# TEEB for Agriculture & Food Interim Report

A report by
‘The Economics of Ecosystems & Biodiversity’

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## The Economics of Ecosystems and Biodiversity (TEEB)

is a global initiative focused on “making nature’s values visible”. Its principal objective is to mainstream the values of biodiversity and ecosystem services into decision-making at all levels. It aims to achieve this goal by following a structured approach to valuation that helps decision-makers recognize the wide range of benefits provided by ecosystems and biodiversity, demonstrate their values in economic terms and, where appropriate, capture those values in decision-making.

## Disclaimer

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The contribution of nature to agricultural productivity throughout the globe has not received the recognition it deserves. Global and national economic policies and programmes have for many years failed to fully acknowledge the contribution of biodiversity and ecosystem services in the global and national economies.

Rarely do we see the invaluable contributions of nutrient cycling, pollination, pest control and water flow from catchment areas reflected in national agricultural production accounts. This may be attributed to a wide range of reasons including the complexity of attaching monetary values to natural goods and services among others.

This initiative led by The Economics of Ecosystems and Biodiversity (TEEB) office of the United Nations Environment Programme (UNEP) is a very welcome step towards influencing global and national perspectives on the complex interrelationship between agricultural productivity and availability of healthy biodiversity and ecosystems. It will also bring to the fore some of the challenges increasing agricultural productivity poses to the environment, such as climate change and pollution and their attendant impacts on global and national economic and human well being.

I am fully convinced that the results of the initiative will greatly influence and raise the level of recognition and appreciation of these "invisible" values provided by nature. In turn, that recognition and appreciation will influence global discussions and decision making in different sectors of the global economies.

It is my sincere hope that the initiative will be highly successful and will receive the support of all relevant state and non state stakeholders.

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# THE COMPLEXITY OF THE WORLD'S FOOD SYSTEMS AND THE CHALLENGES AHEAD

## Why and how "The Economics of Ecosystems and Biodiversity" (TEEB) can contribute to the long-term sustainability of food for all

Our food systems are incredibly complex, diverse and interlinked by trade, climate and a host of other factors that respect no borders. Today's food systems range from local to global, from subsistence agriculture to feed one's own family to the global, high-volume trade in commodities. Each food system is made up of different production, processing and distribution elements. Our consumption patterns are as diverse as our production systems and are influenced by culture, by nutritional needs and by changing dietary preferences.

Food systems have been the subject of numerous analyses capturing certain elements of the system and/or how the system is performing (and how this performance might be enhanced) measured against certain criteria, such as fighting hunger, improving food security, climate change mitigation, or reducing overall ecosystem impacts.

These research findings are filling libraries. Titles such as "The Poorest and Hungry"[1], or the annual "The State of Food and Agriculture"[2] to "Food Security and Climate Change"[3] and "Feeding Frenzy"[4] and "SCN Reports on the World Nutrition Situation"[5] constitute but a tiny fraction of the range of publications available, and this list does not begin to cover the diversity of research conducted in universities, or available in grey literature, all over the world.

Much of the research on our food systems express sustainability concerns in both the short term and (even more) in the long term. Johan Rockström summarized the current alarming state of the natural resource base of our economy thus, in an article in The Guardian: "As long as the Earth was relatively large, with good resilience and ample abundance of resources, we could benefit from subsidies from ample natural resources, a forgiving ecosystem and a stable climate. Ecosystems provide fresh water, pollination, fertile soil and food. Indeed, the stability of the global climate over the past 11,000 years, which geologists call the 'Holocene'[6], has been the foundation for our global civilisation". But human activities have led to a fundamental changes in our ecosystems and indeed, they are destabilizing our ecosystems. The latest assessment on the state of the biosphere estimates that as a result of human activities, we have already crossed four planetary boundaries (climate change, biodiversity loss, deforestation and fertiliser use)[7]. And our current food systems are part of the problem.

In light of this, we have started a new analytical work stream concentrating on what most assessments to date have only partially addressed – if at all. “The Economics of Ecosystems and Biodiversity for Agriculture and Food” (TEEBAgFood) identifies the values that well-functioning biodiversity and ecosystems (‘natural capital’), skills & knowledge (‘human capital’), finance and machinery (‘physical capital’) and societal interactions, relationships, formal and informal institutions (‘social capital’) bring to our food systems, and how these systems depend on them. Equally, it identifies the impacts of diverse food and agricultural systems on natural, human and social capital stocks, which comprise the most significant parts of the wealth of nations[8].

As a project, since 2009, TEEB has highlighted that nature provides human society with a vast diversity of benefits such as food, fibres, clean water, healthy soil, carbon capture and many more[9]. These benefits are called ‘ecosystem services’ and they - together with biodiversity - represent the natural wealth of the Earth. They are our life support systems. Nothing short of our very existence depends on the continuing flow of these services. Technology can alter ecosystem services and biodiversity but it cannot replace them.

Whereas TEEB has a wide, cross-sectoral mandate[10], for TEEBAgFood we specifically want to capture the values of ecosystems services and biodiversity across different agricultural systems where a variety of management practices are used. We look at the impacts arising from the production, processing and distribution of food on natural and social capital, and analyse both the health impacts of consumption patterns and the impacts of the systems on human health. The true cost of producing one kilogram of wheat or one litre of milk can vary markedly from the price we pay as consumers if we take into account the role of all ecosystem services and biodiversity along the value chain. At the heart of this study, we are asking the question: are we paying the correct price for our food? Sometimes we may be paying too little (as the economic system does not capture the full range of public costs through negative impacts on natural and social capital), and in other instances we may be paying too much.

TEEBAgFood will not merely take into account only the visible values of ecosystems and biodiversity as they are captured in the price tags of our food. We want to also value the invisible costs and benefits of food systems – both the provisioning of clean water and air (a positive value) and the polluting of water and air (a negative value). Capturing the complexity of food systems, looking at the positive and negative impacts, and analysing the visible and invisible inter-relations with nature and society are at the centre of this study. Contrary to ‘putting a price on nature’, as some have confused with TEEB, the goal is to examine more closely the implicit values of the services that nature provides at zero or close to zero cost.

The discussions during the negotiations of the Sustainable Development Goals[11] (SDGs) highlighted the importance of changing our development pathways – which the international community agreed to do. Agriculture and food systems are key for the transition towards the sustainability of sectors in this regard. TEEBAgFood will present evidence on how different production systems are based on ecosystem services, how they both depend upon and impact on natural and social capital (in both a positive and negative way) and how they can contribute to the transformation required and aspired to in the SDGs.

In this Interim Report, we present the first results of several exploratory studies as well as snapshots of selected production systems. The intention is to illustrate what different food systems look like, how interactions with the environment and society can be described and finally present some preliminary and indicative value estimates of the use of social and natural capital in some contexts. The new research outcomes quoted in this Interim Report largely concentrate on agricultural production systems (i.e. within the farm gate) but we also highlight the importance of wider supply chain impacts on ecosystems and on human health.

After the publication of this report, i.e. in TEEBAgFood phase II, we will systematically value our food systems from farm to fork (and indeed beyond to include waste management), i.e. beyond primary production. As an analytical framework, we divide global food systems along the food value chain as follows:

1. The interactions between people, nature, knowledge and technology in the agricultural sector to produce food;
2. Production of food and distribution of the produce at local, regional and global scale; and
3. Consumption of food by humans and management of waste.

We know that each of the categories includes vast variability. In this Interim Report, we provide an example (Chapter 2) for category (1), showcasing the diverse range of production systems and processes that are employed by smallholder farmers in Asia to produce rice, and how real positive and negative ecosystem impacts and dependencies (and thus real costs and benefits) are linked to these systems and processes. This is not merely a theoretical exposition - it demonstrates that the concepts developed in TEEB are also applicable to the analysis of real-world food systems. We also set out striking examples from the exploratory studies (see Appendices) of how a TEEBAgFood assessment can demonstrate options for simultaneously improving livelihoods and reducing the impacts on ecosystems.

In Phase II of TEEBAgFood, we will not only look at other agricultural production systems (such as mixed production systems) but also analyses beyond the farm gate: production, processing, distribution, consumption and food waste, and both ecosystem health and human health impacts and dependencies. We know that this will be very complex and challenging but we are convinced that the long-term sustainability of our food systems requires such an integrated approach.

We also want to make clear that valuation of ecosystem services and biodiversity does not mean commodification or monetization or indeed privatization of nature, or of social assets. Just because food has a price tag does not mean that all ecosystem services must have one. Indeed many should not and cannot, such as the spiritual values that agricultural landscapes provide us. These are real ecosystem services, they affect our wellbeing – in fact they can provide purpose to our lives – but they will not have a Dollar price tag. They are included in our TEEBAgFood Framework (Chapter 3) that provides a proposed methodology for capturing values to include all visible and invisible value additions in decision-making for a sustainable future for all.

**Alexander Müller**
**TEEBAgFood Study Leader**

Photo: © Claudia Leisinger

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## Agriculture at the centre of human wellbeing and sustainable development

1. Human history is inextricably tied to the development of agriculture. This tie has always been about more than agriculture as a source of food for human sustenance; agriculture has influenced our value systems, our cultural heritage, the structure and location of our communities, and the development of other sectors in the economy. Agriculture is central to our lives.

2. Human well-being is affected by these disparate ties. We need sufficient quantities of food with adequate nutritional value in order to survive – this is a fundamental physiological need, and this human need is still not being met for a significant portion of the world's poor, a central challenge reflected in several of the Sustainable Development Goals. However, all of the other ties also reflect elements of sustainability.

3. How we produce, distribute and consume food affects these ties and thus our well-being. Increasingly however, the ties between food systems and human health, cultural heritage, and the impacts that our production systems are having on nature have become largely invisible, or worse, severed completely.

4. This invisibility can move us away from stewardship of our natural resources, to their unsustainable use, generating negative impacts for both present and future generations.

## Agricultural systems and the provision of food and nutrition

5. Food systems are producing more than enough calories to feed the world today. Since 1970, the amount of food available for every person for direct consumption has increased from 2370 to 2770 kcal/person/day. In aggregate, there is sufficient food available for everyone to be fed, and nearly everyone to be well-fed. That this is not happening points to systemic failure in equity and meeting basic human needs.

6. Indeed, owing to problems of access and distribution, some 2.3 billion people in developing countries consume under 2,500 kcal/day (500 million of whom consume less than 2,000 kcal/day), while 1.9 billion in developed countries are consuming more than 3,000 kcal/day. While many are dying of want and starvation, others suffer from lifestyle diseases stemming from over-consumption.

7. And this need not be so. Approximately one-third of the food produced in the world for human consumption every year — approximately 1.3 billion tonnes — gets lost or wasted. If food waste were a country, it would be the third largest emitter in the world in terms of greenhouse gas emissions (3.3 billion tonnes).

## The role of women in the agricultural sector

8. On average, women comprise 43 per cent of the agricultural labour force in developing countries; this figure ranges from around 20 per cent in Latin America to 50 per cent in parts of Africa and Asia, and exceeds 60 per cent in certain countries. Although largely restricted to growing food crops and rearing poultry and livestock, women are responsible for 60 to 80 per cent of food production in developing countries.

9. However, women only represent between five and 30 per cent of all agricultural landholders in lower income regions.

10. If women had the same access to productive resources as men, FAO estimates that they could increase yields on their farms by 20 to 30 per cent, raising total agricultural output in developing countries by 2.5 to 4 per cent.

11. Closing the gender gap in terms of access to agricultural inputs alone could lift 100 to 150 million people out of hunger.

## The positive impacts of agriculture on human livelihoods

12. As well as providing the food and sustenance we need, agriculture and food systems also create employment and income. The sector employs one in three people of the world's economically active labour force, or about 1.3 billion people.

13. An estimated 2.5 billion people are involved in full- or part-time smallholder agriculture, while over one billion people living in rural poverty are dependent on agriculture for their livelihoods. As such, agriculture is the socio-economic backbone of rural landscapes. Smallholder farms (i.e. less than 2 hectares) represent over 475 million of the world's 570 million farms and, in many low income countries, they produce over 80 per cent of the food consumed.

14. The agricultural sector does not produce only food - it also produces feed for animals (for human consumption), fuel (both traditional fuels and modern biofuels) and fibre for artisanal and industrial production. Thus the agricultural sector contributes inputs to many other industrial sectors.

15. The FAO estimates that about 500 million hectares around the world are dedicated to agricultural heritage systems that still maintain their unique traditions with a combination of social, cultural, ecological, and economic services that benefit humanity.

## The impacts of our food consumption and production patterns on human health

16. Globally, an estimated two billion people are experiencing micronutrient malnutrition. By contrast, global levels of obesity have more than doubled since 1980. Recent estimates show that over 1.9 billion adults are overweight, 600 million of which are obese.

17. Vitamin A deficiency – the greatest preventable cause of needless childhood blindness and increased risk of premature childhood mortality from infectious diseases – still affects 250 million preschool children and a substantial proportion of pregnant women in lower-income countries.

18. In some African countries, yields from rain-fed agriculture could be reduced by up to 50 per cent by 2020 owing to climate change. This is likely to aggravate the burden of undernutrition in developing countries, which currently causes 3.5 million deaths each year, both directly through nutritional deficiencies and indirectly by intensifying vulnerability to diseases such as malaria and diarrhoea, and respiratory infections.

19. How we grow our food also impacts on human health via environmental factors. In Sumatra, recent peat fires associated with clearing of agricultural land have forced the evacuations of infants from the region with air quality indices remaining above 1000 for several weeks (>300 is deemed dangerous).

20. While research on the health impacts from exposure to agrochemicals is limited, evidence is starting to build. Recent research explores the health impacts of pesticides as 'endocrine disrupting chemicals' (i.e. chemicals that interfere with hormones). In the EU alone, pesticide exposure causes the highest annual health and economic costs at roughly $127 billion, almost four times as high as the second highest category (plastics).

## The impact of food consumption and production on ecosystems and biodiversity

21. It is estimated that 52 per cent of land used for agriculture worldwide is moderately or severely affected by land degradation and desertification.

22. Eutrophication has contributed to the creation of over 400 oceanic dead zones worldwide, primarily concentrated in Europe, eastern and southern US, and Southeast Asia. In total, these zones cover a total area of 245,000 square kilometres, or more than half the size of California.

23. Agriculture is thought to cause around 70 per cent of the projected loss of terrestrial biodiversity. In particular, the expansion of cropland into grasslands, savannahs and forests contributes to this loss.

24. Agriculture also makes positive contributions to nature, if well-managed. Sowing crops that bloom in different periods may increase wild-insect populations. In Sweden, bumble bee reproduction was improved in landscapes with both late-season flowering red clover and early-season mass-flowering crops. As a result, an adequate proportion of cropland in heterogeneous landscapes can be beneficial to some wild fauna taxa if appropriate crop management practices are adopted.

## We cannot manage what we do not measure

25. There are many benefits provided by agriculture but also many costs. These benefits and costs are often invisible in the sense that they are not traded in the market and do not have a market price. But they do nonetheless impact on our wellbeing. All of these invisible as well as visible impacts will need to be assembled and evaluated through a universal framework, in order to provide analytical consistency and comparability across systems, across policies, and across business strategies.

26. These positive and negative impacts might be created by one agent in society but borne by others, i.e. they are positive and negative 'externalities'. The large negative externalities arising from our eco-agri-food systems complex can be addressed by a range of regulatory reforms, policy reforms including fiscal policies and incentives, and market-based mechanisms.

27. A universal, widely accepted framework for recognising, demonstrating and, where appropriate, capturing the values of these externalities will play an important role in addressing this challenge. Furthermore, to be comprehensive, all hidden costs and benefits of different food systems must be assessed in their entirety, both in terms of their life cycle and their impacts on all dimensions of human well-being.

28. The full range of stakeholders will need to be involved in managing and reducing negative externalities and increasing the provision of positive externalities: farmers, agri-businesses involved at all stages of the value chain (in food processing, distribution and disposal), government entities (at local, national, regional and international levels), and citizens.

29. The first step, however, is to categorize and measure these impacts and externalities, as we cannot manage what we do not measure.

## TEEB for Agriculture and Food (TEEBAgFood) – changing the discourse on food systems

30. The TEEBAgFood study is designed to provide a comprehensive economic evaluation of the 'eco-agri-food systems' complex, and demonstrate that the economic environment in which farmers operate is distorted by significant externalities, both negative and positive, and a lack of awareness of our dependency on nature.

31. The 'eco-agri-food systems' complex is a collective term encompassing the vast and interacting complex of ecosystems, agricultural lands, pastures, fisheries, labour, infrastructure, technology, policies, culture, traditions, and institutions (including markets) that are variously involved in growing, processing, distributing and consuming food.

32. Operations within the entire agricultural value chain - production, processing, distribution, consumption and waste – not only have impacts but also depend on the state of the environment,

socio-economic well-being, and human health.

33. TEEBAgFood seeks to overcome the common practice of viewing ecosystems, agriculture and food systems as distinct ´silos´. A selective analysis, not recognizing agriculture holistically, leads to suboptimal decisions with far-reaching consequences.

## Exploratory TEEBAgFood Interim Report studies

34. TEEBAgFood has commissioned a series of exploratory studies that attempt to populate the TEEBAgFood framework: livestock (dairy, poultry and beef production); rice; palm oil; inland fisheries; agro-forestry; and maize.

35. Indicative results demonstrate that (i) it is possible to quantify and value a sub-set of the positive and negative impacts and externalities in the framework and (ii) in so doing, we can highlight outcomes that both improve human livelihoods and also reduce impacts and dependencies on ecosystems and biodiversity. As such, we have some of the theoretical building blocks for assessing the 'true cost' of food, including the impact of food production on human health and well-being.

36. Worldwide, around 80 million hectares of irrigated lowland rice provides 75 per cent of the world's rice production. This predominant type of rice system receives about 40 per cent of the world's total irrigation water and 30 per cent of the world's freshwater resources withdrawn from the natural cycle .

37. The System of Rice Intensification (SRI) includes intermittent flooding, the transplanting of young (8-10 day old) single rice seedling, and applying intermittent irrigation and drainage to maintain soil aeration. In addition, the use of a mechanical rotary hoe or weeder is suggested under SRI to aerate the soil and control weeds.

38. The rice study compared SRI with conventional production methods. In Senegal, the impacts of water consumption under conventional systems was valued at US$801/ha as compared with US$626/ha under SRI. Further, revenues per hectare are estimated to be higher under SRI (US$2422/ha) versus conventional (US$2302/ha). Switching to SRI, society could save around $11 million/annum in water consumption related health and environmental costs in Senegal, and at the same time the rice producing community would gain around US$17 million through yield increases.

39. This is one of many examples of win-win outcomes generated by our exploratory studies. In other cases, the research highlights trade-offs between categories of positive and negative impacts and dependencies. The results are suggestive of additional insights that can be gained by widening and deepening the lens.

## TEEBAgFood Next Steps – lessons learned from the exploratory studies

40. The exploratory studies commissioned by TEEBAgFood have led to the following suggestions for further research:

a. Include all significant dependencies and impacts from biodiversity-agriculture linkages, as critical elements in understanding the economics of ecosystems and biodiversity;

b. Typologies evaluated should include mixed systems, reflecting the full complexity and diversity of smallholder agriculture, and suggestive of resilient production systems at larger scales;

c. Off-farm dependencies and impacts to be included, taking the full 'eco-agri-food' value chain as boundary, to inform our analysis;

d. Health impacts to be included - arising from unhealthy diets, or arising from agricultural impacts on air quality, water quality, and vector-borne diseases, as important elements in tracing the hidden costs of current production and consumption patterns;

e. The full gamut of impacts and externalities identified in the TEEBAgFood framework should be applied across all major system typologies, developing and informing efforts to identify 'full cost pricing' of food.

## Towards an engaged TEEBAgFood community

41. This Interim Report has sketched out the myriad and inter-related factors that link agriculture, food, and human well-being. It is a call for evidence and contributions, addressed to institutions and experts (contributors, authors, reviewers, practitioners in policy and business, and civil society representatives).

