., McDonald R.K., Kot C.Y., Kelez S., Bjorkland R.K., Finkbeiner E.M., Helmbrecht S.r., Crowder L.B. (2010) Global patterns of marine turtle bycatch. *Conservation Letters,* 3: 131-142. DOI: 10.1111/j.1755-263X.2010.00105.x.

Wansink B. (2004) Environmental factors that increase the food intake and consumption volume of unknowing consumers*. *Annual Review of Nutrition,* 24: 455-479. DOI: 10.1146/annurev.nutr.24.012003.132140.

Watson R.A., Cheung W.W., Anticamara J.A., Sumaila R.U., Zeller D., Pauly D. (2013) Global marine yield halved as fishing intensity redoubles. *Fish and Fisheries,* 14: 493-503. DOI: 10.1111/j.1467-2979.2012.00483.x.

Waycott M., Duarte C.M., Carruthers T.J., Orth R.J., Dennison W.C., Olyarnik S., Calladine A., Fourqurean J.W., Heck K.L., Hughes A.R. (2009) Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proceedings of the National Academy of Sciences,* 106: 12377-12381. DOI: 10.1073/pnas.0905620106

Weidema B. (2006) The integration of economic and social aspects in Life Cycle Impact Assessment. *The International Journal of Life Cycle Assessment,* 11: 89-96. DOI: 10.1065/lca2006.04.016.

Wessells K.R., Brown K.H. (2012) Estimating the Global Prevalence of Zinc Deficiency: Results Based on Zinc Availability in National Food Supplies and the Prevalence of Stunting. *PLoS ONE,* 7: e50568. DOI: 10.1371/journal.pone.0050568.

Westhoek H., Lesschen J.P., Rood T., Wagner S., De Marco A., Murphy-Bokern D., Leip A., van Grinsven H., Sutton M.A., Oenema O. (2014) Food choices, health and environment: Effects of cutting Europe's meat and dairy intake. *Global Environmental Change*. DOI: 10.1016/j.gloenvcha.2014.02.004.

Westhoek H., Rood T., Berg M.v.d., Janse J., Nijdam D., Reudink M.A., Stehfest E. (2011) *The protein puzzle : the consumption and production of meat, dairy and fish in the European Union,* The Hague / Bilthoven, PBL (Netherlands Environmental Assessment Agency).

Whitty C.J.M., Jones M., Tollervey A., Wheeler T. (2013) Biotechnology: Africa and Asia need a rational debate on GM crops. *Nature,* 497: 31-33. DOI: 10.1038/497031a.

WHO (2012) *Global targets 2025 To improve maternal, infant and young child nutrition. Resolution 65.6* Geneva, World Health Assembly - World Health Organization.

WHO (2013) *Obesity and overweight Fact sheet N°311 updated on March 2013,* http://www.who.int/mediacentre/factsheets/fs311/en.

WHO (2014) *Global Health Observatory data: overweight, situation and trends. World Health Organization.* http://www.who.int/gho/ncd/risk_factors/overweight_text/en/ *last accessed 28-01-2015*, .

WHO; UNDP (2009) *The energy access situation in developing countries. A review focusing on the Least Developed Countries and Sub-Saharan Africa,* New York, United Nations Development Programme.

Wiggins S. (2014) African agricultural development: lessons and challenges. *Journal of Agricultural Economics* 65: 529-556. DOI: 10.1111/1477-9552.12075.

Wong V. (2014). Four Reasons Why Coca-Cola Will Stick to Sweet Sodas, *Businessweek*,10 April 2014. Retrieved from http://www.businessweek.com/articles/2014-04-10/four-reasons-why-coca-cola-will-stick-to-sweet-sodas

Wood S., Sebastian K., Scherr S.J. (2000a) *Agroecosystems - Pilot Analysis of Global Ecosystems,* Washington, World Resources Institute and International Food Policy Research Institute and World Resources Institute.

Wood S., Sebastian K., Scherr S.J. (2000b) *Agroecosystems - Pilot Analysis of Global Ecosystems,* Washington DC, International Food Policy Research Institute and World Resources Institute.