42. TEEBAgFood intends to commission and synthesize research that generates the complete picture, therein providing important evidence for policy interventions. By identifying various points in the value chain where the most important impacts and dependencies between the different systems occur, TEEBAgFood has developed a robust analytical frame that can inform and influence policy debates on food systems, and underlying relationships to ecosystems and biodiversity. It will also make solutions towards sustainability more accessible, with the Sustainable Development Goals as a possible policy 'hook'.

43. At all levels -policy, corporate and individual- the economic invisibility of natural wealth and degradation is influencing both the short and the long term sustainability of agriculture and food systems. Therefore, TEEBAgFood foresees different messaging for different target groups and cross-sectoral engagement of government, private, academic and civil society stakeholders. The TEEBAgFood will aim at gaining better engagement not only with the 'unaware', but also with 'critics'.

44. The four guiding principles uniting this community are 'quality', 'transparency', 'inclusion', and 'change' with the overall objective being to better inform the management and stewardship of the various components of the eco-agri-food systems complex.

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# GLOSSARY & KEY CONCEPTS

**Agroforestry -** a collective name for land-use systems in which trees and shrubs are grown in association with crops and pasture and/or livestock, in a spatial arrangement, a rotation or both, and in which there are both ecological and economic interactions between the tree and non-tree components of the system

**Biodiversity (biological diversity) -** 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

**Carbon sequestration -** the process of increasing the carbon content of a reservoir other than the atmosphere

**'Cultural' ecosystem services -** all the non-material, and normally non-consumptive, outputs of ecosystems that affect people's physical and mental states

**Driver (direct or indirect) -** any natural or human-induced factor that directly or indirectly causes a change in an ecosystem

**Eco-agri-food systems complex -** a collective term encompassing the vast and interacting complex of ecosystems, agricultural lands, pastures, fisheries, labour, infrastructure, technology, policies, culture, traditions, and institutions (including markets) that are variously involved in growing, processing, distributing and consuming food

**Ecological infrastructure -** a concept referring to both the services provided by natural ecosystems, and to nature within man-made ecosystems

**Ecosystem -** a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit

**Ecosystem service -** the direct and indirect contributions of ecosystems to human well-being *(see also 'Provisioning', 'Regulating and Maintenance' and 'Cultural' ecosystem services)*

**Equity -** fairness in the distribution of rights and of access to resources, services or power

**Externality -** a state where: (i) the actions of one economic agent in society impose costs or benefits on other agent(s) in society; and (ii) these costs or benefits are not fully compensated for and thus do not factor into that agent's decision-making

**Food security -** a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life

**Human capital -** people and their ability to be economically productive. Education, training, and health care can help increase human capital

**Human well-being -** a context- and situation-dependent state, comprising basic material for a good life, freedom and choice, health and bodily well-being, good social relations, security, peace of mind, and spiritual experience

**Landscape -** an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors

**Market failure -** a state in which markets fail to allocate the resources efficiently and effectively, for instance due to the existence of externalities or market power (monopolies) or public goods

**Multiplier -** the multiplier effect refers to an increase in final income arising from any new injection of spending

**Natural capital -** the limited stocks of physical and biological resources found on earth. Also refers to the capacity of ecosystems to provide ecosystem services

**Physical capital -** the stock of value inherent in the quantity and quality of machinery, manufactured goods and finance

**Planetary boundaries -** a series of biophysical thresholds for Earth systems, which can be defined as a safe planetary operating space that will allow humanity to continue to develop and thrive for generations to come

**Precautionary principle -** The precautionary principle permits a lower level of proof of harm to be used in policy-making whenever the consequences of waiting for higher levels of proof may be very costly and/or irreversible

**'Provisioning' ecosystem services -** all nutritional, material and energetic outputs from living systems

**Public goods -** a good or service in which the benefit received by any one party does not diminish the availability of the benefits to others, and where access to the good cannot be restricted

**'Regulating and Maintenance' ecosystem services -** all the ways in which living organisms can mediate or moderate the ambient environment that affects human performance

**Resilience (of ecosystems) -** their ability to function and provide critical ecosystem services under changing conditions

**Social capital -** the value inherent in relationships and networks amongst people and institutions that enables societies to function more effectively

**Threshold/tipping point -** a point or level at which ecosystems change, sometimes irreversibly, to a significantly different state, seriously affecting their capacity to deliver certain ecosystem services

**Tradeoffs -** management choices that intentionally or otherwise change the type, magnitude, and relative mix of services provided by ecosystems

**Valuation, economic -** the process of estimating a value for a particular good or service in a certain context (in monetary or non-monetary terms)

**Value addition -** the contribution of invisible and visible flows to human well-being through their positive (or negative) impacts along the agricultural value chain

**Value Chain (agriculture) -** the agricultural value chain refers to the whole range of goods and services necessary for an agricultural product to move from the farm to the final customer

Photo: ©James Whitesmith

# LIST OF ACRONYMS

**AFOLU** - agriculture, forestry and other land use
**AKST** - agricultural knowledge, science and technology
**AMR** - antimicrobial resistance
**CBD** - Convention on Biological Diversity
**CGIAR** - the Consultative Group for International Agricultural Research
**CICES** - Common Instrument for the Classification of Ecosystem Services
**$CO_2$** - carbon dioxide
**CRP** - Conservation Reserve Program
**DALY** - disability-adjusted life year
**EU** - European Union
**FAO** - Food and Agriculture Organization of the United Nations
**GBD** - Global Burden of Disease
**GDP** - Gross Domestic Product
**GHG** - greenhouse gas
**GLEAM** - Global Livestock Environmental Assessment Model
**GLOBIO** - Global Methodology for Mapping Human Impacts on the Biosphere
**GM(O)** - genetically modified (organism)
**IAASTD** - International Assessment of Agricultural Knowledge, Science and Technology for Development
**IASS** - Institute for Advanced Sustainability Studies
**ICRAF** - World Agroforestry Centre
**IPCC** - Intergovernmental Panel on Climate Change
**IPM** - integrated pest management
**IRRI** - International Rice Research Institute
**Kcal** - kilocalorie
**Kg** - kilogram
**LUC** - land-use change
**MA** - Millennium Ecosystem Assessment
**$MH_4$** - methane
**MSA** - mean species abundance
**N** - nitrogen
**$N_2O$** - nitrous oxide
**OECD** - Organisation for Economic Co-operation and Development
**PAN** - Pesticide Action Network
**PES** - payment for ecosystem services
**PPP** - purchasing power parity
**QALY** - quality-adjusted life year
**REDD+** - Reducing Emissions from Deforestation and Forest Degradation
**SDG** - Sustainable Development Goal
**SEEA** - System of Environmental-Economic Accounting
**SLCP** - (China's) Sloping Land Conversion Program
**SNA** - System of National Accounts
**SRI** - sustainable rice intensification
**TEEB** - The Economics of Ecosystems and Biodiversity
**TEEBAgFood** - The Economics of Ecosystems and Biodiversity for Agriculture and Food
**UN** - United Nations
**UNEP** - United Nations Environment Programme
**UNEP-WCMC** - United Nations Environment Programme World Conservation Monitoring Centre
**UNESCO** - United Nations Educational, Scientific and Cultural Organization
**USD** - US dollar (also US$)
**WHO** - World Health Organization

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## What are 'eco-agri-food systems', and are they working?

Food is the ultimate source of energy and nutrients for every human, and is the basis for agricultural production around the world. Agricultural production systems link human diets to inputs used in agricultural production, to the diverse types and quantities of food (and feed), fuel and fibres produced, to the types of management and land use systems that produce them, to how they are processed, stored and transported to consumers, to how they are regulated and where they ultimately end up. From start to finish, these systems can be envisioned as intertwined threads that tie the health of the environment to the health of people[1].

The 'eco-agri-food systems' complex is a collective term for the fabric woven from these many system threads, encompassing the vast and interacting complex of ecosystems, agricultural lands, pastures, fisheries, labour, infrastructure, technology, policies, culture, traditions, and institutions (including markets) that are variously involved in growing, processing, distributing and consuming food.

*Having set out what the eco-agri-food systems complex is, how can we determine whether or not it is functioning well?*

The primary purpose of the eco-agri-food systems complex can be broken down into three broad objectives: (I) to ensure food security for all; (II) to improve social, economic and cultural well-being and secure over a billion livelihoods; and (III) to not compromise our ability to satisfy the needs of future generations[2]. We comment on each objective in turn.

### Food security for all as a human right

One common metric for food security[3] is to consider the physical availability of food, which is related to levels of food production and supply, stock levels and net trade. Box 1.1 highlights the success of food production systems in meeting this objective.

**Box 1.1 Food systems are producing more than enough calories to feed the world today**[4]

- Since 1970, the amount of food available for every person for direct consumption has increased from 2370 to 2770 kcal/person/day.
- In aggregate, there is sufficient food available for everyone to be fed, and nearly everyone to be well-fed.
- However, owing to problems of access and distribution, some 2.3 billion people in developing countries live with under 2,500 kcal/day (500 million of which live with less than 2,000 kcal/day), while 1.9 billion in developed countries are consuming more than 3,000 kcal/day.

However, food security should also look beyond the supply side, and consider dimensions of economic and physical access to food, food utilization, and their stability over time[5]. These considerations reveal a very different reality of food security in the world (see Box 1.2), illustrating that food security is not simply a matter of producing enough calories per capita, but is much more deeply rooted in our social, economic and political systems.

**Box 1.2 Is food security being achieved?**

- Globally, an estimated two billion people are experiencing micronutrient malnutrition[6], and 794 million people are calorie-deficient[7].
- In contrast, global levels of obesity have more than doubled since 1980. Recent estimates show that over 1.9 billion adults are overweight, 600 million of which are obese[8].
- Vitamin A deficiency – the greatest preventable cause of needless childhood blindness and increased risk of premature childhood mortality from infectious diseases – still affects 250 million preschool children and a substantial proportion of pregnant women in lower-income countries[9].

Food security also depends on what proportion of the food that is produced is actually consumed (see Box 1.3).

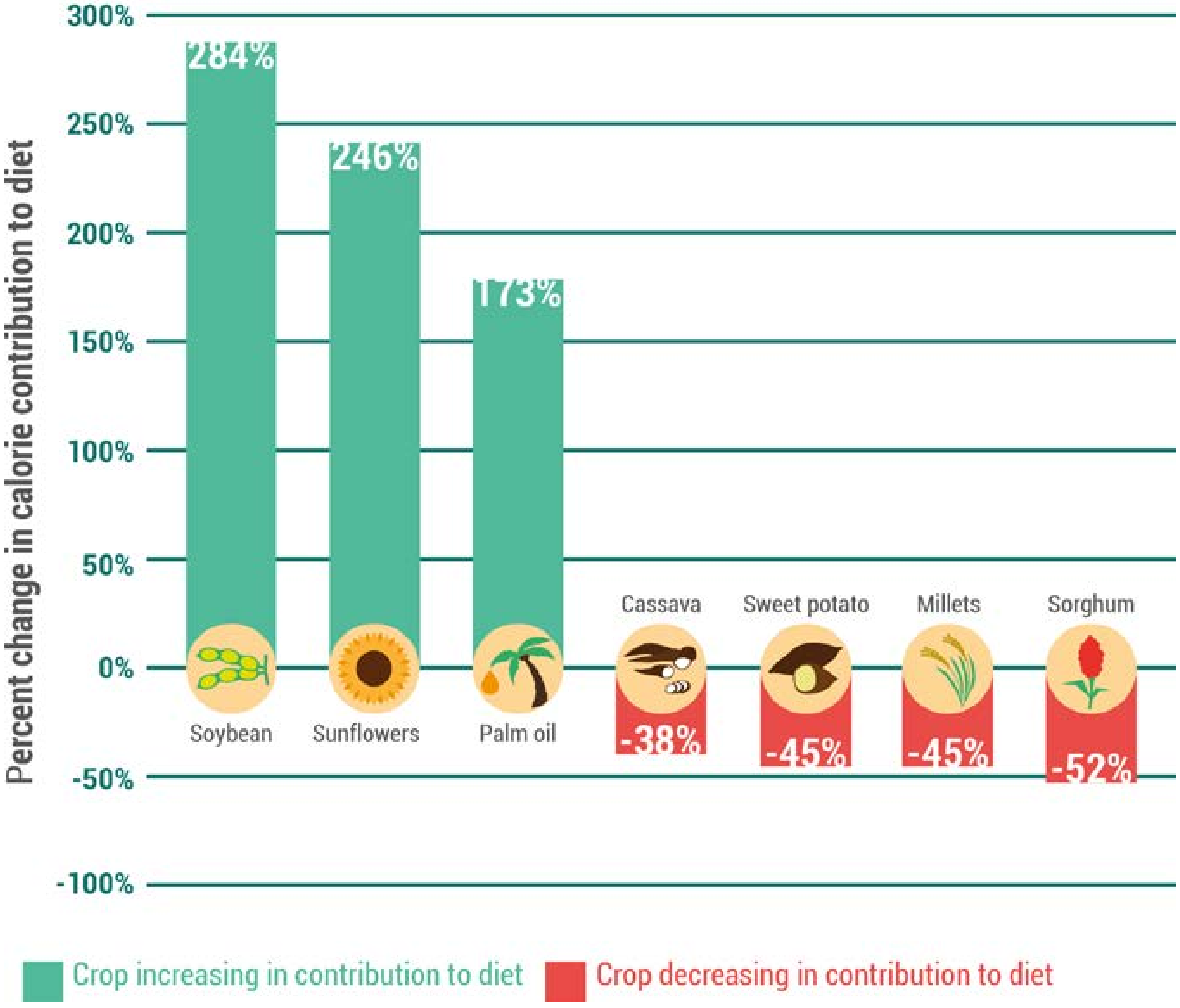
**Box 1.3 One-third of all food produced never reaches a plate**

- Approximately one-third of the food produced in the world for human consumption every year — approximately 1.3 billion tonnes — gets lost or wasted[10].
- An FAO report claims that, if food waste were a country, it would be the third largest emitter in the world in terms of GHG emissions (3.3 billion tonnes)[11].

It is increasingly recognized that a food system must also nourish - that is, provide a healthy, nutritional and well-balanced diet - and not simply supply minimum levels of energy. In an increasingly globalized world, in which a rising share of the population is becoming urban and middle class, and per capita income and consumption levels are rising, consumer demand for 'higher valued foods' (such as meat, dairy, processed food and food consumed away from home)[12] is increasing worldwide, with disastrous consequences for human health (see 'Physical health considerations' below).

Figure 1.1 illustrates another important global trend in the growing contribution of a few major oil crops to diets, and the falling share of regionally important staples. This is a trend that is impacting health in rapidly developing countries more quickly than projected[13], given that these local food crops are often more nutritious and better adapted to grow in local conditions[14].

**Figure 1.1 Average change in the calories from crops in national diets worldwide, 1961-2009**



Source: Khoury, C.K. et al. (2014) 'Increasing homogeneity in global food supplies and the implications for food security', *Proceedings of the National Academy of Sciences*, 111(11): 4001-4006.

In summary, there is a significant risk that the current food system may soon be unable to provide both adequate and nutritious food to the global population.

## Improving well-being and livelihoods

Measuring human well-being has long been discussed and debated[15,16], and that is not the intention of this chapter. However, for the sake of simplicity, it is possible to divide well-being into socio-economic (employment, income), cultural and physical health considerations.

### *Socioeconomic dimensions*

The agricultural sector employs over one billion people worldwide, representing one in three of all economically active workers[17]. In most low- and middle-income countries, agriculture remains the largest employer of the poor and is a major source of livelihoods through wage labour and production for household consumption and markets[18].

Family and smallholder farms are the predominant form of agriculture in the food production sector, but the vast majority of them are small (see Box 1.4) and poor. Indeed, agriculture and rural poverty are closely linked. While the rural poor are more likely than other rural households to rely on agriculture, output per worker is valued much lower in agriculture than in other sectors, resulting in low incomes for people who depend on agriculture for their livelihoods[19].

**Box 1.4 The large world of small farms**

- Family farms, i.e. those that are managed and operated by a family and predominantly reliant on family labour, make up more than 90 per cent of the world's farms[20].
- Family farms also occupy approximately 70 to 80 per cent of farmland, and are estimated to produce about 80 per cent of the world's food[21].
- In lower-income countries, an estimated 84 per cent of farms (or 475 million farms) are 'smallholder farms', i.e. smaller than two hectares[22].
- An estimated 2.5 billion people are involved in full- or part-time smallholder agriculture, while over one billion people living in rural poverty are dependent on agriculture for their livelihoods[23].

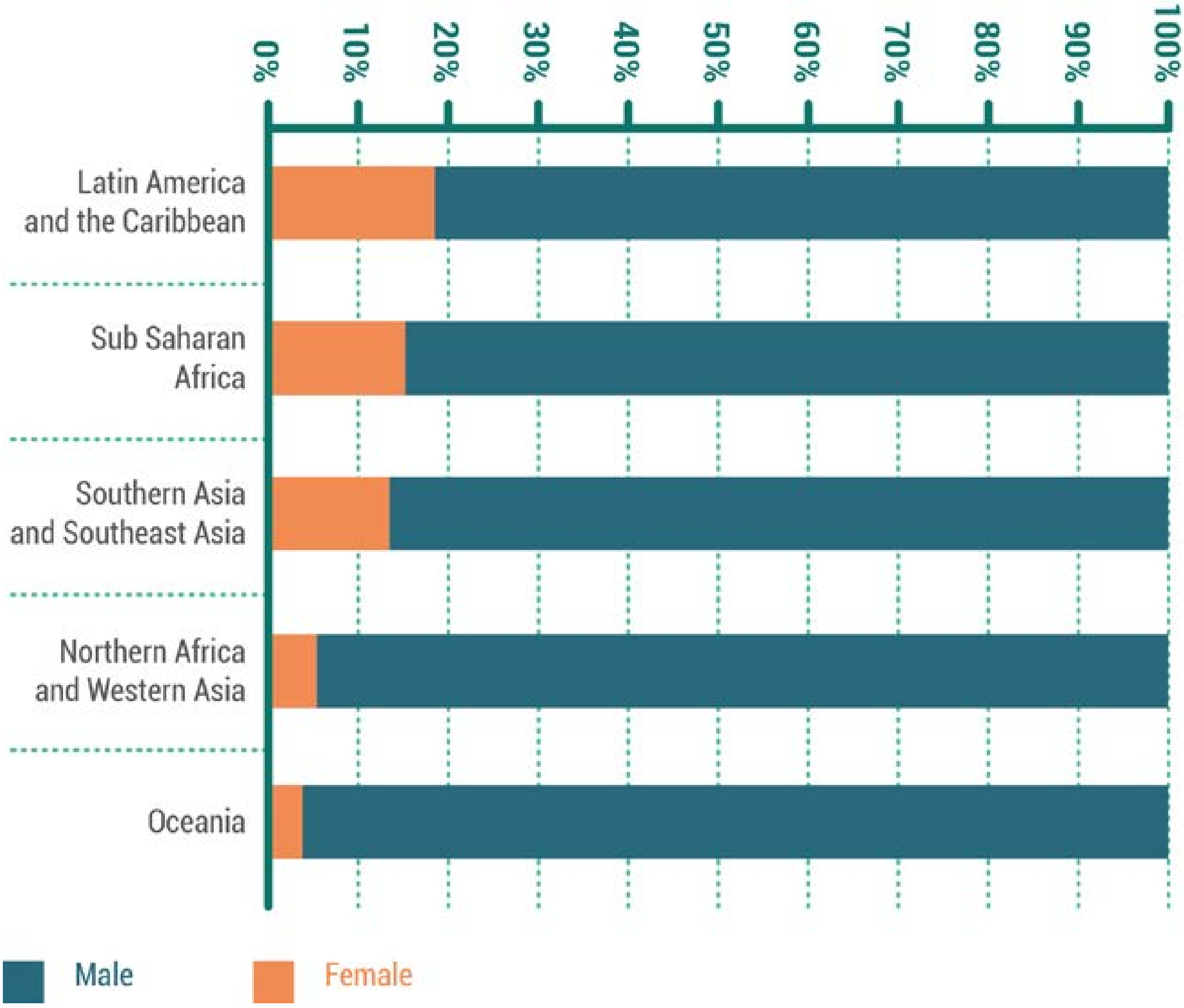
The role of women in agriculture, particularly in developing countries, is also one that deserves more positive attention, particularly with regard to the social and economic opportunities for closing the gender gap. Women comprise on average 43 per cent of farm labour in the developing world[24], whilst owning a tiny fraction of farms. Women also regularly face discrimination in rights and access to resources and support for farms.