World Bank (2007) *World development report 2008: Agriculture for development,* Washington D.C., World Bank.

World Bank (2010) *Deep wells and prudence: towards pragmatic action for addressing groundwater overexploitation in India.*

World Bank (2014a) *Food Price Volatility, Food Security and Trade Policy Conference.*

World Bank (2014b) *World Development Indicators 2014,* Washington, DC, World Bank.

World Bank, FAO (2011) *Missing Food: the case of Post Harvest Grain Losses in Sub-Saharan Africa* Washington WorldBank, FAO, Natural Resources Institute

Worldfoodsummit (1996) *Declaration on World Food Security*, Rome.

WWAP (2015) *The United Nations World Water Development Report 2015: Water for a Sustainable World,* Paris, UNESCO.

WWF (2014) *Adopting healthy sustainable diets: Key opportunities and barriers. LiveWell Project report*, World Wide Fund.

Ywema P.E. (2014) *Personal communication*, Sustainable Agriculture Initiative.

Zilberman D., Hochman G., Rajagopal D., Sexton S., Timilsina G. (2012) The impact of biofuels on commodity food prices: Assessment of findings. *American Journal of Agricultural Economics*. DOI: doi: 10.1093/ajae/aas037.

Annex 1 Resource specific options for a more sustainable and efficient use of natural resources in food systems

This Annex lists a number of resource specific biophysical options to make more sustainable and efficient use of the various natural resources as being used in food systems. It has to be stressed that the choice of options is very resource-specific and, therefore, no general recommendations can be given. Additionally, much more can be said about options for each individual resource than is feasible in the context of this report. For more detailed options and their consequences, specific literature should be consulted (i.e. literature cited below).

Options for more sustainable and efficient land use

Many biophysical interventions exist to enhance the sustainable and efficient use of land and soils. In many cases there are even synergies between these two goals, for example in the case of soil amelioration, although tensions may also exist between the short-term goal of high yields and the long-term goal of sustainable use. Given the large varieties in soils and climatic and socioeconomic conditions, there are no universal solutions, only directions that have to be tailored to the local context. Options for a more sustainable management of land, landscapes and soils include:

- At the landscape level, maintenance or reintroduction of landscape elements and other 'natural' areas, which can provide valuable ecosystem services (Scherr & McNeely, 2008);
- Maintenance of soil organic matter content, because of its role in soil biodiversity, water regulation and nutrient adsorption. Soil organic matter content can be maintained by a regular supply of organic substances (plant residues, manure, compost, etc.).
- Prevention of soil erosion, for example by keeping the soil covered (with growing plants or mulching with leaves for example), by counter ploughing as well as by the maintenance of landscape features such as hedges, tree rows and ditches, as they usually help to prevent erosion. These features also help to provide other ecosystem services such as pollination, pest control and water and nutrient regulation.
- Prevention of overgrazing and restoration of degraded rangelands.

Options for a more efficient management of land and soils include:

- Sustainable intensification, implying higher crop yields per unit of land. As in most cases this will mean a higher or better targeted input of other resources (water, minerals, seeds), the word 'sustainable' in this case means without significant trade-offs. Sustainable intensification is discussed in further detail in Chapter 6.

Options for more sustainable and efficient water use

There are many potential biophysical interventions available for enhancing the sustainable and efficient use of water. In **rain-fed systems** the central point is the increase of the crop yield per raindrop. Farmers have many ways of optimizing crop yield per raindrop. Many of these measures coincide with sustainable and efficient land management practices. First of all, it is important that rainwater can infiltrate into the soil rather than running off the land, which also creates risks of soil erosion. Measures such as maintaining a good soil structure and terracing

the land or counter ploughing are usually helpful to enhance infiltration. Secondly, creating a deep and well-structured topsoil helps to store a larger amount of water in the root zone. Finally, good crop management, weed control and in some cases covering the soil with litter can help maximize the amount of water available to crops. In some areas, supplementary irrigation (addition of small amounts of water to essentially rainfed crops) could be effective.

In many areas where yield gaps exist, supplemental irrigation has an underexploited potential and can be pivotal in lifting people out of poverty (Molden, 2007). An important component is to make more water available to crops when it is most needed, for example during flowering. This usually requires far less water than full-scale irrigation. Supplemental irrigation is possible wherever water storage is feasible, and by relatively simple irrigation methods. Especially in Sub-Saharan Africa, there is a large potential, also given the current limited area that is irrigated. In some areas, small-scale individually managed water technologies can be introduced, such as small affordable pumps and low-cost drip irrigation.

In areas with **large-scale irrigation schemes**, two actions are crucial: increasing water-use efficiency and halting water overexploitation. Water-use efficiency can be increased in many ways, depending on the local situation. Important actions are the reduction of water losses in canals and pipe systems, a balanced division of water between farmers, the introduction of drip irrigation and precision agriculture and good crop management (weed control, appropriate fertilization).

Sources like treated wastewater and recycled grey water could alleviate the pressure of fresh water sources, provided that this water is free from contaminants. Also rainwater harvesting is in some areas a useful technique.

Options for a more efficient use of minerals in food systems

There are many specific measures along the food chain to improve nutrient efficiency. In addition, there are also more generic measures such as a reduction in food losses and wastes and a reduction in the consumption of animal products (see Chapter 6). Concrete options are:

- Improving fertilizer efficiency (recovery) at the crop level through soil testing, appropriate amount and timing of fertilizers (precision agriculture), replacement of mineral fertilizers with animal manure, soil conservation to reduce nutrient losses and the use of catch crops to capture post-harvest soil reserves (Cassman *et al.*, 2002, Oenema *et al.*, 2009, Sutton *et al.*, 2013).
- In some regions, many successful efforts have been undertaken over the last 20 years to improve efficient fertilization at the crop level. For example, in several EU Member States, environmental impacts related to various forms of nitrogen pollution were already recognized in the 1980s, resulting in both national policies and the EU Nitrate Directive (1991) 91/676/EEC. This directive obliged all Member States to take action to reduce nitrate losses from agricultural sources. The directive was followed by the Water Framework Directive (Directive 2000/60/EC), which addresses all sources and all pollutants, and by the NEC Directive (Directive 2001/81/EC), which sets upper limits for each Member State for total emissions of ammonia and other pollutants. These directives were translated into national policies, and several EU countries already implemented policies before they were obliged to do so. This resulted in a reduction in the nitrogen surplus in Denmark by around 30% between 1990 and 2003. Belgium and the Netherlands showed a similar decrease over the period 2000 –2008 (Grinsven van et al., 2012), while the surplus in Denmark continued to decrease. The nitrogen surplus (in kg N per ha) in the Netherlands is still the highest in the EU (EEA, 2010).
- The reduction in surplus was achieved with no or little reduction in production, which means an absolute decoupling as well as a strong increase in overall nitrogen-use efficiency. The reduction in nitrogen surplus was mainly the result of improved manure management, including better application techniques and

timing (just before the growing season instead of all year round), and improved overall fertilization (better timing and amounts based on crop requirements).

- One of the methods propagated is Integrated Soil Fertility Management (ISFM) strategies, which centre on the combined use of mineral fertilizers and locally available soil amendments (such as lime and phosphate rock) and organic matter (crop residues, compost and green manure) to replenish lost soil nutrients: http://www.ifdc.org/.
- In the livestock sector, large improvements are possible. The appropriate feeding of animals is a first important step. In traditional food systems in particular, animal productivity is low, whereas in modern food systems feed composition is not always balanced containing more minerals than is actually necessary.
- Potentially, the largest gain can be realized by re-establishing the crop-feed-manure loop. Concentration of livestock is often caused by a combination of agglomeration effects and a lack of appropriate policies. Solutions consist of proper manure collection in stables, manure storage and manure spreading techniques. To reduce ammonia (nitrogen) losses, manure storage need to be covered, and manure spreading needs to be based on low-emission techniques (Sutton *et al.*, 2011a). Appropriate storage capacity is needed to be able to apply the manure at the right time.
- Minerals in food losses and wastes, food residues and by-products could be recycled better. This would lead to a return flow of minerals from urban to rural areas.
- The final steps involve the minerals from human excreta and other sources in sewage systems. The first concern is that these minerals should not be released into freshwater or coastal systems, where they might cause serious pollution issues. Secondly, recycling of the nutrients will increase overall nutrient efficiency.