These inequities are among the major gender-relative negatives (see Box 1.5) characterizing the role and fortunes of women in agriculture today, despite their central role in household welfare around the world. Indeed, empowering women in agricultural households has been demonstrated to not only improve farm productivity, but also produce wider benefits in improved health, nutrition and education outcomes[25].

**Box 1.5 Women represent 43 per cent of farm labour in the developing world**

- On average, women comprise 43 per cent of the agricultural labour force in developing countries; this figure ranges from around 20 per cent in Latin America to 50 per cent in parts of Africa and Asia, and exceeds 60 per cent in certain countries[26].
- Although largely restricted to growing food crops and rearing poultry and livestock, women are responsible for 60 to 80 per cent of food production in developing countries[27].
- However, women only represent between five and 30 per cent of all agricultural holders in main developing regions (see Figure 1.2).
- If women had the same access to productive resources as men, FAO estimates that they could increase yields on their farms by 20 to 30 per cent, raising total agricultural output in developing countries by 2.5 to 4 per cent[28].
- Closing the 'gender gap' in terms of access to agricultural inputs alone could lift 100 to 150 million people out of hunger[29].

**Figure 1.2 Share of male and female agricultural holders in main developing regions**



Source: FAO (2011), *The State of Food and Agriculture: women in agriculture - closing the gender gap for development*, Rome.

### Cultural dimensions

Agriculture and food are an integral part of our heritage and cultural landscapes, and key to cultural identity. The underpin community values, festivity, social cohesion and tourism; agricultural landscapes are a location and source of recreation and mental/physical health, providing at times spiritual experience and a reinvigorating sense of place.

FAO estimates that about 500 million hectares around the world are dedicated to agricultural heritage systems that still maintain their unique traditions with a combination of social, cultural, ecological and economic services that benefit humanity[30].

### Physical health considerations

Both agricultural production and consumption are directly linked to human health impacts.

While malnutrition and obesity have been mentioned, there is more to be said on the public health (as opposed to food security) dimension. For example, malnutrition is the cause of death for 3.1 million infants and young children every year, largely due to their high nutritional requirements for growth and development. This statistic accounts for 45 per cent of all deaths among children under the age of five, while malnutrition also leads to stunted growth among a further 165 million[31].

Overweight conditions and obesity, on the other hand, are major risk factors for cardiovascular diseases (mainly heart disease and stroke), which were the leading cause of death in 2012, as well as diabetes and some cancers[32]. As illustrated in Figure 1.3, it is projected that, by 2030, the global economic impact of obesity will be US$2 trillion in health costs (2.8 per cent of GDP), equivalent to that of smoking, war and terrorism[33].

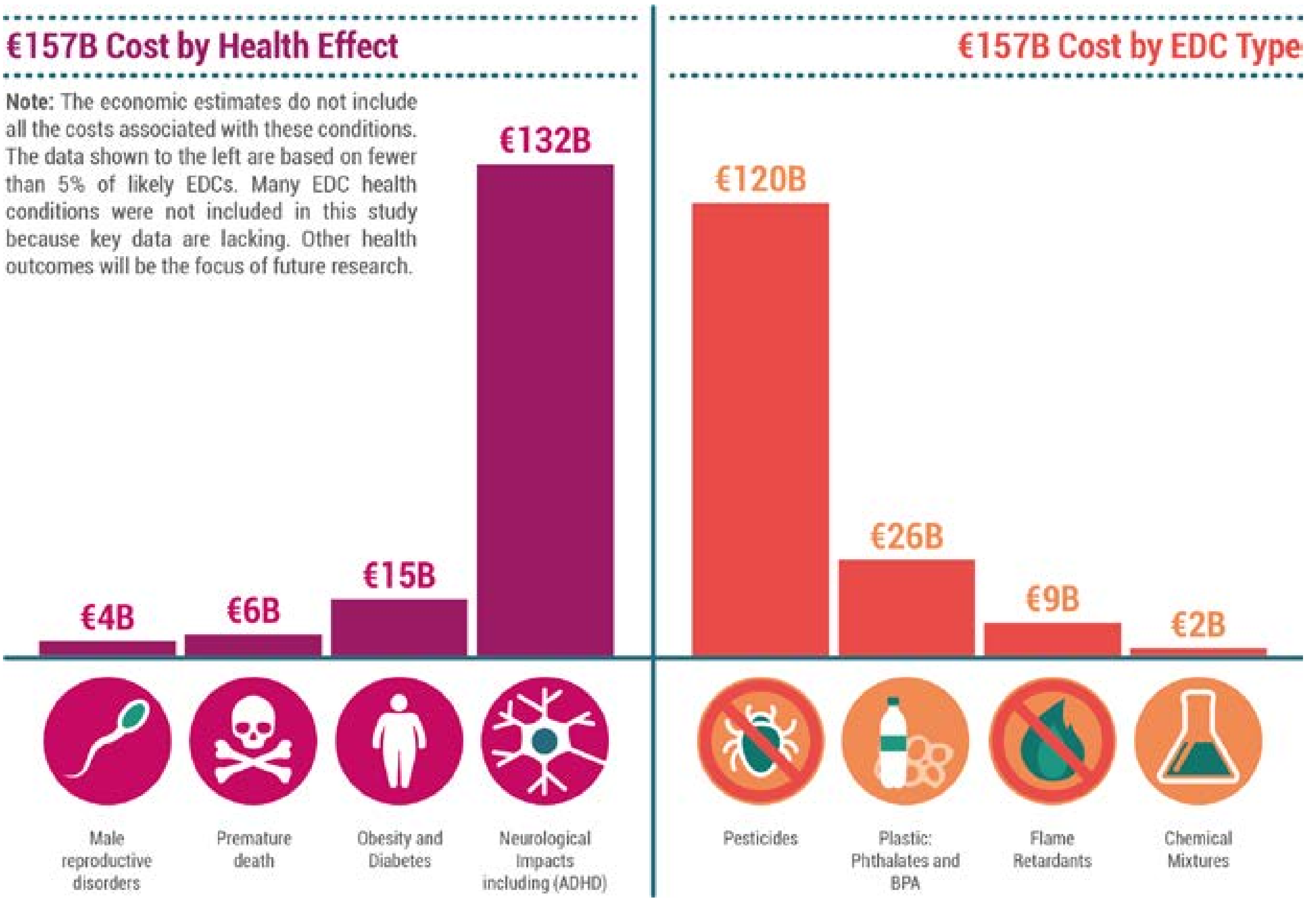
**Figure 1.3 Percentage of global population that is overweight or obese (today and in 2030) and its economic impact**

Source: Dobbs, R. et al. (2014) *Overcoming obesity: an initial economic analysis - discussion paper*, McKinsey Global Institute.

Health impacts are also a cause for concern on the production side of eco-agri-food systems, usually through exposure to agricultural chemicals or the use of antibiotics.

While research on the health impacts from exposure to agrochemicals is limited, evidence is starting to build. Recent research explores the health impacts of pesticides as 'endocrine disrupting chemicals' (i.e. chemicals that interfere with hormones). The results in Figure 1.4 show that, in the EU alone, pesticide exposure causes the highest annual health and economic costs at roughly US$127 billion, almost four times as high as the second highest category: plastics (which is also linked to eco-agri-food systems through the storage of edible goods)[34].

**Figure 1.4 Health effects from endocrine disrupting chemicals cost the US$167 billion each year**



Source: New York University Langone Medical Center (2015), accessed on 18 November 2015 [https://www.endocrine.org/news-room/current-press-releases/estimated-costs-of-endocrine-disrupting-chemical-exposure-exceed-150-billion-annually-in-eu].

Indeed, pesticides by their very nature are designed to be toxic, either to herbs, insects or fungi. However, the vast majority is distributed into the environment and the food chain, where they come into direct contact with humans.

Through direct and indirect exposure, an estimated 20,000 unintentional deaths occur every year as a result of pesticide poisoning[35], while causing acute adverse health impacts to anywhere between 1 and 41 million people[36].

The agricultural sector is also the world's largest user of antibiotics, estimated to use 70 per cent of all that is manufactured globally[37]. This use of antibiotics is suspected to create resistant strains of microbes in humans, posing serious threats to human health. For example, in the US alone, two million people each year develop antimicrobial resistant (AMR) infections, killing at least 23,000 people and incurring treatment costs of around US$20 billion on top of costs to society for lost productivity that are as high as US$35 billion a year, totalling US$55 billion per annum[38].

## Fulfilling the needs of future generations

The needs of future generations are an integral part of the concept of sustainability. Today humanity uses the equivalent of 1.5 planets (or 18 billion global hectares) to provide the resources we use and absorb our waste[39]. As humans continue to cause irreversible damage to our biosphere and place unsustainable demands on the natural resources on which future food security depends, we bring into question the ability of our planet to accommodate humans and human actions.

In order for modern agriculture to become sustainable, it is imperative to preserve the natural resource base - including land, water, and biodiversity - as well as account for the contribution of agriculture to climate change.

### *Soils and land productivity*

The year 2015 is the UN International Year of Soils. Soils are the basis for more than 90 per cent of food production[40], and yet every year, approximately 24 billion tonnes of fertile soil are lost due to erosion[41]. It is estimated that fertile soils can take hundreds, even thousands, of years to generate[42], which highlights the fact that current practices quickly become unsustainable.

Soils provide a critical service by storing more than 4000 billion tonnes of carbon whereas, by contrast, forests and the atmosphere store only 360 and 800 billion tonnes, respectively[43]. As a result of land conversion for crop production, carbon and nitrogen are lost from the soil, which can lead to substantial reductions in the role of soil as a methane sink[44]. Moreover, the loss of carbon and nitrogen also reduces soil organic matter, particularly humus, which greatly increases the water retention properties of soil[45], natural disease resistance in crops[46] and total yield potential[47].

Directly linked to soils is the question of land productivity. Due to severe land degradation (see Box 1.6) in developing countries over the past fifty years, usually in the form of increased

**Box 1.6 Half of agricultural land is degraded**

It is estimated that 52 per cent of land used for agriculture worldwide is moderately or severely affected by land degradation and desertification[48].

salinization of soil, nutrient depletion and erosion, the productivity of lands has decreased by as much as 50 per cent[49]. As a result, it is further estimated that some 50 million people may be displaced within the next ten years[50].

In contrast, several farming techniques and management practices exist that have proven to reverse these processes, for example by regenerating soil structure and attracting beneficial organisms within the soil food web.

### *Water*

Irrigated agriculture currently draws 70 per cent of all water globally withdrawn from rivers and aquifers, despite the fact that rainfed agriculture is the predominant form of agriculture worldwide[51]. With food demand expected to continue to rise, global water demand is projected to increase by 55 per cent by 2050[52].

Nutrient pollution into water sources is arguably one of the most impactful consequences of agricultural systems, occurring primarily as a result of large increases in the use of fertiliser and manure, both of which are rich in nitrogen and phosphorus. The biogeochemical flows of nitrogen and phosphorus have been identified as one of the nine planetary boundaries that indicate safe operating spaces for humanity. They comprise two of three boundaries considered to be 'high risk'[53].

When excess amounts of these nutrients flow into nearby water sources due to run-off and wastewater discharge, a process known as 'eutrophication' occurs. This is when nutrients provide a food source for blooms of blue-green algae ('cyanobacteria') that, as they die and decompose, deplete water of oxygen and slowly choke aquatic life, creating 'dead zones' (see Box 1.7).

**Box 1.7 400 dead zones[54]**

Eutrophication has contributed to the creation of over 400 oceanic dead zones worldwide, primarily concentrated in Europe, eastern and southern US, and Southeast Asia. In total, these zones cover an area of 245,000 square kilometres, or greater than half the size of California.

### *Biodiversity*

The conversion of natural habitats to agricultural land has major implications for biodiversity. As noted in the recent Global Biodiversity Outlook 4[55], agriculture is thought to cause around 70 per cent of the projected loss of terrestrial biodiversity. In particular, the expansion of cropland into grasslands, savannahs and forests contributes to this loss.

An estimated 60 to 70 per cent of global terrestrial biodiversity loss is related to food production, while 'regulating and maintenance' ecosystem services are under pressure[56]. Moreover, recent reviews have highlighted how land use change leads to a decline in biodiversity, including wild pollinators such as bees, flies, beetles, and butterflies[57]. Such environmental degradation can constrain the amount and stability of crop yield, which are essential components of human food security[58]. Indeed, land use change already has reduced the capacity of many ecosystem services to support human activity[59], including crop pollination and the yield of pollinator-dependent crops[60].

Apart from providing biomass in the form of food, feed, fuel and fibre, agriculture provides a variety of ‘regulating and maintenance’ services to the environment. Pollination, for example, is a crucial ecosystem service for crop production. Although crops can provide abundant resources to wild insect pollinators, the short duration of floral availability, the low diversity of resources, the application of insecticides, and the presence of tillage may limit the capacity of one crop species to support wild pollinator populations on its own[61]. Therefore, sowing crops that bloom in different periods may increase wild-insect populations. For example, in Sweden, bumble bee reproduction was improved in landscapes with both late-season flowering red clover and early-season mass-flowering crops[62]. As a result, an adequate proportion of cropland in heterogeneous landscapes with proper crop management can be beneficial to some wild fauna taxa[63].

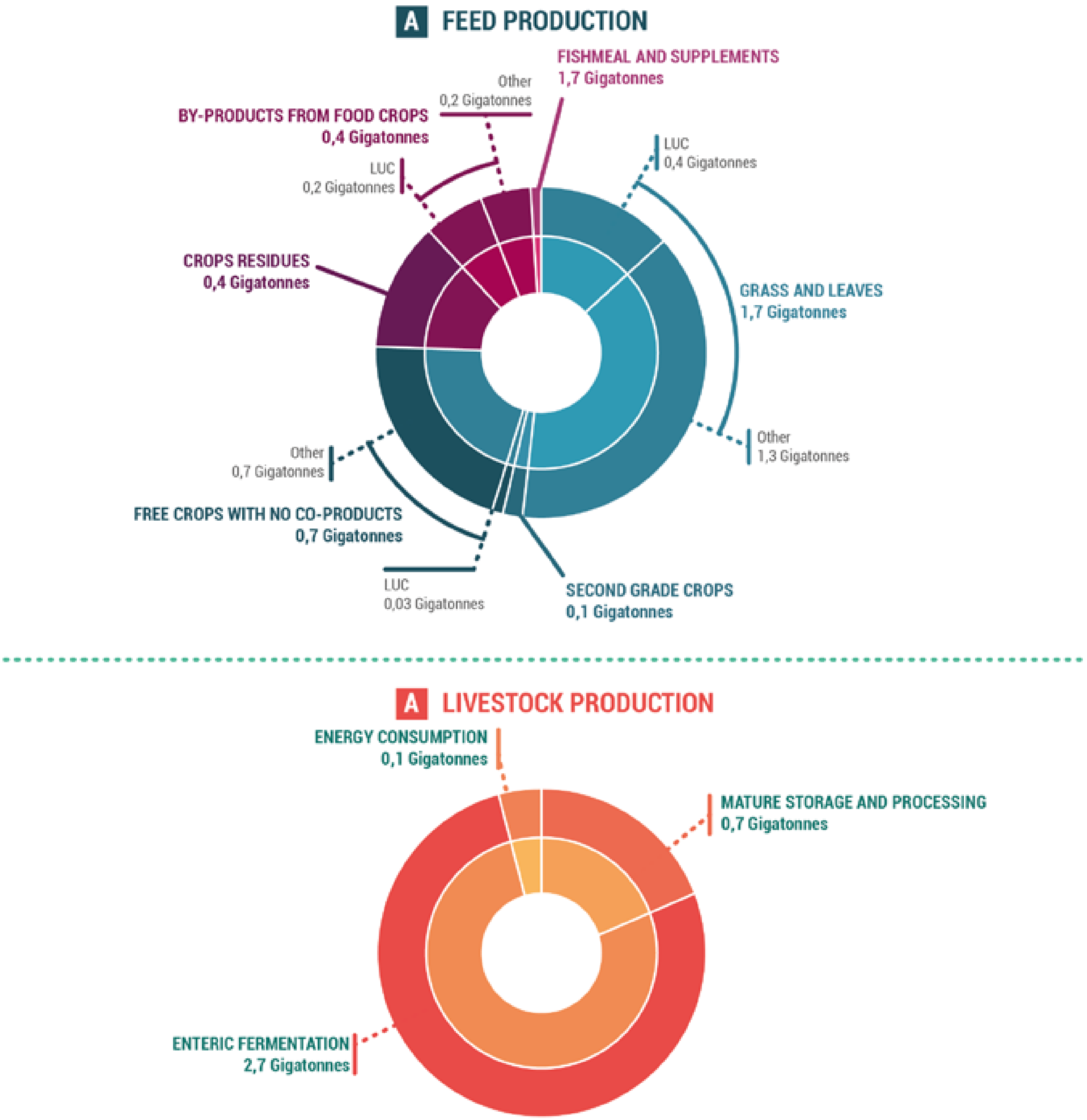
### Climate change

Agriculture accounts for around 22 per cent of total greenhouse gas emissions (GHG)[64]. Within agriculture, the most emissions are caused by the livestock sector, which contributes 40 per cent of that total (roughly 14.5 per cent of total global GHG emissions), mostly in the form of methane ($MH_4$) and nitrous oxide ($N_2O$).

In terms of activities within the livestock sector, Figure 1.5 displays the two main sources of emissions within livestock: (A) ‘feed production’ including processing, transport and land use change (LUC); and (B) ‘livestock production’ including enteric fermentation (digestion and belching from ruminants), manure storage and processing, and energy consumption related to manufacturing. Feed production accounts for 45 per cent of the total from livestock, while livestock production accounts for 50 per cent, 80 per cent of which comes from enteric fermentation alone[65].

Under ‘business-as-usual’, global temperatures are projected to gradually increase up to 3.5°C higher by 2100 from climate change[66], with potentially dire consequences on agricultural production. For example, not only might crop yields be negatively impacted, but levels of carbon stored in the soil could be reduced as a result of faster decomposition and fewer inputs from shortened crop lifecycles. Moreover, land cover types like plantations and others with lower levels of biodiversity are expected to suffer more from climate change impacts due to lower resilience.

Figure 1.5 GHG emissions from global livestock supply chains, by production activities and products



Source: FAO, Global Livestock Environmental Assessment Model (GLEAM).

## How does the eco-agri-food systems complex score overall?

While recognizing the centrality of agriculture and food to human well-being and sustainable development, essentially every statement on the future of agriculture acknowledges that a transformation is needed in the way the sector operates and how it impacts on the environment, human health and culture even if and while production is increased to meet food security needs[67, 68, 69, 70].

Another challenge facing current agricultural systems is that, in many parts of the developing world, conventional high-input agriculture has not – and has little chance – to take hold. In such regions, resource-poor farmers contend with issues of marginal high-risk environments, and experience poor yields just where food security is most vulnerable. The agricultural research establishment has only recently begun to focus increasingly on such sites, and to recognize that highly site-specific resource management systems are needed to sustain productivity under these conditions[71].

Yet the approaches which can address both the heavy negative impacts of conventional production systems and the challenges of resource-poor farmers have a central common thread: they recognize that agriculture and food systems of all kinds are biological and social systems. They can be designed to build upon and harness the forces of biodiversity and ecosystem services such that the processes that underpin agricultural production - soil fertility, natural pest control, pollination, water retention - are optimized and encouraged. This applies to all systems.

A report[72] on a "Biosphere Smart Agriculture in a True Cost Economy: Policy Recommendations to the World Bank" states:

*"In the face of a rapidly overheating climate, collapsing fisheries, degraded soil, depleted water resources, vanishing species, and other challenges directly related to agriculture, we can no longer afford to pursue a flawed accounting system."*

In summary, there are evidently many opportunities for re-evaluation and reform, along many dimensions of our agricultural systems. But we 'cannot manage what we do not measure', and that points to our first task: how do we evaluate the complexity of these systems in a manner which is universal, holistic and fair, enabling comparisons and choices to be made and responses to be optimized in a truly informed manner? As a step towards a framework for such evaluations, it is first important to understand the many invisible flows within the eco-agri-food systems complex, which are discussed and illustrated with an important showcase in Chapter 2.