It should be emphasized that, as previously described, there are more essential minerals than N and P. In fact there are 6 macronutrients (N, P, S, K, Ca and Mg) and 7–10 micronutrients. Proper recycling and increased efficiency should therefore not only focus on N and/or P.

Biophysical options for a more efficient and sustainable use of biodiversity

A more sustainable use of biodiversity and ecosystem services can be achieved in various ways, mostly by reducing pressures. Important aspects are the maintenance of system integrity and stimulation of the resilience of ecosystems. Effective ecological intensification requires an understanding of the relations between crop growth at different scales and the community composition of ecosystem service-providing organisms above and below ground and the contribution to yield the multiple services delivered by these organisms (Bommarco *et al.*, 2013). Farmer knowledge might help understanding these relations and services with respect to local crops, thereby stimulating agro-biodiversity. Understanding ecological processes and addressing how to harness functional biodiversity to secure food production without damaging the wider environment emerge as research priorities. Concrete measures include:

- Conservation or reintroduction of landscape elements such as wetlands, hedges and other more natural areas.
- Agricultural diversification practices such as agroforestry, multi-cropping and crop rotations (Ponisio *et al.*, 2015).
- Adoption of measures to prevent desertification due to overgrazing.
- Reduced and more targeted use of pesticides and other biocides.
- Reduction of land conversion, water use and nutrient losses (see previous sections).

A more efficient and sustainable use of ecosystem services would potentially implicate a shift from current high-input agricultural systems to systems that profit more from ecosystem services such as pest and disease control, pollination, nutrient and water cycling, and provisioning of habitat, while maintaining or even enhancing food production.

Options for a more efficient and sustainable use of genetic resources

Important options for enhancing the sustainable and efficient use of genetic resources are:

- The conservation of the present agro-biodiversity. This is important because the current genetic resources may contain genetic information that is important for future food systems. In some cases, it might be necessary to use the old landraces, as well as wild relatives in further breeding. Fortunately, the conservation of agro-biodiversity has been put on the international and research agenda.
- The conservation of system integrity. System integrity might be at risk for several reasons: (i) the introduction of exotic species, which has taken place often during the last few centuries, sometimes leading to major disasters, especially when the newly-introduced species strongly competed with local species, (ii) the inter-breeding of farm with wild populations, as for example in the case of farmed salmon. This can result in reduced lifetime success, lowered individual fitness, and decreases in production over at least two generations (Thorstad et al., 2008), and (iii) gene flow, being the exchange of genes between cultivated and wild relatives. People are particularly concerned about the consequences of this in the case of Genetically Modified crops.
- New directions for plant and animal breeding. Besides aiming for higher yields, efforts could be directed at plants and animals that perform better under marginal and/or variable conditions. In plant breeding in particular, more attention could be paid to the nutritional value. Other directions that enhance or profit from more agro-biodiversity are plants that are better suited for intercropping or mixed cropping systems, or the use of mixtures of varieties that might increase resilience. Adaptation to climate change might require changing crops, varieties and farming practices (Asfaw & Lipper, 2011).

Options for a more efficient and sustainable use of marine resources

Several measures can be taken to improve both the efficiency and the sustainability of marine resource use. Many assessments emphasize a combination of rebuilding overfished stocks with an increase in sustainable aquaculture in order to meet global fish demands while relieving the pressure on marine ecosystems. Options for fisheries include:

- Limiting fish yields to an ecologically sustainable level, also taking into account social aspects. The concept of Maximum Sustainable Yield (MSY) is often used in policies, although this concept is challenged (see also next bullet point). MSY is the largest yield that is theoretically possible over an indefinite period when a steep, immediate and prolonged reduction of the fishing effort is called for. Model scenarios show that even with a dramatic reduction in the global catch to 12 million tonnes (from currently ~ 80 million tonnes) that is then built up incrementally, it will take 20–30 years to attain a MSY of 80 million tonnes per year (PBL, 2010).
- An ecosystems approach to fisheries management. A more holistic approach to fisheries management is thought to have much more beneficial effects on marine biodiversity than the current species-by-species approach (PBL, 2014a). Given the importance of small-scale operations in the global fisheries sector, policies and other actions should directly address the sustainability and efficiency issues faced by this segment. The predominance of small fishing vessels (~79% of all motorized boats were smaller than 12m in 2012) illustrates the importance of small-scale fisheries and their potential impact on the sustainable and efficient use of marine resources (FAO, 2014c). Small-scale fisheries are increasingly viewed as catalysts of sustainable development in fisheries (PBL, 2012). Differentiation between large- and small-scale operations would have to be carefully designed to secure the sustainability of the stocks that the small-scale segment ultimately depends on.
- Eliminate destructive fishing gear such as dynamite and poison fishing and minimize use of potentially damaging techniques like bottom trawling in vulnerable areas.
- Changing consumers' preferences, for example towards the consumption of smaller

fish, other fish or shellfish species.

- Adopt greener technologies that reduce fossil fuel use and greenhouse gas emissions as well as by-catch. A great example of this is the recently adopted technology of pulse fishing as an alternative to bottom trawling. This technology can reduce fossil fuel use by up to 50%, while at the same time reducing by-catch significantly.
- Increase sustainable aquaculture production. Important options for this sector include improving feeding efficiency, the substitution of fish meal with vegetarian resources and a focus on herbivorous fish; preventing spill over into wild ecosystems by using sterile triploids; minimizing the application of chemicals such as anti-fouling agents and antibiotics and focusing on cultivation for domestic consumption (PBL, 2014a). One of the difficulties in replacing fish meal with plant-based alternatives is that the fatty acid composition is less favorable, as the plant-based alternatives mainly contain omega-6 fatty acids, instead of omega-3 fatty acids.

Options for more efficient use of fossil fuels and replacement with renewable sources

The main pathways to reduce fossil fuel use are:

- Reduce energy-use and improve energy efficiency at all stages: energy-efficient equipment (cooling, transportation), reduction of transport (especially energy-intensive transport as air freight) and through synergies with other resources. For example, a more efficient use of water and fertilizers will reduce energy demand. Change in lifestyle and diets (for example lower consumption of products that need cooling) also lead to reduced energy-use.
- Switch to renewable energy sources, such as solar, wind or forms of bioenergy.

At the same time, the use of bioenergy (notably bio-fuels) as an alternative for fossil fuels has several trade-offs that need to be taken into consideration (UNEP, 2009). A higher demand for biofuels will add to the need of expanding cropland to meet growing food demand, and also creates risks of higher food prices. Expansion may also be at the expense of forests. For instance, in Indonesia an estimated two-thirds of the current expansion of palm oil cultivation has resulted from the conversion of rainforests. In addition, several environmental effects are associated with growing biofuel crops such as increased eutrophication and water quality problems (UNEP, 2009)

Options to reduce greenhouse gas emissions

In the IPCC report on the Mitigation of Climate Change a number of mitigation options were identified for the AFOLU sector, sorted into supply-side options. Demand-side options were also identified, such as reducing food losses and wastes and dietary changes (Chapter 6). These don't include options for other food system activities, although a number of demand-side options (such as reduced food wastes and losses) will affect all food system activities. It should be noted that many of the mitigation options will also have benefits for resource use (notably of land, water and nutrients), while some will also lead to a reduction of nutrient losses. Estimates for the mitigation potential of supply-side options from the agricultural sector range from 0.3 to 4.6 Gt CO_2-eq/yr at prices up to 100 USD/tCO_2-eq (IPCC, 2014a). The IPCC WG III report states that demand-side options are largely under-researched. Changes in diet and reductions in losses in the food supply chain could however have a significant impact on GHG emissions from food production (0.76–8.55 GtCO_2-eq/yr by 2050).