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# MAKING THE INVISIBLE VISIBLE

Photo: ©Curt Carnemark/World Bank

## The invisibility of nature in decision-making

The Economics of Ecosystems and Biodiversity (TEEB), in its earlier work, highlighted the implications of the invisibility of nature in decision-making, and presented both the sizeable impacts and dependencies of economic activities on nature[1]. Ecosystems and biodiversity are mainly public goods and, while invisible in their contributions, they are fast degrading due to various pressures, raising pertinent concerns about sustainability.

The first chapter highlighted some of these questions. It illustrated that agriculture and food systems are a significant driver of ecosystem degradation, biodiversity loss, health, social and cultural externalities, and GHG emission. But at the same time, compelling evidence was presented on the benefits of these systems such as food for humans, feed for animals, fibre for artisanal and industrial production, raw material for fuels, employment and cultural cohesion. Many of these positive and negative flows are economically invisible, hence unaccounted for in public and private decision-making. Similarly, economically invisible ecological inputs to agriculture, such as freshwater provisioning, nutrient cycling, and pollination[2] are also unaccounted for, rendering them invisible in our decisions.

The TEEB Agriculture and Food (TEEBAgFood) work builds upon the previous work of TEEB to take a closer look at the 'eco-agri-food systems' complex, and addresses this major gap in decision-making. The core rationale of TEEBAgFood is, as captured by its mission statement in Box 2.1.

## Unpacking TEEBAgFood

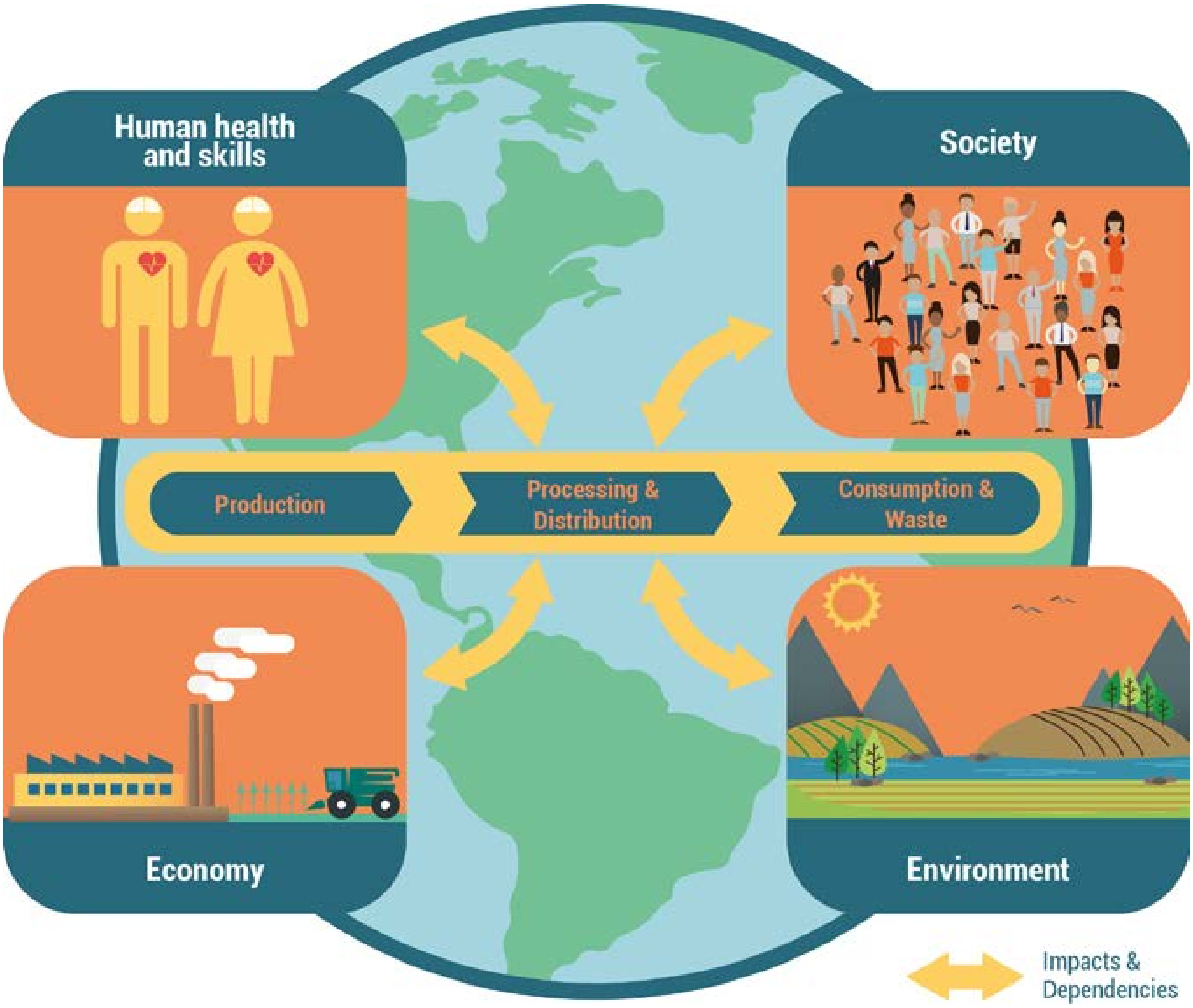
The significant yet hidden benefits and costs of our current agricultural and food systems not only impact natural systems, but also human, social, and economic systems. As described in its mission statement, TEEBAgFood seeks to take a comprehensive look at these hidden benefits and costs, and make them visible. As a first step, the various systems that interact

**Box 2.1 TEEBAgFood Mission Statement**

*"The economic environment in which farmers and agricultural policy-makers operate today is distorted by significant externalities, both negative and positive. Indeed, most of the largest impacts on the health of humans, ecosystems, agricultural lands, waters, and seas arising from various different types of agricultural and food systems, are economically invisible and do not get the attention they deserve from decision-makers. There is therefore a need to evaluate all significant externalities of eco-agri-food systems, to better inform decision-makers in governments, businesses and farms. Furthermore, there is a need to evaluate the eco-agri-food systems complex as a whole, and not as a set of silos."*

and make up the eco-agri-food systems complex must be recognized. As demonstrated in Chapter 1, operations within the entire agricultural value chain - production, processing, distribution, consumption and waste – not only have impacts but also depend on the state of the environment, socio-economic well-being, and human health (see Figure 2.1).

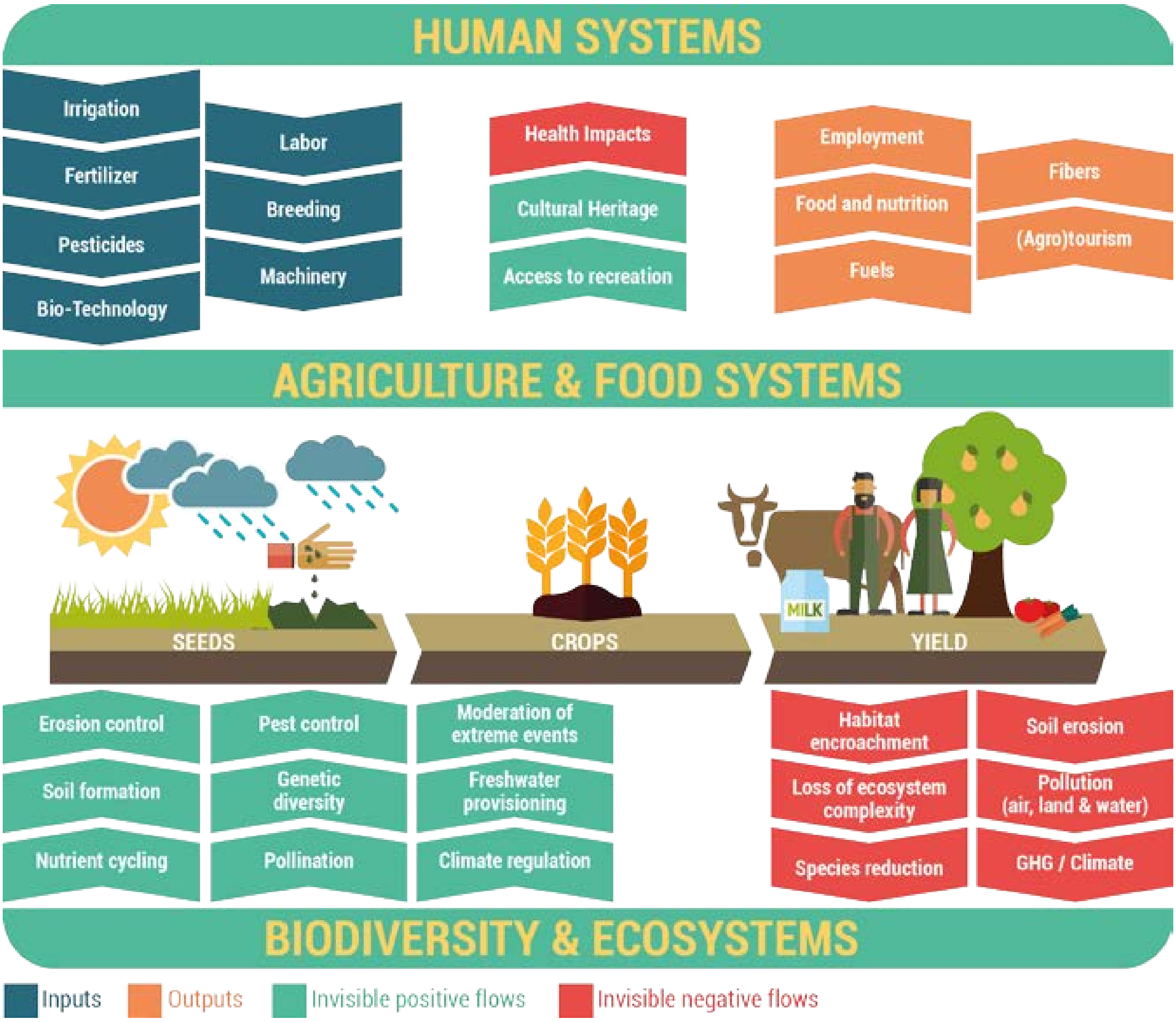
**Figure 2.1 Eco-agri-food systems complex – impacts and dependencies**



TEEBAgfood, in its first phase (2014-15), started preliminary work on unpacking the first part of the food value chain: production. Building upon previous work of TEEB on ecosystem services, the first step involved assessing the impacts and dependencies of agricultural activities on human and natural systems, a significant component of agricultural value chains.

Figure 2.2 offers a closer look at the production stage of the value chain, providing a broad-brush characterization of the complexity and inter-relatedness of the eco-agri-food systems complex. It highlights some of the significant (yet hidden) flows between 'agriculture and food systems', 'human (economic and social) systems' and 'biodiversity and ecosystems'.

**Figure 2.2 The visible and invisible flows of agricultural production**



At the centre of the eco-agri-food systems complex is the agriculture and food system. This system both depends on - and impacts - natural resources to deliver ecosystem services. It also interacts with the human system, for example through providing food and raw materials. The flows between different systems can be divided into two categories: visible (e.g. food and raw materials that are provided by agriculture and food systems, contributing to human well-being) and invisible (e.g. ecosystem services such as pollination, provided by natural systems as inputs to food production).

The broad categories of ecosystem service types are listed in Box 2.2. TEEBAgFood follows the Common International Classification of Ecosystem Services (CICES)[3], as the latest commonly agreed classification to be used, particularly in accounting contexts.

**Box 2.2 Ecosystem service types**[4]

- Provisioning services cover all nutritional, material and energetic outputs from living systems
- Regulating and maintenance services cover all the ways in which living organisms can mediate or moderate the ambient environment that affects human performance.
- Cultural services cover all the non-material, and normally non-consumptive, outputs of ecosystems that affect physical and mental states of people.

It is important to note here that the goal of the TEEBAgFood study is not only to assess a wide range of hidden costs and benefits of various agricultural production systems (making values visible), but to also build an evidence base that provides context-specific examples and recommendations for sustainable food systems that can feed the world, while maintaining and improving ecosystem services for the benefit of all including generations to come.

In the next section, using the example of smallholder rice farming in Asia (based on a TEEBAgFood exploratory study)[5], we illustrate how invisible costs and benefits within eco-agri-food systems can be made more visible.

## A TEEBAgFood Showcase: Ecosystem services in smallholder rice production systems in Asia

Rice is the largest staple food in the world and is central to the food security for nearly half of the world's seven billion people. More than 90 per cent of world rice production and consumption takes place in Asia[6]. Small (often very small) family farms are the standard production unit throughout Asia, with rice providing livelihoods to around 140 million rice farming households[7]. Furthermore, rice production is facing a set of significant challenges in terms of ecosystem degradation and stable supply of and access to healthy, well-functioning ecosystems[8].

For these reasons, it has been decided to showcase below an assessment of smallholder rice production systems in Asia, recognizing the many hidden benefits from this type of farming system. However, TEEBAgFood as an initiative will look at a much wider range of farming systems to ensure that a variety of socio-economic and ecological contexts are assessed, including conventional cropping systems. Context-specificity will be an essential discipline for such analysis, to ensure realistic and useful evaluations.

Although many of the invisibilities in smallholder rice systems are described below, the assessment is nevertheless partial and limited. While addressing the interlinkages between 'biodiversity and ecosystems' and 'agricultural and food systems' (as seen in Figure 2.2), it does not address some of the negative health externalities of fertiliser and pesticide use, nor does it assess important metrics such as employment generation. Nevertheless the examples provide a useful insight into the value of these services to human well-being, and builds a case for addressing these invisibilities.

## Food

As mentioned in Chapter 1, food is not merely about caloric intake. Dietary diversity, defined as the number of different foods or food groups consumed over a given reference period[9], can be enhanced by diverse rice agro-ecosystems. This is crucial for the health of rural communities since many households depend on homogenous diets that are too high in carbohydrates and too low in animal protein foods and micronutrient-rich fruits, fish and vegetables[10].

Over 90 per cent of the world's rice is grown under flooded conditions, providing an environment not solely for the crop alone but also for a wide range of aquatic organisms[11], as described in Box 2.3.

### Box 2.3 Combined rice-and-farm fishing[12]

Combined rice-and-fish farming is practiced in many countries in the world, particularly in Asia where consumption is largely dependent on rice as the staple crop and fish as the main source of animal protein. Many traditional systems in Asia are based on concurrent cultivation of rice and fish, whereas other systems alternate between rice cultivation in one season and fish culturing in the other. Other systems - especially those in more commercialized rural economies - rely on separate fish culturing systems. Fish in rice-and-fish systems does not refer only to fin-fish; it includes the wide variety of aquatic animals living in rice fields: shrimp, crayfish, crabs, turtles, bivalves, frogs, and even insects. Farmers may also allow aquatic weeds to grow, which they harvest for food. Surveys in Cambodia, for example, have documented the harvest of over ninety different organisms from rice paddies, used by rural households[13].

Photo: ©Rice fish farm/©Halwart

The wild and gathered foods from aquatic habitats provide important diversity, nutrition and food security, supplying essential nutrients that are otherwise not adequately found in diets. Often these are the primary sources of protein for the rural rice farming communities, and therefore of immense nutritional value - not just for the rice farmers alone, but also for landless members of the community[14].

## Raw materials

Although rice straw and husks are still largely considered as a waste product, they can also be used for animal feed and bedding. Rice husks are also used as raw material for energy. Other innovative uses are increasingly being promoted, as illustrated in Box 2.4. These examples show that the annotation of 'food' and 'fibre' as visible outputs is a broad-brush characterization.

**Box 2.4 From rice husk to pure drinking water[15]**

Tata Chemicals, a company of India's Tata Group, co-designs and sells a rice-husk based water filter. Its active element is a bulb of rice husk ash impregnated with nano silver particles, for purifying water and destroying germs and bacteria. Tata SWACH is a low-priced product (under US$20) and is widely used (over 400,000 units and bulbs sold in 2014-15). It reduces the environmental impact of water purification by eliminating i) the need for boiling, thus conserving electricity and/or liquefied petroleum gas; and ii) the use of harmful chemicals.

## Genetic diversity

With its long history of cultivation and selection under diverse environments, rice has acquired a wide adaptability, enabling it to grow in a range of environments, from deep water to swamps, irrigated and wetland conditions, as well as on dry hill slopes. The quality preferences of rice consumers, over millennia, have resulted in a wide diversity of varieties specific to different localities. Although the exact diversity cannot be gauged, it is estimated to be around 140,000 different genotypes[16]. Evidence has shown that individual cultivars, strains and breeds of the same (rice) species do have significantly different nutrient content[17]. In fact, there are thousands of different rice varieties, some of which have been around for centuries while others are new hybrids bred to increase rice yields or reduce the susceptibility to rice pests. Paddy rice farmers in Asia regularly exchange seed with their neighbours because they observe that any one variety begins to suffer from pest problems if grown continuously on the same land for several years. The temporal, spatial, and genetic diversity resulting from farm-to-farm variations in cropping systems confers at least partial resistance to pest attack.

This example links 'food' (diversity), 'genetic diversity' and human health. It also demonstrates the often invisible but significant benefits of smallholder systems.

### Habitat for species

Rice fields harbour a surprisingly rich level of biodiversity, thought to be amongst the greatest of any tropical rainfed system. As an example of this, 589 species of organisms were recorded in a rice field in Thailand, and more than 800 species per hectare in rice fields in Java, Indonesia[18]. Rice fields serve as habitat for birds and vertebrate wildlife for part or all of their life cycle.

### Biological control

Smallholder and family farmer practices that maintain complex food webs have benefits both for natural pest control and for wild biodiversity[19]. Additionally, farmer field schools in Asia have a long history of working with smallholder farmers to promote natural pest control and integrated pest management (IPM)[20]. For instance, naturally occurring frogs , toads and carnivorous fish keep rice pests at a low level. A study carried out in China reported 68 per cent less expenses incurred for pesticides and 24 per cent less chemical fertiliser when rice-fish culture was practiced as compared to monocultures[21]. Data analysed from five different Asian countries found that, in 80 per cent of the cases, the introduction of fish led to higher rice yields by at least 2.5 per cent[22]. This increase can be explained by a decreased likelihood of weeds and stembores, which inevitably leads to healthier rice plants.

These examples show a complexity of linkages, with 'genetic diversity' impacting on 'food' and 'pest control'. Like other ecosystem services, the provision of 'pest control' is dependent on not only local eco-agrological conditions but also how we manage these conditions, constraints and opportunities. Quantifying and subsequently valuing pest control in TEEBAgFood is particularly challenging because of the time dimension. The IPM option is one that must be applied with a medium-term time horizon, whereas a sudden (one-off) high pesticide application can destroy this build-up of a 'stock' of pest resistance in a short time frame. But the analysis above nonetheless tells us that it is valuable and often invisible.

### Freshwater

The second example of the contributions of 'biodiversity and ecosystems' to 'agriculture and food systems' is hydrological services – water quantity and quality. The rice terraces that characterize upland rice farming systems throughout east, south and southeast Asia are ancient (and current) examples of farmers working with nature. In these mountainous areas, the act of growing rice remains labour intensive - built and maintained by generations of farmers sculpting the land, and preserving water and soil. Water supply, the most important aspect of rice terraces, comes from rivers and mountain streams. The different levels of rice terraces allow water to flow successively down each level.

Watershed management in Ifugao, the Philippines[23], where the rice terraces have been named a UNESCO World Heritage Site, is based on indigenous knowledge management of muyong, a private forest capping each terrace cluster. The communally-managed forestry areas on top of the terraces are highly diverse, harbouring indigenous and endemic species. The terraces and forests above serve as a rainwater and filtration system and are saturated with irrigation water all year round.

### Cultural heritage

As the product of indigenous agricultural innovations, communal decision-making and local customs, smallholder rice production systems provide a living testament to the possibilities of a harmonious relationship between humans and nature. The ancient Subak water management systems developed more than a thousand years ago for paddy rice cultivation in Bali, Indonesia are an excellent example of this[24]. Paddy fields in Bali were built around water temples and the allocation of water has traditionally been made by a priest, in accordance with Hindu traditions.

It is difficult (and at times inappropriate) to value cultural services in monetary terms, but this 'limitation' sits comfortably with the TEEB framework in general and TEEBAgFood in particular. TEEB is not in any way supportive of the commodification of nature. These values can be expressed in qualitative terms, or quantified, or quantified as well as valued. Each of these alternatives works, in its appropriate human and institutional contexts.

## Measuring what we manage: the need for re-evaluation

The rice example discussed in this chapter allows us to understand in some depth the dependencies and impacts of Asian rice production on ecosystems and biodiversity, but it is still limited in scope, and paints an incomplete picture. For example, it excludes other types of rice production, and their far-reaching impacts on environmental or human health. Only partial conclusions can therefore be drawn from this exercise. Further work needs to be done to examine our food systems through a comprehensive lens that not only enables us to view the entire value chain - including production as well as processing, distribution, consumption and waste - but also includes the full range of their hidden costs and benefits on human, natural, and social systems. Chapter 3 illustrates what one such comprehensive lens might look like.

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# EVALUATING COMPLEXITY: WHAT SHOULD WE VALUE AND WHY?

Photo: ©Maria Fleischmann/World Bank

Chapter 1 and 2 have illustrated some of the hidden, yet significant costs and benefits in the way we produce, process, distribute, and consume food. These hidden costs and benefits are rarely captured by conventional economic analyses that usually value goods and services that have a market price. In the case of agriculture and food systems, this approach does not value vital (but economically invisible) ecological inputs to agriculture, such as freshwater provisioning, nutrient cycling, and pollination[1]. Similarly, economically invisible impacts of agriculture and food systems, both positive and negative, on water quality, emissions, and food safety are also not typically accounted for.

To make improvements in our agricultural systems, and to mitigate their significant negative impacts, governments, businesses, and citizens need to be aware of costs associated with various agricultural production systems, and consider these in their decisions. Similarly, invisible positive impacts of different production and consumption systems can be better enhanced once made visible. To enable such decision-making, a common frame of analysis is needed wherein each food system, production alternative, or consumer choice could be held to a common assessment of costs and benefits. Furthermore, to be comprehensive, all hidden costs and benefits of different food systems must be assessed in their entirety, both in terms of their life cycle and their impacts on all dimensions of human well-being. This chapter presents the TEEBAgFood valuation framework (see Box 3.1).

**Box 3.1 What is the TEEBAgFood ‘valuation framework’?**

- The TEEBAgFood valuation framework is a frame of analysis that can enable us to answer the question “what should we value, and why?”
- The framework ensures that nothing important is missed, and that the full range of impacts and dependencies (including externalities) from eco-agri-food systems can be individually examined and collectively evaluated for the application in question, be it a typology comparison, a policy evaluation, a business question or an accounting question.

- Using a universal framework such as the one recommended here, each type of food system, production alternative, or consumer choice can be held to a common form of assessment of all significant costs and benefits, whether they be economic, social or related to risks and uncertainty.

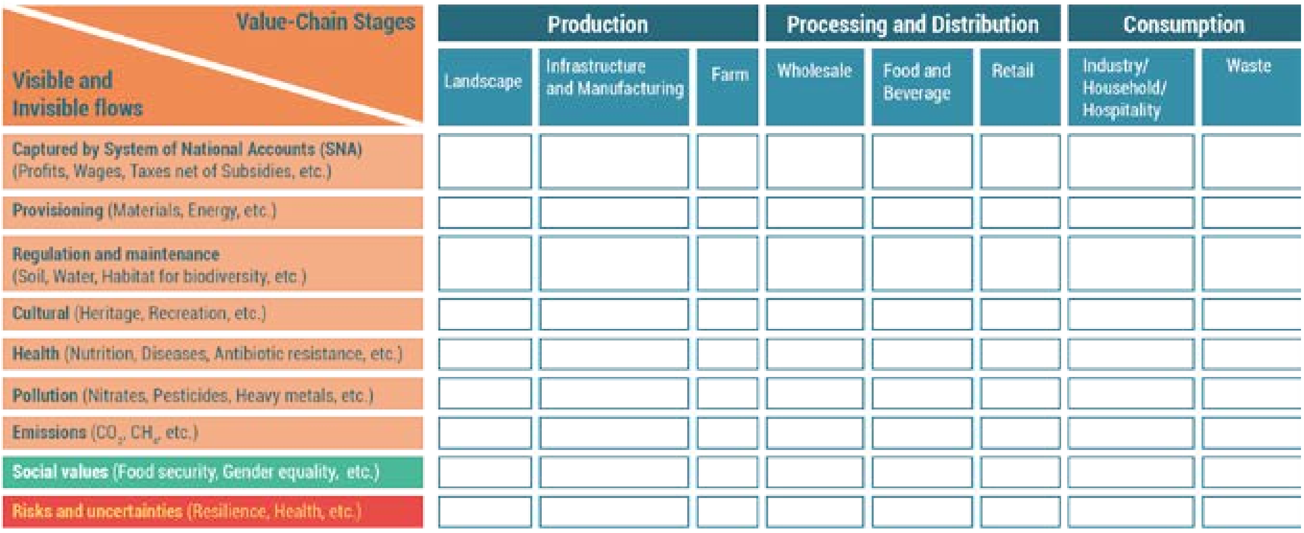
## Towards developing a universal framework

As mentioned in TEEBAgFood's mission statement, one objective of the project is to evaluate all significant impacts and externalities of the 'eco-agri-food systems complex'. The challenge therefore is to develop a framework that captures this significance in a robust and widely accepted manner.

Two underlying principles are evident in our framing of the 'eco-agri-food systems complex'. First, our analyses are not limited to natural systems, but also include social, economic and political systems, and interactions across and within them. In other words, each of the four 'capitals' commonly found in environmental economics literature[2, 3, 4, 5, 6] are recognized: physical capital (e.g. financial resources, machinery, buildings, etc), human capital (e.g. people, their health, skills and knowledge), social capital (e.g. trust, norms and institutions) and natural capital (e.g. minerals, forests, and land). These capitals generate both positive and negative flows within the eco-agri-food complex, some economically visible, and others that are not. Second, our analyses are inclusive of all stages of the value chain of eco-agri-food systems and not just the farm.

A holistic perspective such as this is essential for the proposed TEEBAgFood valuation framework (Figure 3.1). Indeed, to be an improvement on available knowledge, our evaluations will need to recognize agriculture not only as a supplier of food and raw materials, but as the largest employer globally, as central to the well-being of nearly a billion people in rural poverty, and as a cultural activity deeply embedded in everyday life.

**Figure 3.1 TEEBAgFood Valuation Framework**



| Value-Chain Stages / Visible and Invisible flows | Production | | | Processing and Distribution | | | Consumption | |
|---|---|---|---|---|---|---|---|---|
| | Landscape | Infrastructure and Manufacturing | Farm | Wholesale | Food and Beverage | Retail | Industry/ Household/ Hospitality | Waste |
| **Captured by System of National Accounts (SNA)** (Profits, Wages, Taxes net of Subsidies, etc.) | | | | | | | | |
| **Provisioning** (Materials, Energy, etc.) | | | | | | | | |
| **Regulation and maintenance** (Soil, Water, Habitat for biodiversity, etc.) | | | | | | | | |
| **Cultural** (Heritage, Recreation, etc.) | | | | | | | | |
| **Health** (Nutrition, Diseases, Antibiotic resistance, etc.) | | | | | | | | |
| **Pollution** (Nitrates, Pesticides, Heavy metals, etc.) | | | | | | | | |
| **Emissions** ($CO_2$, $CH_4$, etc.) | | | | | | | | |
| **Social values** (Food security, Gender equality, etc.) | | | | | | | | |
| **Risks and uncertainties** (Resilience, Health, etc.) | | | | | | | | |

## The Opportunity

There are a large number of variables involved in any comprehensive analysis that seeks to evaluate trade-offs between different approaches. These variables need to be clearly identified and widely accepted so that they can be used appropriately, consistently and with confidence in the valuation process.

Any lens that selects only positive elements of value, be they visible or invisible, while omitting negative elements, or vice-versa, can distort evaluations and lead to sub-optimal or even perverse outcomes. Unfortunately, much of what we see in policy and business practices around eco-agri-food systems today, in the absence of a widely accepted valuation framework, is the result of such incomplete or selective analyses. This often leads to poor policy choices and value-destructive business practices, with sub-optimal outcomes[7].

Thus the opportunity for TEEBAgFood is to present a universal framework that would guide evaluations to use a widely accepted and common lexicon, enabling decision makers to recognize, demonstrate in economic and social terms, and (where appropriate) capture not just the economically visible elements, but also, in a consistent way, the significant, yet 'hidden' costs and benefits of different farming systems and value chains, in different ecological and socio-economic contexts. This is a fundamental 'first step' in the direction towards an eco-agri-food systems complex that produces, processes and distributes food in a manner that is ecologically sustainable, socially just and provides nutrition, food safety and health, for generations to come.

## The Challenges

Developing a universal framework that would present the eco-agri-food systems complex in terms of its various components – ecosystems, food, agricultural value chains, and how these relate to human well-being - presents its own set of challenges.

The first of these challenges is a 'perception challenge': overcoming the tendency to view ecosystems, agricultural systems, food processing, distribution and consumption as distinct 'silos', instead of one comprehensive interacting whole. As illustrated in the earlier work done by MA, TEEB, and CICES[8], environment and human well-being are connected, dynamic systems.

In the case of eco-agri-food-systems, these relationships are even more apparent. Agriculture is squarely dependent on ecosystems. The production of agricultural commodities require ecosystem services such as water provisioning, pollination, and genetic diversity, to name a few[9]. Human well-being, in turn, is also dependent on agricultural and food systems, which provide various economic and social benefits – income, livelihood, culture, and nutrition[10, 11, 12]. Some agricultural activities however can compromise the very integrity of environmental systems they depend on, raising serious concerns of sustainability[13]. Therefore, the universal framework to be developed needs to establish a common understanding of the complex as a whole, wherein these services and impact flows can be recognized and reflected in cross-Ministry coordination and private-public dialogues for decision-making.

The second challenge in developing a universal framework is an 'adaptability challenge'. Since the framework is to be used to assess significantly different food systems, evaluate different policy scenarios, monitor food systems over time, and help guide business decisions and consumption choices, it needs to be adaptable. For example, livestock can be reared in various ways, ranging from traditional pastoral systems to intensive factory farms. These different livestock production systems interact with environmental and socio-economic systems very differently; in other words, their main impacts and externalities, both positive and negative, would differ. Furthermore, these different food production systems are dependent on ecosystems in different ways, and deliver hidden costs and benefits at different geographical scales. Selecting appropriate system typologies and scales therefore, without selection bias, is a challenge that must be faced directly in developing a universal framework.

The third challenge in assessing the eco-agri-food systems complex is a 'comprehensiveness challenge'. A comprehensive framework would ensure that all hidden costs and benefits are assessed for the agricultural value chain as a whole, including both upstream and downstream dependencies and impacts. For example, various inputs to farming, such as freshwater and pollination, are generated at the watershed/landscape level (upstream), beyond farm borders. Similarly, some hidden costs of farming, such as eutrophication caused by farm runoff, may occur downstream of the farm. While analyses that are limited to the farm may have the virtue of simplicity, they are partial and can potentially mislead. Furthermore, value chains for agricultural commodities can differ substantially within the same commodity, leading to different environmental and social costs and benefits for different types of food systems. For example, corn produced for human consumption or animal feed has different impacts on both environment and human health, as against corn produced for ethanol, throughout their respective value chains.

Furthermore, with globalization, agricultural supply chains stretch longer and are more complex[14], where hidden costs and benefits occur well beyond national borders, raising questions of traceability. This combines both the challenge of being comprehensive and that of identifying all value chain processes for a particular commodity. Yet addressing all of these dimensions is essential for a comprehensive assessment of the eco-agri-food systems complex.

The last challenge is not unique to TEEBAgFood; it is a 'systems challenge', which is the difficulty of recognizing and addressing the dynamic complexity of food production and consumption[15, 16, 17]. Eco-agri-food systems are constantly changing over time and space, and these dynamics have to be understood, forecasted and modelled in any robust evaluation. Policymakers and businesses both struggle with forecasting changes in demand and predicting variables that influence agricultural value chains. The gradually changing mix and supply of ecosystem services due to climate change, habitat encroachment and land use is another example of the dynamic nature of the complex we seek to evaluate.

## Elements of the Valuation Framework

The elements of the framework include selecting value chain boundaries, defining scale, and identifying the values being considered. But first, we need to differentiate between framework, approach and methodology.

### Valuation 'Framework' versus 'Approach' versus 'Methodologies'

Valuation framework (i.e. what to value and why), valuation approach (i.e. how to structure and conduct valuation applications) and valuation methodologies (i.e. the actual valuation models and techniques used to derive economic value and other forms of value) are the cornerstones of economic valuation in general, as they will be for TEEBAgFood.

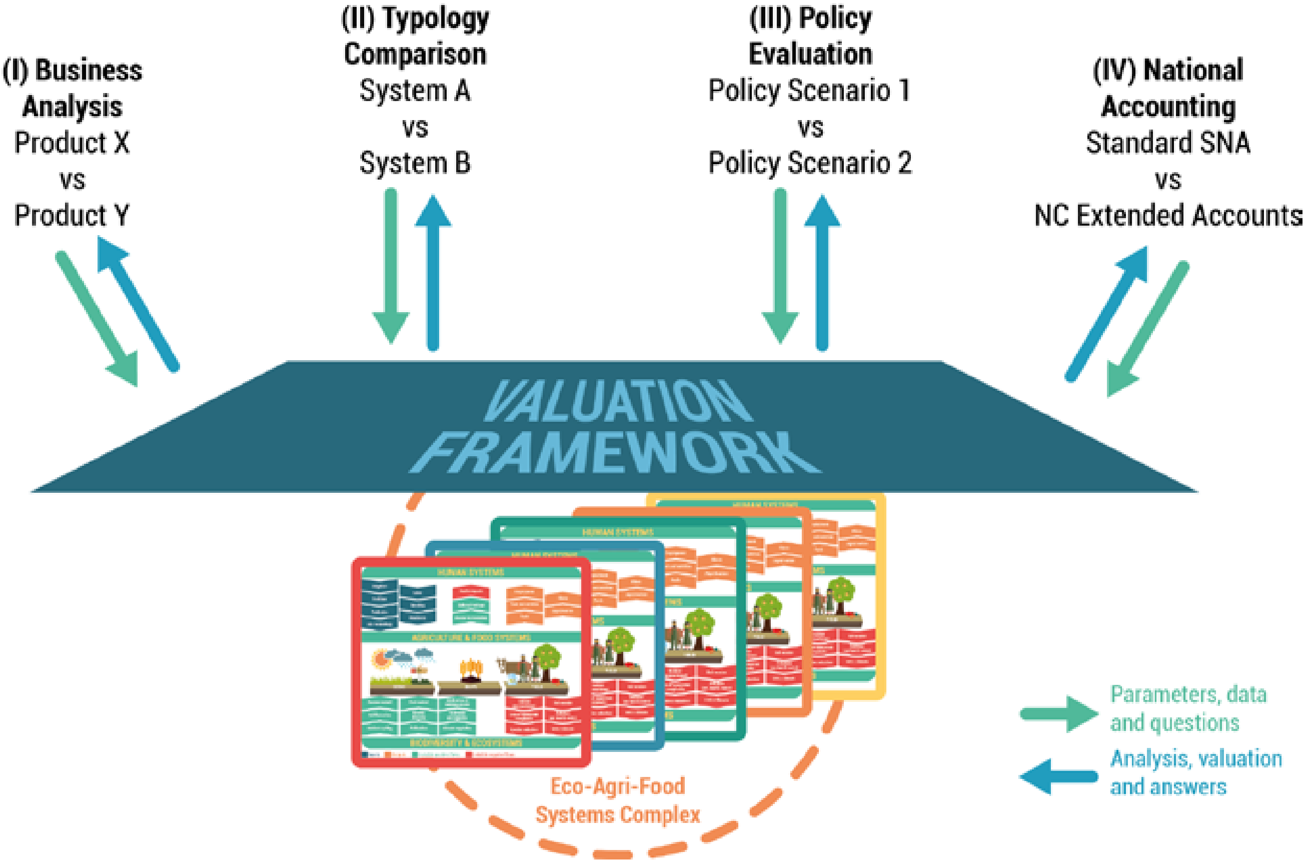
The approach to valuation will always be context-specific and will depend on the application being considered. For example, recent applications of valuation have emerged in the context of policy, business and national accounting[18, 19, 20, 21]. The approach in each context and application will be different. However, for the sake of completeness and comparability, it is important that the elements of value considered and evaluated in each approach are the same, defined and described in a consistent manner. Failing that, it would not be possible to draw policy or business conclusions from comparisons across different scenarios or strategies, as each evaluation would be using its own lexicon, making its own choices of what should be valued and why. This is precisely why we need a universal framework that consistently and clearly answers the question: "What should be valued, and why?"

Figure 3.2 shows how a universal framework can be used as a lens to focus the valuation question being asked, and a filter to select relevant parameters and data, in order that the vast eco-agri-food systems complesx that is being evaluated is viewed in a manner appropriate to context and application.

The framework provides a structure and an overview of what should be included in the analysis, but does not prescribe methods for valuation. Methods of valuation will depend on the values to be assessed, availability of data, and the purpose of the analysis. The framework is recommended for use in an interdisciplinary manner, where all relevant stakeholders, including policymakers, businesses and citizens, understand and identify questions that are to be answered by a valuation exercise. From this understanding, the scale, scope, relevant variables, and appropriate methods are selected.

Finally, it should be made clear that valuation is neither a simple undertaking nor a panacea to all our problems. TEEB treats valuation as a human institution which is contextual to a place and time[22] and, as such, allows us the opportunity to reflect on our decisions while offering a potential way to better inform them.

**Figure 3.2 Four applications of valuation supported by one universal "Valuation Framework"**



## Value–addition': Valuing costs, benefits and externalities

'Value addition', or the idea that we can change the state (space, time, and characteristics) of a product to make it more valuable to humanity, is central to our proposed valuation framework.

At the business level, value addition is a measure of operating profit, i.e. sum of factor returns and surplus generated by firms over and above their purchases from other firms. At the national level, a System of National Accounts (SNA) incorporates value addition through the income approach of calculating the Gross Domestic Product (GDP) indicator, which is the sum of compensation of employees, taxes less subsidies on production, and the operating surplus of the producer[23].

However, the mechanisms for estimating value addition, at both business and national levels, generally rely on market prices, thus ignoring economically invisible flows that form important components of the eco-agri-food systems complex. To address this gap, our proposed framework defines value addition as “the contribution of invisible and visible flows to human well-being” through their positive (or negative) impacts along the agricultural value chain (Figure 3.1).

MA, TEEB, CICES and others have, to a considerable extent, identified some of the hidden flows within the eco-agri-food systems complex. These bodies of work have evolved widespread consensus on a typology of ecosystem services that connect natural systems to human well-being, and allow us to identify these relationships within eco-agri-food systems.

For example, agricultural systems both depend upon and impact natural capital in their ability to deliver ecosystem services[24, 25]. Services such as rainfall and pollination act as critical inputs to agricultural production, but agricultural production can impact the functioning of ecosystems that deliver these services through water pollution and loss of biodiversity[26].

Agricultural systems also enhance human well-being through cultural experiences around agricultural activities, food security, and resilience. While some of these services or disservices[27] cannot be (and from an ethical standpoint, should not be) reduced to a monetary value, they still need to be recognized and accounted for in decision-making. On the other hand, some flows of agricultural systems (e.g. food yields, employment) are economically visible, have market prices, and are accounted for in business as well as national accounts. However, even with market prices, other welfare effects like food security related to these transactions may not be visible.

At this point, it is important to reiterate that TEEBAgFood adopts an anthropocentric approach – that of “value addition” to human well-being - in order to analyse the eco-agri-food systems complex. Therefore, we also accept the ethical perspective that this presumes. We acknowledge that there exist alternative perspectives, such as a rights-based approach that recognizes value to other species, and the rights of Mother Earth[28, 29], and we respect such alternatives.