Annex 2 Glossary

Biodiversity	The Millennium Ecosystem Assessment (MA, 2005) defines biodiversity as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems." Biodiversity forms the foundation for ecosystem services
Ecosystem services	Ecosystem services are defined as benefits people obtain from ecosystems.(MA, 2005)
Efficient resource use	An efficient use of resources is defined as 'high output per unit of input', to be measured at various spatial and temporal levels.
Environmentally-sustainable food systems	An environmentally-sustainable food system is a food system in which the environmental bases to deliver food security for future generations is not compromised. A sustainable and efficient use of natural resources for, as well as a limited environmental impacts of, food system activities are key components of an environmentally-sustainable food system.
Environmental impacts	Environmental impacts (of food systems) refer to impacts of food system activities on the environment. Main environmental impacts are a result of direct human interventions, such as deforestation, as well as in the form of emissions (e.g. of nutrients, greenhouse gases and pesticides).
Food chain	A food chain is the set of activities within the food system, usually including producing, processing, distributing, preparing and consuming food.
Food losses and waste	Food loss and waste (FLW) refers to a decrease of the amount of food that was originally intended for human consumption, regardless of the cause. It can occur at any stage of the food chain from harvesting to consuming. Food losses refers to a decrease, at all stages of the food chain prior to the retail or consumer level, in mass, of food that was originally intended for human consumption, regardless of the cause. Food waste refers to food appropriate for human consumption being discarded or left to spoil at retail or consumer level – regardless of the cause. Based on HLPE(2014a)
Food security	A state or condition when all people, at all times, have physical, economic and social access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life CFS (2009)

Food system	A food system gathers all the elements (environment, people, inputs, processes, infrastructures, institutions, etc.) and activities that relate to the production, processing, distribution, preparation and consumption of food, and the outputs of these activities, including socio-economic and environmental outcomes (HLPE, 2014a)
Genetically -modified (GM) organisms	Genetically modified organisms (GMOs) can be defined as animals or plants in which the genetic material (DNA) has been altered in a way that does not occur naturally by pollination and/or natural recombination. It allows selected individual genes to be transferred from one organism into another, also between nonrelated species. Foods produced from or using GM organisms are often referred to as GM foods. (WHO)
Genetic resources	The diversity of plants, animals and micro-organisms on which all food systems depend
Intermediate food systems	Food systems which show part of the characteristics of traditional food systems, but also characteristics of modern food systems
Malnutrition	Bad nutrition, either too little or too much on required calories and nutrients
Minerals	Minerals in this report refer to the chemical elements (apart from C, H and O) which are essential for plant growth, animals and humans (e.g. P, K, Ca and Mg). Minerals can be naturally present in the soils, or can be mined from geological stocks. The terms minerals and nutrients are use as alternate terms.
Modern food systems	'Modern' systems (alternatively referred to as 'high external-input food systems') are food systems which depend on a range of inputs such as new crop varieties, fertilizers, pesticides, veterinary applications, machinery and other high-tech equipment for producing food, and high-tech systems for storing, transporting, processing and retailing activities.
Non-renewable resources	Non-renewable resources are exhaustible natural resources whose natural stocks cannot be regenerated after exploitation or that can only be regenerated or replenished by natural cycles that are relatively slow at human scales" (OECD, 2002). They include fossil fuels, metals and minerals. (UNEP, 2010)
Nutrients	See minerals. These terms are in these report largely used as synonyms. The term nutrients is more related to their use and function in plant production. The term nutrients as used in human nutrition compromises more substances than minerals.
Nutrition security	A state or condition when all people at all times have physical, social and economic access to food, which is safe and consumed in sufficient quantity and quality to meet their dietary needs and food preferences, and is supported by an environment of adequate sanitation, health services and care, allowing for a healthy and active life (Horton and Lo, 2013).
Obesity	Obesity is a medical condition in which a high amount of body fat increases the chance of developing medical problems.
Obese	Adults with a Body Mass Index (BMI) higher than 30.0