To summarize, within our framework, value additions are divided into two broad categories of flows:

1. **Visible:** Value addition generally accounted for in systems of national accounts and in business accounts. For example, profits, wages, indirect taxes, etc. are accounted for by the ‘income method’ of GDP compilation.

**2. Invisible:** Value addition generally not accounted for in national or business accounts, including many environmental, social, and cultural flows. Examples include: water provisioning at the landscape level for agriculture; human health effects of consuming food containing harmful chemicals; food security; and unpaid labour. We propose to adopt CICES classification for environmental flows ('ecosystem services') and add to that other significant social and cultural flows.

It should be noted that these visible and invisible flows are generated by all types of capitals – human, social, physical, and natural – and can be both positive and negative, and can either increase or decrease over time. For example, negative human health effects from consuming certain foods are identified as negative value additions, and benefits such as employment and resilience are identified as positive value additions. Furthermore, degradation of natural, social, and human capital can lead to declines in the flow of value additions over time.

### Beyond Economic Value-addition - Social value, resilience value, risks & uncertainties

While we suggest using the metric of value addition to capture value generated from economic, environmental, social, and cultural flows within the eco-agri-food complex, we acknowledge that the eco-agri-food systems complex has significant implications for sustainability and equity, and that limiting evaluations to the yardstick of 'value addition' does not address important equity and resilience issues.

Furthermore, it is equally important to recognize the existence of risks and uncertainties that are not included in current assessments of flows and impacts, and may not even be fully understood at present. For example, information on health impacts of food systems is controversial and contested. At the same time, however, human health is inextricably tied to food systems, and ignoring this important link would weaken a universal framework that seeks to capture most, if not all, of the flows within the eco-agri-food systems complex. In the human health context of the valuation framework of TEEBAgFood, risks would need to be measured in terms of available health and medical statistics, as well as estimates of potential treatment costs. The distinction between risk and uncertainty is widely discussed in literature[30]. In essence, *"risk"* is a quantifiable possibility of loss, injury or any other form of damage, while *"uncertainty"* is when we not only do not know what is going to happen next, but we also do not know the possible outcomes nor their respective probabilities.

An example of uncertainty is the state of knowledge on the effects of genetically modified (GM) crops. This is evidenced inter alia by the fact that 300 scientists in a joint statement published recently in the journal *Environmental Sciences Europe*[31] said that:

> *"...the totality of scientific research outcomes in the field of GM crop safety is*

> *nuanced; complex; often contradictory or inconclusive; confounded by researchers' choices, assumptions, and funding sources; and, in general, has raised more questions than it has currently answered."*

The case for recognizing *uncertainty*, and using the *precautionary* principle when bringing evaluations of uncertainty into responses from policy-making and business strategy was highlighted (in the context of the state of knowledge about ecosystem thresholds) by TEEB[32].

Thus we also propose to develop and use additional 'social' and 'resilience' indicators of value (both quantitative and qualitative) for different models of agriculture. For example, we could consider the following indicators:

- Total number of jobs provided by a particular type of agricultural production;
- Agricultural income as a fraction of household income in poverty-affected areas;
- Food output distributed to food-insecure areas as a fraction of total farm output; and
- Risks and uncertainties of impacts on human health from various agricultural inputs.

It should be highlighted that the dominant models of agricultural management today are largely focused on using the common yardstick of profit, and so the data we seek may not be readily available. However, by establishing this valuation framework, we also wish to establish (as well as respond to) the need for necessary further research to obtain and use such data in appropriate policy and management contexts.

### Typology and Scale – recognizing diverse systems, reflecting real landscapes

The 'adaptability challenge' identified earlier allows us to recognize that the framework must be adaptable so that different types of farming systems can be assessed using this universal framework as a guide.

Farming systems can be characterized based on various criteria: the diversity of crops grown; type and intensity of inputs such as chemical or organic fertilisers and pesticides; type of irrigation; size of farms; and socio-economic and cultural contexts etc. Furthermore, since the valuation framework takes account of multiple values of food production systems, beyond food provisioning, farms are to be examined in their entirety. This will allow us to identify and assess the overall contributions and impacts of mixed farming systems.

Relatedly, the framework should allow for different geographical scales to be accommodated. While some agricultural systems create impacts at a smaller scale, others can reach well beyond the watershed. Whether analysis is limited to a watershed or a river basin or a broader landscape may be determined depending on the context, and the framework allows for this adaptability.

While this does introduce a diversity of variables and we do recognize the challenges of context and comparability, it is important to include these so that non-marketed values of household resilience and multiple values of mixed systems can come to light and be evaluated.

## Boundaries – life cycle approach and value chains

Value chain boundaries allow us to identify which stages in the life cycle of food production ought to be assessed, and identify value addition at each of these stages. Boundaries determine the variables to be included or excluded in our analysis. For example, using the farm as a boundary would limit the analysis to farm-level processes of food production, excluding upstream value chain processes that contribute to food production, and downstream value additions of food distribution and consumption. To ensure that these essential relationships are adequately captured, the framework is designed to encompass the entire value chain of agricultural systems.

We have therefore mapped three important life cycle stages ('production', 'processing and distribution', and 'consumption') and their main component stages in order to provide a framework for evaluation that is comprehensive. Within each of these stages, we also identify the value additions that relate to all four capitals, including risk and resilience. These value-addition elements and value-chain stages in our Framework are summarized in Figure 3.1.

It should be borne in mind that all 'value addition' components are made explicit in the valuation framework to ensure that each is given due attention, but that they are not always additive. This is for various reasons.

Firstly, some value additions, in the form of regulation and maintenance services are generated by intermediate flows that contribute to the provisioning of certain final value additions. For example, regulation of soil fertility is an intermediate (invisible) flow that contributes to the provisioning of (visible) food yields. Adding both of these flows would lead to double counting. However, these are effectively decoupled in the framework, due to the importance of recognizing the role and ability of ecosystems in delivering both of these intermediate flows over time. This is critical for sustainable planning and public policy.

Secondly, while some value additions can be measured in economic terms, some cannot. For example, while water provisioning services can be quantified, cultural flows that add to social capital are qualitative. While these are not additive, the recognition of these flows, independently, is important for assessing trade-offs between different food systems using evaluation approaches such as multi-criteria analysis.

Lastly, value additions may generate secondary value additions. For example, wages, a form or primary value addition generated at the farm, may be invested in education, which can generate secondary value additions. While the TEEBAgFood framework does not include secondary value additions, appropriate multipliers may be used to assess these, depending on context.

This choice of boundary does impose considerable analytical challenges. Therefore, we do not expect that every research consortium that contributes to TEEBAgFood with expertise in farm-level assessment will have sufficient expertise in downstream impacts. Notwithstanding, their contributions could be valuable as they cover important points in the overall matrix of TEEBAgFood evaluations.

### System Dynamics - modeling evolving policy & physical environments

Policy and decision-makers in agriculture and food need to make choices and balance different demands on land use, plan appropriate actions and respond to potential future pressures on ecosystems, and do so within a complex, fast-changing and highly uncertain world[33, 34]. It is therefore not sufficient to consider and compare agricultural systems as they are now. We should consider how they may change in the future under the influence of external factors that are difficult to predict, and what this may mean for biodiversity and ecosystems over time, space, and along the value chain.

Because the interaction and dependencies between biodiversity and ecosystem services and agriculture, food and other human systems vary in space and over time, and interactions occur across multiple scales[35, 36, 37, 38], it is important that the framework adopts a ‘system dynamics’ perspective. Furthermore, as agricultural systems often generate impacts on ecosystem services beyond the farm or even beyond the landscape or watershed, it is important to use spatially explicit analyses. Modelling, and spatially explicit modelling, in particular, helps to simulate the complex multi-scalar interactions in human environments and systems. Moreover, it can help assess the outcomes of a range of alternative development pathways for agricultural systems.

Scenario development and modelling can help explore the many uncertainties facing agricultural systems by describing how the future may develop, based on different assumptions about key relationships and driving forces at different scales. The framework can support the development of scenarios with interventions addressing specific types of value generation or elements of the life-cycle considered. The framework by itself does not analyse causal relationships, which is where modelling of various pathways, ideally in a spatially explicit manner, contributes. The framework then allows the assessment of how different strategies or management options affect the natural capital that agriculture both depends - and impacts - upon. In that regard, the framework can significantly contribute to the development of scenarios and their quantification (in biophysical units or economic values) using system dynamic modelling.

## Using the framework

This framework is not intended to be a "plug-and-play" type of tool. It links the multiple dimensions of agriculture and food systems that need to be taken account of when applying valuations to inform policy choices, inform business management decisions, identify agricultural research needs, and so on.

The three core elements of this framework are:

a) Value addition as a common unit of value measurement and analysis;
b) Adopting a standard typology of farming systems that allows for cross comparisons between different alternatives, e.g, food systems, products or policy options; and
c) A systems perspective where a life-cycle approach allows the analysis of all relevant impacts along the entire value chain from production to consumption so that all value additions can be captured.

These three elements can enable policymakers and businesses to:

1. Identify the various points in the value chain where the most value additions (both positive and negative) occur;
2. Compare various options of farming systems, or management practices, distribution systems, and policy options on the basis of their value additions; and
3. Contextualize agricultural systems within economic or development policy, highlighting the various hidden costs and benefits of eco-agri-food systems, such as the value of smallholder farming systems for both employment generation and food security.

### At a policy level

The policy landscape influences the agricultural sector in various ways; land use and spatial planning, import/export regulations, subsidies and taxes, investments in agricultural research and development all influence the way in which we produce, process, distribute and consume food[39].

Using this framework as guide, central and local governments can account for various public investments and expenditures across different types of farming systems, or consumer policies along with their associated costs and benefits on human health, ecosystem functioning, GHG emissions, and other public goods. This can allow governments to measure trade-offs between different systems, and reward different options for agricultural production, through changing regulations, incentives or investment patterns. Furthermore, fiscal policy decisions on subsidies, pollution taxes, research and development policies, and priority setting can be informed by using this framework.

Governments and international agencies can contextualize agricultural systems in development policy, highlighting the various hidden costs and benefits of eco-agri food systems, such as the value of smallholder farming systems for both employment generation and food security.

Decisions on land use can be informed by including value additions at a higher spatial scale – beyond farm gate. Recognizing the role of economically invisible inputs to farming, such as pollination, freshwater cycling and nutrient cycling, can support policy decisions to sustain 'public goods' by investing in conservation and integrated watershed management, using instruments such as protected area creation, Payments for Ecosystem Services, and the creation of wildlife corridors.

It should be noted that there is a political economy to decisions made by governments which goes beyond valuations and cost benefit assessments. Merely the act of providing a holistic valuation is no guarantee of the right policy action for change. However, it is our proposition, and the argument of all TEEB reports, that economic invisibility worsens policy decisions, and conversely, that providing valuations in the right context can help support policy changes towards improved impacts on society and especially its less privileged members.

### At a business level

Environmental changes present both risks and opportunities for businesses, particularly agri-businesses and the food and beverages industry. Companies make decisions based on various risks and opportunities (operational, regulatory, reputational, market and product, and financing), and accounting for value additions in supply chains can allow for companies to identify these, and take appropriate action. For example, companies can use this framework to determine sustainability criteria in purchasing decisions, particularly the food and beverages industry.

Emerging markets for carbon, biodiversity, watershed services, and eco-labeling have developed over the years[40]. The framework can help companies identify where and how value additions are being affected, and how positive values can be secured and negative impacts avoided through the entire value chain. Businesses can also compare different value chain trajectories based on the value they generate. Applications of the lens of the valuation framework include risk management, option appraisal and exploring new revenue streams.

Lastly, the value addition framework can also allow the company to identify and invest in the ecosystem services that their production depends on. For example, agribusinesses can invest in the protection of watersheds that deliver vital intermediate value additions in the form of hydrological services.

### At a national accounting level

Within the TEEBAgFood framework, value additions happen through flows within the eco-agri-food systems complex that build (or deplete) the four capitals (human, social, physical, and natural). For example, value addition arising from nutrition flows from agricultural systems can lead to an increase in human capital in the form of improved health.

In 2012, the System of Environmental-Economic Accounting (SEEA) Central Framework was adopted by the UN Statistical Commission as a complementary statistical standard to facilitate a broader assessment of economic activity and its links to natural capital than provided in standard national accounts. In 2013, this work was further advanced through the release of SEEA Experimental Ecosystem Accounting[41]. Both of these SEEA documents provide a platform for integrating information on the changing stocks of environmental assets, including their depletion and degradation, and information on ecosystems and their services, with the standard economic information of the national accounts framework. A key feature of SEEA is its articulation of accounting in both monetary and physical terms, recognizing that integrated information relies on: (i) understanding the systemic, physical relationships between environmental assets and the supply of goods and services; and (ii) estimating the relative importance and value of these relationships.

It is however accepted that the extensions to the national accounts presented in SEEA only integrate aspects related to natural capital. The full integration of human and social capital within national accounting frameworks remains a work in progress, albeit one of ever increasing interest in the light of both global sustainable development initiatives and targeted assessments such as those envisaged in the TEEBAgFood study and the proposed valuation framework.

### And overall

It is expected that this proposed framework would allow consumers, policymakers, and businesses to recognize, and where appropriate, capture hidden flows of the eco-agri-food systems complex in their decision-making. This framework is a lens that allows us to make the invisible visible: it helps to evaluate the impacts of and dependencies on these important flows which have mostly been treated as non-existent by decision-makers.

The framework itself does not prove or establish causal relationships between the various value chain components – such as how consumption affects production, or how ecosystems affect farms. It can however be used in a systems analysis approach, wherein value additions can be determined across spatial and temporal scales. Furthermore, while the framework itself does not measure ecosystem assets or their ability or inability to deliver ecosystem services over time, it is an important component of valuation and ensures that risks and uncertainties should be recognized and accounted for, especially as analyses can be carried out over varying time horizons.

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# THE WAY FORWARD: FROM ECONOMIC ANALYSIS TO SOLUTIONS FOR POLICY, FARMING, BUSINESS AND CONSUMERS

Photo: ©Flickr/Enshahdi

The case for examining the eco-agri-food systems complex (and especially different production systems with their specific interactions with people and nature) has been set out in the first chapter. The development of the TEEBAgFood framework in Chapter 3 will guide us to carry out assessments. The ultimate aim of the TEEBAgFood study is not only to make an assessment of the positive and negative externalities of the different production systems (making values visible) but also to build an evidence base to formulate recommendations (see Box 4.1) toward solutions for sustainable and resilient food systems that feed the world while maintaining and improving ecosystem services for all people.

In this regard, TEEBAgFood is also a contribution to a transition in the eco-agri-food systems complex towards long-term sustainability at a time when a growing demand for food, feed, fuel and fibre, and the new and additional challenges of climate change (both in terms of mitigation and adaptation), will add to the already existing pressures on this system. Making previously invisible positive and negative externalities visible and valuing all externalities will enable us to make informed decisions for better solutions. And the challenges are huge. FAO put it in the following way: "*Addressing the food-energy-climate change nexus will be agriculture's greatest challenge this century.*"[1] To date, economic analysis has concentrated mainly on the visible outcomes of the agricultural sector as yields per hectare, prices for unit produced, and costs of inputs, focusing less on the invisible externalities that are not priced in the market. But without them we do not fully understand how the system is working and what we have to do to maintain ecosystems for food production and as life support systems for us all.

Solutions have to be sympathetic to the needs, aspirations and constraints of the full range of affected stakeholders on both sides of the economic equation: the supply side (landowners, farmers, agri-business, processors and distributors) and the demand side (consumers). Solutions are required at all scales, within all systems, and across all stages of the value chain. The overall added benefits of feeding a growing population while ensuring the long-term

**Box 4.1 Summary of our recommendations**

Learning from our exploratory studies and wide consultations, our key proposals towards crafting the way forward for TEEBAgFood are:

**1. Seek Holistic Evaluations through a Universal Framework:**

a. Include all significant dependencies and impacts from biodiversity-agriculture linkages, including agricultural biodiversity
b. Typologies evaluated should include mixed systems
c. Off-farm dependencies and impacts to be included, taking the full 'eco-agri-food' value chain as boundary
d. Health impacts to be included - arising from unhealthy diets, or arising from agricultural impacts on air & water quality & vector-borne diseases
e. The full gamut of impacts and externalities identified in the TEEBAgFood framework should be applied across all major system typologies

**2. Evaluate Policy Response Options at Different Points in the Food Value Chain:**

a. Supply-side measures
b. Market-based instruments such as removing perverse incentives, certifications, PES schemes
c. Information-provision for farmers (stimulating the supply and adoption of appropriate Agricultural Science, Knowledge and Technology)
d. Demand-side measures: Information provision for consumers (e.g.: eco-labelling), incentives and disincentives
e. 'Ecological Infrastructure' investments to secure agricultural dependencies & resilience

**3. Calls for Collaboration, Knowledge, Transparency & Disclosure:**

a. A call for evidence and how to contribute: Inviting experts covering diverse aspects, geographies, value-chains of eco-agri-food systems to provide evidence and suggest analysis towards our objectives
b. Applying the TEEBAgFood framework: Commissioning and synthesizing research that generates the complete picture, thereby providing important evidence for policy interventions
c. Developing a community of practice: Building collaborations with institutions and experts (contributors, authors, reviewers, practitioners in policy and business, civil society representatives)
d. Implementing a dissemination and outreach strategy that targets the wide range of actors in the eco-agri-food systems complex

sustainability of the systems that food production depends on will significantly outweigh the costs of change. Without change, the most vulnerable people and the poorest (mainly in developing countries) will have to pay the costs of inaction.

The TEEBAgFood framework can help us to make informed choices, as there are many agents in the eco-agri-food systems complex. Trade-offs are inherent – some agents will be better off, others worse off – but in populating the framework we make these trade-offs explicit, and include impacts and externalities that would otherwise likely remain invisible (and thus not accounted for in our trade-off calculus).

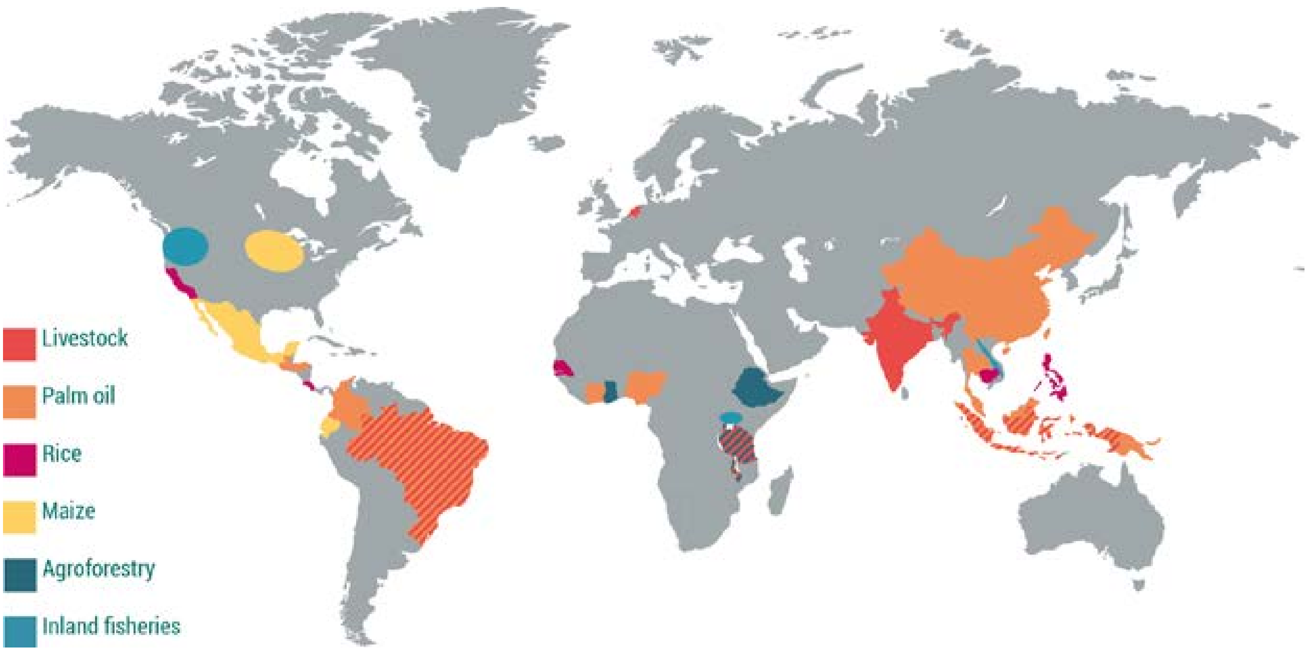
For instance, communities that engage in artisanal fishing may see their livelihoods impacted by eutrophication from upstream fertiliser run-off from crops that are being grown for the export market, and thus foodstuffs that never reach local markets. On the other hand, these same export-focused agri-businesses might contribute positively to the local economy in terms of taxes paid (that then fund public services) and employment creation. This example shows a range of trade-offs - across agents, across the value chain, and across categories of value-addition. Further, these trade-offs will change over time, as systems are in a constant state of flux.

In Phase I of the TEEBAgFood project (April 2014 – December 2015), TEEB commissioned research in various externality-heavy agricultural sectors to examine such trade-offs (see abstracts in Appendix I). As these studies come to a close, they represent our first analysis by providing a global perspective on a wide range of different products, production systems and management practices, in each case considering positive and negative externalities and the degree of impact.

Figure 4.1 shows the geographical coverage of the various 'exploratory studies'. They represent the state of the art (for example in linking environmental economics valuation with geo-spatial modelling) and have laid the necessary foundation for the way forward.

Each exploratory study was predicated on the overall TEEBAgFood vision (making impacts and externalities visible) and they supported the development of the framework (Chapter 3), which was agreed in an expert workshop with more than 100 participants (from a range of sectors) in Brussels in September 2015. These studies do not assess the entire supply chain but rather focus on impacts and dependencies on-farm (with some analysis of inputs feedstuffs) and in some cases in the wider landscape. They do not consider off-farm processing, distribution and final consumption, which has been identified as a critical research gap. Further, although there is some assessment of health impacts arising from pesticide and fertiliser application (changes in air quality and in vector borne disease), the information is partial and does not capture the full range of health externalities that TEEBAgFood will look at in Phase II.

**Figure 4.1 Geographical coverage of the 'exploratory studies'**



In Appendices II-V, we provide a snapshot of the research methodologies developed and applied, data sources and limitations, and indicative first biophysical and valuation results for selected case studies from the rice, livestock and agroforestry studies. They are presented to demonstrate proof of concept and focus on moving from assessing production to the valuation of production systems.

## Contextualizing the sector-specific case studies

In Phase I of TEEBAgFood, research was delineated based on single sectors. This delineation has its pros and cons. On the plus side, sector-level assessment is typical in accounting in the business sphere. The focus on single sectors also reduced the complexity of the analysis and facilitated a 'deeper dive' into the impacts of individual management practices associated with the production systems. Another benefit is that outcomes can be generalized since these case studies link to typologies of production systems and the specific management practices they include. This focus facilitates trade-off analysis and the valuation of changing management practices from the perspective of multiple beneficiaries. Thus there is value-added beyond the confines of the specific case study country/agro-ecological system. This is important as TEEBAgFood is a global initiative.

There are also downsides to this approach. First, different eco-agricultural systems interact with each other; this is why TEEBAgFood assesses eco-agri-food systems as a *complex*. Second, a commodity-based approach is often associated with monocultures and these may be less sustainable than mixed systems[2]. Starting with a commodity-based approach however facilitates the aggregation of these same commodities across landscapes, a focus of Phase II.

Across the 20+ combinations of sector/production system/country assessed in the six exploratory studies, four case studies are presented in the Appendices along with the rationale for their inclusion:

**I. Rice production practices.** The rice study looks at alternative production practices within eco-agricultural systems. It develops a typology of such practices, and shows trade-offs or synergies between ecosystem functioning and livelihoods.

**II. Livestock production assessment.** This case study provides a synopsis of the 'bottom-up' approach as applied to all three livestock sub-sectors in scope (i.e. poultry, beef and dairy) but then focuses on dairy by way of example. It sets out a typology of dairy systems and also explicitly addresses biodiversity loss. Since the analysis relies to some extent on global datasets, the study does not allow for local conditions in-country to the same degree as the third case study (Maasai Steppe), but it provides indicative results that can inform international policy dialogues.

**III. Pastoralism in the Maasai Steppe.** This case study is part of the overall livestock study. It is a 'deep dive' where the local socio-cultural and agro-ecological context is embedded in the analysis, and local data are used where possible. It also demonstrates how the optimal choice changes across the time horizon when we take a broad set of ecosystem services into account, i.e. what is best if we focus only on today is not best if we look across the next 20 years.

**IV. Bio-physical modelling of coffee, cacao and pastoral agro-forestry systems.** There are a range of modelling tools that can be used to assess the implications of different strategies within complex production systems at the landscape scale, and this study summary presents some of the applications (and results) across three agro-forestry systems in Africa.

The four case studies vary in terms of the granularity of the datasets used (which in turn depends on the geographical scope of the study), production systems versus production practices, and the role of modelling. As such, the results not only look back to the achievements in Phase I but also look forward to the options for new research in Phase II. The case studies are presented in the Appendices. (II-V)

## Taking stock: What have we learned from the exploratory studies?

The exploratory studies provide a proof-of-concept for TEEBAgFood, in that they demonstrate that it is possible and necessary to evaluate and then value agro-ecological systems at different scales, across a diversity of systems, and assessing trade-offs (e.g. higher yields versus lower agro-biodiversity).

### Biodiversity

The exploratory studies were tasked to consider the link between biodiversity and agricultural production. This is a complex and emerging field of enquiry[3], approached in different ways across the exploratory studies. The livestock consortium developed a methodology that links production to land-use change modelled under GLOBIO[4]; this was then linked to a measure of biodiversity loss (Mean Species Abundance, or MSA[5]). Global databases of biome values were then used to estimate the value of this loss, but this valuation was partial and did not fully address location-specific ecological and socio-economic conditions. So the analysis is useful as a point of departure for future TEEBAgFood work but such analysis needs to be developed further in Phase II.

### Impacts and Externalities

Each exploratory study provided estimates for some subset of the externalities and impacts set out in the TEEBAgFood valuation framework. This subset differed across studies, which is to be expected given the nature of the sectors. These choices are explained in the main exploratory study reports. TEEBAgFood will look to add to this subset of externalities and impacts within some of the six agricultural sectors in Phase II.

### Extending the scope of work

The rice and livestock studies provided evidence of the benefits of mixed systems. The scope of work in Phase II will be extended to include not only new agricultural sectors (such as soy or quinoa) but also further assessment of mixed systems. Mixed systems can include but are not limited to increasing diversity at the field, farm, or landscape scale, as well as over time (for example crop rotations, agroforestry systems, polycultures, or the management of field margins as buffers and barriers). As such, we must first develop a typology of mixed systems and then assess impacts and dependencies for the selected systems. There is also a need to consider land restoration, and again this requires the development of appropriate case studies to provide coverage of the heterogeneity across a range of agricultural landscapes.

Such extensions (to include mixed systems, land restoration and more sector-specific ecosystem impacts and dependencies) are extensions at the farm-level. TEEBAgFood Phase II will include scenario analysis and spatially explicit modelling in complex multi-scalar agro-ecological systems (see Box 4.2).

Such modelling can help explore potential alternatives to business as usual situations and identify solutions and opportunities for change by considering the influence of factors along the whole value chain, from farming practice and production, processing and distribution to consumer behaviour and choice. Combined with economic valuation, scenario analysis can help clarify the costs and benefits of different strategies, who will bear those costs and where they will be borne.

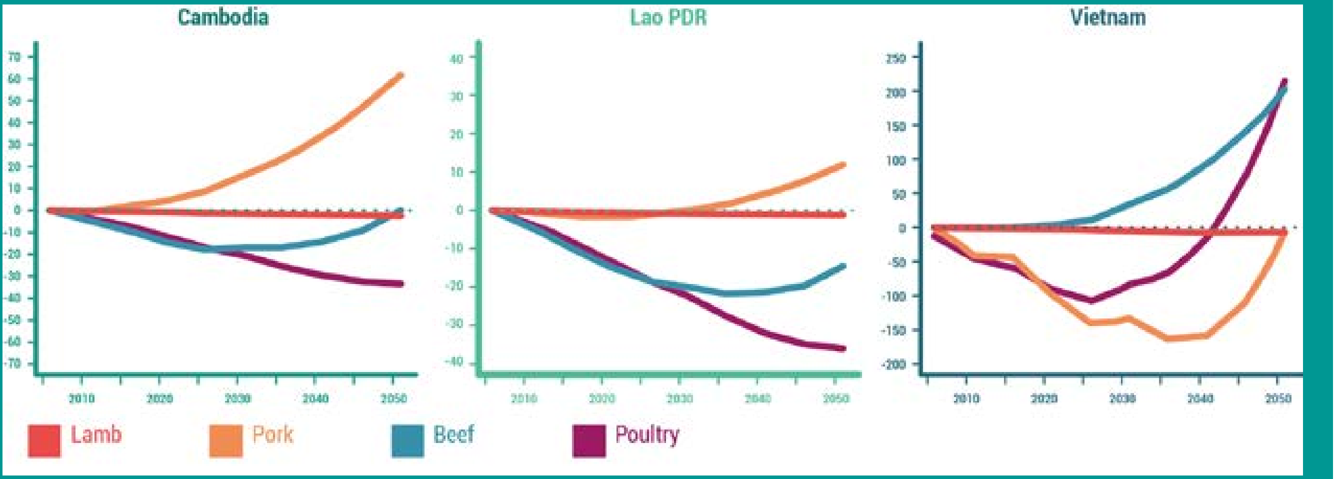
## Box 4.2 Modelling trade-offs between potential future agriculture development and biodiversity and ecosystem services in the Andes, Mekong and African Great Lakes[6]

UNEP-WCMC have developed an analytical framework that can provide spatially-explicit information and analyses on the effects of different potential future pathways of agricultural development on biodiversity and ecosystem services at multiple geographic scales. These pathways are determined by different plausible future socio-economic scenarios that affect the agricultural value chain through changes in human population, consumption patterns, commodity markets and agricultural production. The framework was applied in three regions (Andes, Mekong Basin and Great Lakes of East and Central Africa) for two groups of scenarios, modelled using the IMPACT economic model[7] and the LandSHIFT[8] land use change model, in each case for sub-watersheds:

1. Global scenarios of change up to 2050 using Global Environment Outlook (GEO-4) with land-use change modelling at 5-arc minute resolution (~9 km)
2. Regionally-developed scenarios for three countries in each region with land-use change modelling at higher resolution (~1 km)

The study found that, in the Mekong region, meat production is expected to triple under almost all scenarios. By 2050 meat production is projected to surpass demand in Viet Nam while Cambodia and Lao PDR will need to import meat to satisfy domestic demand (Figure 4.2). With regards to crops, rice production in Viet Nam is projected to increase only marginally by 2050 and to decrease in China.

**Figure 4.2 Difference between domestic production and demand for meat products in Cambodia, Lao PDR and Viet Nam between 2005 and 2050 for the Land of the Golden Mekong regional scenario (most positive scenario modelled using IMPACT)**



Source: Robinson, S. et al. (Forthcoming) 'The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT); Model description for version 3.x', International Food Policy Research Institute, Washington DC.

Throughout the region the area of cropland is projected to decrease for all scenarios while pasture areas expand, in particular in eastern Thailand and surrounding Lake Tonle Sap in Cambodia. Under most scenarios, agricultural expansion is mainly on land already under agricultural use, or natural grass-and shrubland. This is critical for TEEBAgFood as the agricultural expansion leads to loss of habitat and consistent declines in biodiversity and ecosystem function values (including food production). These results, including for the other regions, can be further explored at http://macarthur.unep-wcmc.org/.

## Feedback loops: Ecosystem health-human health

The TEEBAgFood framework set out in Chapter 3 includes health impacts and externalities. A methodological approach to value human health impacts from pesticide and fertiliser applications (their effects on air and water quality) has been developed for the exploratory studies (see Box 4.3). Although a useful first step, it is partial both in terms of scope and also might be improved with further field studies and geo-spatial data.

The relationship between ecosystem health and human health is complex and can be fully addressed only in a systematic framework that considers the food system as a 'dietary pattern enabler'. The type of dietary pattern enabled (made easy to access and consume) and, essentially, disabled (made difficult to access and/or consume) depends on a range of policy and structural developments[10]. Human health is impacted in a variety of ways. The

**Box 4.3: Assessing impacts on human health[9]**

Each and every individual human life is priceless and it would be morally reprehensible to value life per se. What does seem more defensible is to value the loss in productivity and income that arises from illness or decreased life expectancy, i.e. valuing the 'economic component', and the economic component alone, of health outcomes.

Health externalities are one of the hidden costs of the eco-agri-food systems complex and valuing them makes them more visible to the decision-maker, but we have to be cautious in our approach. In the same way that TEEB does not support the commodification of nature, similarly it does not support in any manner or form the commodification of human health outcomes. Just because we might value the loss of productivity from an illness does not mean that we accept an outcome which causes such illness. For policy-makers, it is useful to know in the aggregate what effects different policy interventions have on human health as this in turn affects economic output.

In TEEBAgFood Phase I, the metric used for this economic valuation is disability adjusted life years (DALYs). This metric quantifies the burden of disease on human populations and can be thought of as one year of healthy life lost. The methodological steps applied in the rice, palm oil and livestock exploratory studies are outlined below:

1. Measure changes in physical conditions, such as an increase in the concentration of a pollutant in the atmosphere. This also includes the identification of the drivers for change, such as the use of pesticide inputs.

2. Biophysical modelling of the impacts caused by changing physical conditions. This includes identifying factors such as the endpoint of pesticides in the environment, for example human beings, and quantification of changes in DALYs caused by the ingestion or inhalation of pesticides.

3. The final step involves the economic modelling component of the valuation. This includes the identification of the final recipient of the impact, such as local populations who are negatively impacted by ingesting or inhaling pesticides, and then selecting an appropriate valuation technique to monetize the change in biophysical conditions.

There are a number of methodological challenges. Pollutants emitted to the environment disperse in different ways to affect human health, but country-specific models simply do not exist in all instances. Phase I results estimate effects by disease type, disaggregated into cancer and non-cancer diseases, calculating the damage on the total human population, rather than on specific actors or sections of society. More granular and detailed modelling could overcome these issues.

There is also the more fundamental question of which metric to use. The quantification of DALYs in general and in this study includes years of healthy life lost due to disability, and years of life lost due to premature death. If an inappropriate valuation approach is applied (step 3 above), then the use of DALYs might be challenged on the basis that it assumes that ‘disability prevents work’; this is not what the data tells us. However, in TEEBAgFood Phase I, the valuation methodologies used in step 3 accounted for wider changes in quality of life (including pain and discomfort). We will explore the alternative metrics in Phase II to quantify impacts on human health, such as quality adjusted life years (QALYs).

Interim and indicative findings from Phase I suggest that health externalities comprise a significant portion of total (monetized) impacts. A study on land conversion techniques for palm oil producers in Indonesia highlights how the impacts on human health from GHG and air pollutant emissions vary with the method employed. Land conversion options include both burning and mechanically clearing vegetation in primary forest, disturbed forest, or grassland ecosystems. These ecosystems are supported by various types of soil which have been categorized as either mineral or peat soils; the latter can release vast amounts of $CO_2$ when burnt. Results indicate that, when converting primary forest on peat soils by burning the native vegetation, the health impacts of haze constitute 37 per cent of the total impact costs.

same practices that can have adverse ecosystem health impacts can also have adverse human health impacts (for example nitrate contamination of groundwater[11] or tillage-driven wind erosion[12]). The human impacts can be more distant – for example pesticide contamination of vegetables shipped to market[13] - while the ecosystem impacts are very local (e.g. destruction of native pollinators[14]). The reverse may also apply.

While the individual case studies conducted in Phase I can say much about the direct relationships (e.g. potential for pesticide poisoning), they cannot say much about the indirect or distant relationships and impacts. In addition, there are human health impacts that need an even larger landscape and system level analysis that can be addressed more fully in Phase II. For example, it is clear to most that the best way to approach the notion of food security (both under- and over-nutrition) in a highly-populated world is to consider dietary patterns and shifts over time[15]. In Phase II, it will be useful to contextualize the farm and landscape level analysis to consider two downstream effects: first, the ability of systems with greater levels of ecosystem resilience to meet anticipated food demands (i.e. 'enough food'), and second, the ability of these systems to 'fit into' a healthy eating pattern that can simultaneously meet cultural and public health needs (i.e. the 'best food plate') as well as providing sustainable livelihoods for the greatest number of citizens.

Achieving this will be challenged due to increasing temperatures and more variable precipitation, which are expected to reduce crop yields in many tropical developing regions. In some African countries, yields from rain-fed agriculture could be reduced by up to 50 per cent by 2020[16]. This will likely exacerbate undernutrition in developing countries (which today causes 3.5 million deaths per year), both directly due to reduced food supply as well as indirectly by increasing susceptibility to diseases such as diarrhoea, malaria, and respiratory infections[17].

There are three principal pathways by which eco-agri-food systems impact human health: diet, environmental (air, water and chemical quality), and vector borne diseases (see Box 4.4). In summary, how we process, distribute, market and then consume food affects health outcomes, and our evolving attitude to food and nutrition affects our cultural identity (and vice versa). This will be a key focus of TEEBAgFood Phase II.

## Policy as a cause and catalyst for change

The success of TEEBAgFood as a project depends on the extent to which it catalyses change in the eco-agri-food systems complex. Policy intervention comes in disparate forms and also is targeted at different constituencies. This section focuses on the range of policy interventions. TEEBAgFood Phase I has in the main focused on the first two steps in the TEEB Approach, namely 'recognizing' and 'demonstrating' the value of ecosystems and biodiversity to the eco-agri-food systems complex. This will continue and expand in Phase

**Box 4.4 Pathways by which eco-agri-food systems impact human health**

*Diet:* Caloric intake and the composition of the foods we eat (dietary diversity and pattern) is a fundamental element of human health and an important driver of the double burden of disease. These not only impact human well-being but have quantifiable health care costs. For example Murray[18] estimates that following the 'Global Burden of Disease' (GBD) recommended diet would have reduced US health expenditure in 2006-2010 by US$130 billion per year – a six per cent reduction[19]. Another study[20] similarly demonstrates that changing to a Mediterranean, pescatarian, or vegetarian diet can reduce the relative risk of mortality by type II diabetes by 16 to 41 per cent and coronary mortality by 20 to 26 per cent. Murray provides a provocative thought experiment – suggesting that if a goal were to provide the global population with the "low risk diet", we would have to increase fruit, nut and vegetable production by 44, 68, and 11 per cent respectively, while reducing red meat and whole grain production by 80 per cent and 35 per cent respectively.

*Environmental:* Agricultural practices can have important impacts on air and water quality. They can also increase human exposure to (foreign) chemical compounds. Agricultural practices such as burning for clearing fields or post-harvest field management degrade air quality with quantifiable impacts on human health. In Sumatra[21], recent peat fires associated with clearing of agricultural land have forced the evacuation of infants from the region with air quality indices remaining above 1000 for several weeks (>300 is deemed dangerous).

*Vector-Borne Diseases:* Changes in agricultural land use changes risk exposure to vector-borne diseases. Flooding of agricultural lands for rice cultivation can increase exposure to malarial vectors – particularly when residences are adjacent to irrigated areas as they are in many parts of the world[22]. Similarly the impact of agricultural simplification can amplify disease risk. Studies of landscape fragmentation in the Northeast US has shown that small forest patches with low mammal diversity amplify Lyme disease, whereas larger forest patches in the same landscapes can dilute and reduce disease transmission[23]. Water-borne diseases can be impacted by aquatic agricultural systems. The combined effect of introduced Nile perch and the invasive water hyacinth in the Lake Victoria Basin have increased the incidence of schistosomiasis in the region with as of yet unmeasurable health related costs[24].