Overweight	Adults with a Body Mass Index (BMI) 25.0 to 29.9
Renewable resources	Renewable resources stem from renewable natural stocks that, after exploitation, can return to their previous stock levels by natural processes of growth or replenishment, provided they have not passed a critical threshold or 'tipping point' from which regeneration is very slow (e.g. soil degradation), or impossible (e.g. species extinction) (UNEP, 2010). Crucial renewable resources for food systems are land, water, biodiversity (including genetic and marine resources) and ecosystem goods and services
'Resource-Smart' Food Systems	Alternate term for environmentally-sustainable food systems
Sustainable food system	A sustainable food system (SFS) is a food system that ensures food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition of future generations are not compromised. (HLPE, 2014a)
Sustainable intensification	Sustainable intensification can be defined as simultaneously improving the productivity and sustainable management of natural resources, although various, overlapping definitions exist (Buckwell *et al.*, 2014, Garnett *et al.*, 2013, Pretty *et al.*, 2011)
Traditional food system	'Traditional' food systems (or 'low external input-intensive food systems') involve farmers and fishers using mainly inputs available on the farm, applying growing and harvesting techniques established already for a long time and moving produce by foot, animal or cart to local markets, where they usually sell or trade their commodities relatively unprocessed. (Chapter 3)
Undernourishment	Undernourishment means that a person is not able to acquire enough food to meet the daily minimum dietary energy requirements, over a period of one year. FAO defines hunger as being synonymous with chronic undernourishment.
Water efficiency	Water efficiency is described by the ratio of useful water outputs to inputs of a given system or activity. It implies using less water to achieve more goods and services and entails finding ways to maximize the value of water use and allocation decisions. (UNEP, 2011b)
Water productivity	Water productivity measures how a system converts water into goods and services. It refers to the ratio of net benefits derived from e.g. crop, forestry, fishery, livestock and industrial systems to the amount of water used in the production process (product units/m3). Generally, increased productivity of water means increasing the volume of benefit, i.e. output, service or satisfaction from a unit of water used. When water productivity is measured in monetary output instead of physical output, we speak about "economic water productivity". (UNEP, 2011b)

For more information,
contact:

International Resource Panel Secretariat,
United Nations Environment Programme
Division of Technology, Industry and Economics

Email: resourcepanel@unep.org

Website: www.unep.org/resourcepanel

Twitter: @UNEPIRP

Global food systems have radically changed over the last 50 years. Food production has more than doubled, diets have become more varied (and often more energy-intense) satisfying people's preferences in terms of form, taste and quality, and numerous local, national and multi-national food-related enterprises have emerged providing livelihoods for millions. Nonetheless, over 800 million people are still hungry (70% of which live in rural areas in developing countries), about two billion suffer from poor nutrition, and over two billion are overweight or obese.

The resource use implications and environmental impacts of these food systems are significant. In general, of all economic activities, the food sector has by far the largest impact on natural resource use as well as on the environment. An estimated 60% of global terrestrial biodiversity loss is related to food production; food systems account for around 24% of the global greenhouse gas emissions and an estimated 33% of soils are moderately to highly degraded due to erosion, nutrient depletion, acidification, salinization, compaction and chemical pollution.

This report looks at food as a crucial connection point (a 'node') where various societal issues coincide, such as human dependence on natural resources, the environment, health and wellbeing. Rather than looking separately at resources such as land, water and minerals, the International Resource Panel (IRP) has chosen a systems approach. The report looks at all the resources needed for the primary production of food, as well as for other food system activities (e.g. processing, distribution) considering not only the set of activities, but also the range of actors engaged in them and the outcomes in terms of food security, livelihoods and human health.

In this report, the IRP assesses the current status and dynamics of natural resource use in food systems and their environmental impacts and identifies opportunities for resource efficiency improvements in global food systems, responding to policy-relevant questions like *what do sustainable food systems look like from a natural resource perspective? How can resource efficiency improvements be made to enhance food security? How to steer transition towards sustainable food systems?*

www.unep.org
United Nations Environment Programme
P.O. Box 30552 Nairobi, 00100 Kenya
Tel: (254 20) 7621234
Fax: (254 20) 7623927
E-mail: uneppub@unep.org
web: www.unep.org

UNEP

ISBN: 978-92-807-3560-4
Job Number: DTI/1982/PA