II, but the focus will include 'capturing' these values. There are many types of policies that can capture values, and equally many ways of categorizing them:

1. **Supply-side measures** (how food and fibres are produced) and **demand-side measures** (how they are consumed, e.g. measures to reduce food waste and measures to negate the recent shift in food consumption patterns towards a 'Western diet', especially increased

meat and excess calorie consumption[25]).

2. Types of policy instruments, grouped as **market-based** (removing market failures and distortions, and incentivizing the uptake of good practice) and **regulatory** (mandatory government legislation). Examples provided in **Boxes 4.5 and 4.6**.

3. **Institutional changes to the environment in which farmers operate.** These interventions directly and indirectly influence the choice of production methods and what is produced, as well as where the costs and benefits of this production fall within the economy. Local in-country institutional changes include shifts in tenure arrangements. Fiscal measures also significantly influence farmer behaviour, such as agricultural subsidies for pesticides or on-farm fuel use. Example provided in **Box 4.7**.

4. **Institutional changes to the environment in which food processors and distributors operate.** These directly and indirectly influence the shaping of supply chains and the ability of people within the supply chain to ensure sustainable livelihoods for themselves. Fiscal measures are also relevant here, such as rules on corporation tax.

5. Cross-cutting policies include **information-provision** such as eco-labelling (either voluntary or mandatory), and the provision of appropriate and targeted agricultural knowledge, science and technology (AKST). Examples provided in **Boxes 4.8 and 4.9**.

6. Making a broader set of technologies and management options available for farmers. This includes in the main **further scientific research** to increase and secure agricultural production while at the same time maintaining or ideally enhancing other ecosystem services, i.e. ‘ecological infrastructure’ investments.

**Box 4.5 Market-based measures: removing perverse incentives**

Perverse subsidies encourage behaviours which have negative impacts on ecosystems and biodiversity on which output depends, therein affecting food security. Examples can be found across a range of eco-agri-food systems[27]. In Botswana, loan schemes have supported the purchase of livestock that can stimulate overgrazing on communal rangelands around settlements. Overgrazing and desertification can lead to acute poverty, leading to the overharvesting of fuelwood and other products to sell as a means of earning an income.

Subsidies are very common in the agriculture sector. Across the OECD[28], for example, countries transfer - on average - US$250 billion annually in support to the agriculture sector. Not all of these have a negative impact on the natural environment. Trends show that the composition of producer support is tending to include a higher proportion of support decoupled from production requirements. In this context, support based on commodity outputs dropped from over US$200 billion in 1990 (30 per cent of gross farm receipts) to US$110 billion (8 per cent of gross farm receipts) in 2011. Payments based on non-commodity criteria, including the retirement of land and other practices that support biodiversity, increased from US$3 billion in 2000 to over US$5 billion in 2010.

Indonesia provides a specific example of this shift in support[29]. In the early 1980s, the overuse of pesticides had wiped out the natural enemies of many pests, including the brown rice planthopper, leading to US$1.5 billion worth of damage to the rice sector from pest infestations. As a response, in 1986, the Indonesian government removed pesticide subsidies (realizing a fiscal saving to the public purse of US$100 million) and banned the import of broad spectrum pesticides. Farmers and agri-business responded to this market-based intervention: pesticide applications halved while rice production grew by three million tonnes over four years. Part of this increase in yields was brought about by concurrent programme to support Integrated Pest Management, a programme that was well-funded and widely disseminated nationally.

However, researchers found that while paying the agriculture industry to help the environment seems to be working, the agri-environment schemes are still a drop in the ocean compared to huge government subsidies received by farming industries for environmentally damaging practices[30]. They argue for a redressing of the massive imbalance between government money spent on farming subsidies, and that spent on lessening the damage farming does to the environment.

**Box 4.6 Market-based measures: 'Payment for Ecosystem Services' (PES) schemes**

Agents in agricultural systems can receive positive financial rewards for the ecosystem services they provide. An interesting example is the Costa Rica PES program which has been successful in incentivizing forest conservation[31], in part through the use of targeting tools to determine where payments should be made in order to increase the efficiency of payments. Examples include compensating farmers where agroforestry would help to increase connectivity for wild biodiversity in addition to habitat, and targeting farms on highly erosive soils and slopes as a means of protecting downstream hydropower infrastructure. These PES schemes are structured so as to recognize the multiple services provided by farms and farm managers in these landscapes.

The Conservation Reserve Program (CRP) is the largest private-lands conservation program in the United States. Famers enrolled in the program discontinue agricultural production on environmentally-sensitive land and agree to cultivate plant species that improve environmental health. In exchange, they receive a yearly rental payment for the duration of a 10-15 year contract. The goal of the CRP is to rehabilitate land and increase land cover, which can in turn improve water quality, mitigate soil erosion, and reduce habitat loss[32]. By September 2015, over 24 million acres of cropland had been enrolled in the CRP, with annual rental payments of over US$1.6 billion[33].

The CRP was seen to have the largest impact in the Mountain, Southern Plains, and Northern Plains regions, where average farmland values increased by 5 to 14 per cent, 4 to 6 per cent, and 2 to 5 per cent, respectively[34]. However, the program is not without unintended (and adverse) impact due to the slippage effect. For every one hundred acres of land in the central United States under CRP, twenty more acres of non-cropland were converted to cropland., This offset the positive impacts of CRP on water erosion reduction by 9 per cent, and on wind erosion reduction by 14 per cent[35].

Another example of payments for ecosystem services is China's Sloping Land Conversion Program (SLCP), also known as the "Grain for Green" program, a supply-side payment scheme that is one of the largest and longest-term in the world. SLCP offers per-hectare payments to households in the Yellow and Yangtze River Basins in exchange for converting steep cropland back into grassland and forests. Analysis has shown that the program has positive ecological effects, as well as generally positive socioeconomic impacts. The SLCP also had broader effects, as it increased overall vegetation cover, increased carbon sequestration, and controlled soil erosion, which in turn reduced dust in other countries[36].

**Box 4.7 Institutional changes: Meeting the Aichi targets**

A 2012 report to the Convention on Biological Diversity[37] estimated the resource requirements needed to meet its 20 globally agreed Aichi Targets. Target 5 looks at reducing the rate of habitat loss. The costs of halving wetlands loss are estimated to be in the order of US$33 billion per year. Meeting this target would likely lead to significant benefits and hence it was presented as an investment, however, a large proportion of the cost of achieving the target is assumed to derive from paying compensation for loss of potential earnings (or opportunity costs) to those carrying out activities which would degrade wetlands under business as usual.

Whether such activities would continue to be rewarded by the market however (and hence justify the level of compensation that might be required) can also be impacted by the economic and institutional environment. That is, if businesses impacting wetlands in some way faced more of the wider costs of so doing, they would make different decisions. US$30 billion of the US$33 billion resource requirement is made up of payments relating to opportunity costs.

An alternate example which demonstrates how agriculture management can make a positive contribution to meeting Aichi targets on habitat loss is found in California rice productions systems[38]. The shifting from fall burning of rice stubble to winter flooding of fields as a means of controlling agricultural waste and diseases led to the creation of 220,000 ha of wetlands which are used by more than 250 species of waterfowl migrating through the Pacific flyway. Flooded rice fields have thus doubled the wetland habitat in the central valley of California.

The California Department of Fish and Game estimates that it would cost US$2 billion to purchase the equivalent in habitat, and more than US$35 million per year in management costs. U.S. Fish and Wildlife likewise estimate that duck hunting in these fields contributes US$1.2 billion in hunting licenses, merchandise and jobs.

**Box 4.8 Information-provision on the supply-side: Investing in appropriate 'agricultural knowledge, science and technology' (AKST)**

There is an urgent need for novel technologies that permit farmers to efficiently make use of biodiversity and ecosystems' invisible benefits, including pollination, pest control services, and nutrient cycling and storage. Production systems that utilize agro-biodiversity conjure images of low tech production systems reserved for marginalized communities and eccentrics, but this image is erroneous.

Research highlights the contribution of precision agriculture to improving both yields and ecosystem services of production systems, i.e. potential 'win-win' outcomes[39]. Precision agriculture permits farmers to apply external inputs at dosage levels that meet plant production needs while limiting excess run-off into adjacent water systems. Conservation agriculture similarly shows promise for increasing yields, and the capacity of production systems to store carbon, but may require specific technologies that facilitate seeding, weeding, and harvesting. This is also the case with some polycultures for which there is still a great deal of need, and room for innovation in management technologies.

California rice serves as a good example of where remote technologies are supporting sustainability[40]. The main trade-off with winter flooding is the increase in emissions of methane as a greenhouse gas. In order to maintain the habitat values provided by flooding, but limiting the extent and the duration of flooding to reduce methane emissions, The Nature Conservancy and farmers are using crowd-sourced data on locations of migratory flocks as they move through the valley to bid on the rental of fields which are flooded on an as-needed basis. An ecosystem based approach to agriculture and food does not imply one that is devoid of technology - quite the opposite. This is an area of tremendous need and innovation.

To advance these innovations, expanded investment in agricultural knowledge, science, and technology (AKST) is needed, as well as a shift in the nature of investment. AKST investment has risen consistently since 1980, though global rates flattened in the 1990s and public investment dropped in 26 countries in Sub Saharan Africa during that time[41]. From 2000 to 2008, global public investment rose from US$26.1 to US$31.7 billion, and low-and middle-income countries now account for half of all AKST investment. However, funding remains clustered in a small number of countries, particularly the United States, Japan, India, Brazil, and China, which drove 38 per cent of investment growth over that period[42].

Analysis shows that rates of return on AKST have remained high (40 to 50 per cent) across commodities, countries, and regions over time. However, investment has been focused almost exclusively on conventional agriculture. In 2014, only 15 per cent of the USDA's Research, Extension, and Economics US$2.8 billion budget was used to support projects involving agroecology[43]. This investment gap is a major challenge, as is the need for broader investment in locally-specific technologies. CGIAR's 'Diffusion and Impacts of Improved Varieties in Africa' project found that while overall research and cultivated area of modern varieties has increased substantially across Africa (from 20 to 35 per cent between 1998 and 2010), investment remains heavily focused on maize, while research intensity for widely cultivated crops such as cassava, yams, and pearl millet is disproportionately low relative to their cultivation and production values[44].

### Box 4.9 Information-provision on the demand-side: Eco-labelling as a means to provide access to market

Labelling of food products has been a critical means of communicating both the positive and negative externalities of agriculture to the consumer, while exhibiting tremendous capacity to influence preference for not only specific commodities, but also for production practices associated with agricultural systems. Several labels are well known, including Organic, Fairtrade, Rainforest Alliance and GMO free. The "Responsibly Grown" label[45] favoured by Whole Food associates fresh produce with a 'good', 'better', 'best' label in relation to the production methods used, focusing on: soil health; impacts on air, energy and climate; waste reduction; farmer welfare; water conservation and protection; ecosystems and biodiversity; and finally pest management. TEEBAgFood can contribute to the development of such schemes by providing credible data and analysis on such metrics, so as to preserve the integrity of these labels as they scale up for large, corporate users[46].

Challenges with labelling are many, though their impact on moving the sustainability agenda forward has been undeniable. Of particular relevance is the current inability of certification and labelling to address landscape-scale costs and benefits of eco-agri-food systems. The assumption is that the activities at the farm level are scalable and yield relevant off-farm benefits, which is often not the case. The demand for eco-labelled products is in the main restricted to sophisticated and affluent consumers, typically in developed country markets. Shifting labelling from this niche sector to the mainstream is challenging, but a significant opportunity in terms of providing small-scale producers (in particular) access to markets.

While certification schemes for foods have succeeded in many parts of the world, they depend upon monitoring and transparency that is not reproducible in the street vendor and local market environment that are common in developing countries[47].

Deciding which type of policy to choose depends on the local policy context. Which stakeholders are affected by and/or have a voice in any change? What is the distribution of winners and losers arising from a proposed change, and are individuals within these groups ready or able to adapt and innovate? How do these systems interact with other systems in the same landscape and what is their aggregate impact on ecosystems and biodiversity? What are the mechanisms available for capturing the value of nature (e.g. market-based, information-provision, regulatory)? What are the tools for understanding strategies that maximize human livelihood development/ preservation within the 'green zone' of planetary boundaries[26]? What are the institutional and governance regimes? What are the factors that are key to expediting or hindering the adoption of change? Phase I of the TEEBAgFood study touched on these questions, but Phase II will do so more explicitly.

What Boxes 4.5-4.9 show is that there is a range of policy options that can be used to impact upon the eco-agri-food systems complex. The optimal choice of policy instrument depends on case-specific social, financial, ecological and economic conditions, and the institutional and governance conditions, i.e. what might be termed the 'policy space'. This is the space that TEEBAgFood will ultimately inform, toward creating real transformative change.

It is important to recall why TEEBAgFood requires the development of research and the appraisal of policy options: the call for the end of business-as-usual.

## A call for the end of business-as-usual and the need to act now

This Interim Report has shown that business as usual, i.e. neglecting the value of the positive and negative externalities of the eco-agri-food complex, will in turn lead to decisions that are undermining the productive capacity of ecosystems. There is a clear and present danger in that we are fast approaching (or indeed transgressing) planetary boundaries; some elements of the agri-food sector are contributing significantly to our collective pathway towards potential systemic 'overshoot and collapse'. The *Precautionary Principle*[48] should steer our collective mindsets and our private and public actions, but far too often the argument is made that we 'cannot afford sustainability in our agri-food systems', or that such a perspective is a form of neo-colonialism from the richer nations to stifle development in the developing world.

The first aim of TEEBAgFood is to make the case that it is in the best interests of individual farmers, agri-businesses, municipalities and governments to account for the previously economically invisible externalities and impacts in the eco-agri-food systems complex. This is first and foremost about self-interest. Failures to account for the benefits that ecosystems and biodiversity provide for food and agriculture leads to such benefits being eroded over time – and that time has already begun. It is the here and now. It is (for instance) about the adoption of appropriate Agricultural Knowledge, Science and Technology to provide solutions to today's problems of freshwater scarcity and poor water quality, and understanding that the core source of problems is likely off-farm. It is about agri-business responding today to consumers increasingly turning to eco-labelling to make informed decisions that are hitting their bottom line. It is about national governments recognizing that short term yield increases from agricultural encroachment adversely impact today on other economic sectors in the national economy.

So there is a need to act now out of self-interest, and because of today's problems. But there is also the need to take a medium-term perspective, and most projections are of worsening livelihood outcomes in farming, especially for the family farmer. We must design an economic system that operates effectively across generations, and even when self-interested behaviour does not coincide with societal interests.

## How can TEEBAgFood contribute to change?

The TEEBAgFood report will focus on developing the approaches (whether in terms of knowledge generation or policies) which are needed to allow decision makers at all levels to make choices that together will lead to a new scenario where human and ecosystem health outcomes are reinforced by an eco-agri-food systems complex that targets these through the products it generates and the way it delivers them. This is the high-level aspiration. To achieve this, TEEBAgFood will commission and leverage new research streams, develop a community of practice and apply a communication strategy.

### Commissioning and leveraging research on all aspects of the eco-agri-food systems complex

This chapter has set out some of the lessons learned from the exploratory studies, including gaps. In terms of research to recognize the value of ecosystems and biodiversity, we have signalled the need to have some more 'deep dive' assessments (c.f. Maasai Steppe case study), studies that look at integrated production systems including production practices (c.f. rice case study) and also a work stream on health externalities, particularly (but not exclusively) beyond the farm gate. All such analyses require scenario assessment and different types of modelling to support this (c.f. agro-forestry case study). Options include extensions of current sector foci and/or the addition of new production systems, especially mixed systems, and land degradation. All this work is on theoretical foundations.

There is also research – of a different nature – that needs to be carried out on policy appraisal, i.e. capturing values. This work stream may align directly with the case studies, e.g. what are the governance regimes, legal preparedness for and institutional arrangements around policy implementation in Tanzania to enable a switch to extended Ngitili agroforestry systems with increased tree cover, or to secure pastoralism in the Maasai Steppe? But there is also a need for policy research that is distinct from the case studies, e.g. drawing lessons from behavioural science to stimulate shifts in diets.

Linked to these two overarching research themes, TEEBAgFood intends to publish its two major reports ('TEEBAgFood Scientific & Economic Foundations' and 'TEEBAgFood Policies, Production & Consumption') in late 2016 and early 2017, respectively.

The first TEEBAgFood technical report ('Foundations') will set out the scientific and economic underpinnings of the evaluation of the nexus between the agri-food sector, biodiversity and ecosystem services, and externalities from agriculture on a global scale. It will need to connect ecological and agricultural science, and ecological and agricultural economics, in order to produce a state-of-the-art, comprehensive overview of existing thinking in these two areas.

A second technical report ('Policies') will draw from the scientific and economic foundations of its antecedent in order to provide a policy evaluation of different agro-ecological production systems in different socio-economic contexts. The Policies report will consider a wide range of policy interventions in the domains of development, food, climate, health, and energy, assessed across the entire value chain, from production to consumption. The policy questions that could be assessed are virtually limitless.

For instance, to what extent (if any) can the externalities of large scale livestock ranching in Brazil be compared and contrasted with small-scale pastoralism in Tanzania? What is the appropriate lens through which to view different types of production systems and agricultural practices? Efficiency? Equity and distributional issues as they affect rural livelihoods? Food security? Is it conceivable that, given OECD-FAO projections on population projections and changes in diet (to a more animal protein-rich diet) that up-scaling small-scale production could meet demand projections? Is this even the right question, i.e. should we be voicing concerns about food waste and also the appropriateness or otherwise of a meat-rich diet? If so what are the range and types of policy levers and can they be assessed in isolation?

We mention commissioning and leveraging research. This is linked to developing a TEEB Community of Practice.

### Developing a TEEBAgFood Community of Practice: A call to get involved

The TEEBAgFood vision statement is one that cannot be achieved by any one project or agency in isolation. In previous TEEB assessments, TEEB was highly successful in developing and mobilizing a community of practice around its core vision, i.e. determining the benefits of action and cost of policy inaction associated with conserving biodiversity and ecosystem functioning. Hundreds of scientists from multiple disciplinary areas provided pro bono inputs to TEEB, policy-makers made frequent reference to TEEB (including explicit mention in National Biodiversity Strategy and Action Plans), and the TEEB for Business Coalition (now The Natural Capital Coalition) was spawned.

TEEBAgFood has already shown the need to look at the eco-agri-food systems complex more broadly, commissioning research and generating policy change through multi-disciplinary and multi-sectoral work which brings together a community of practice and knowledge which will have the capacity to deliver benefits beyond the boundaries of the studies commissioned. As with the original TEEB study which has gone on to stimulate similar research in many countries and businesses around the world, it is intended that the TEEBAgFood community will do the same.

We have begun to develop a TEEBAgFood community of practice and hope that you, the reader, will join us in this journey. Please do send TEEBAgFood any evidence or share experiences that can contribute to our shared vision. Send us an email (teeb.agfood@unep.org) and follow us on social media (Twitter @teeb4me and facebook.com/teeb4me)

### Dissemination, outreach and communications through novel means

TEEBAgFood is collaborating with the Global Alliance for the Future of Food[49] and the Food Tank[50] to develop a communications and outreach strategy that can mobilize stakeholders to respond to the results of the study. This coordinated communications strategy allows access to dissemination via United Nations channels and associated high-level political fora, as well as the Global Alliance network which ranges from large corporations to organizations supporting grass-root activism across the globe. The Global Alliance membership includes Foundations that have a special interest in innovative media applications.

Using media of all kinds –from peer-reviewed academic journals through to social media – will allow the work of TEEBAgFood to reach a wide audience and have the impact we hope to achieve. We need to develop alternative pathways to bring about change. Food and agricultural systems touch all our lives in so many different ways, and so our outreach activities must be similarly varied and innovative – but also targeted. Again, we hope that the reader can contribute to this aspect of TEEBAgFood.

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# APPENDICES

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| APPENDIX IV | Ecosystem services and pastoralism in the Maasai Steppe |
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# APPENDIX I

# Abstracts of TEEBAgFood exploratory studies

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## RICE

This study is designed to provide a comprehensive economic evaluation of the ‘eco-agri-food systems’ complex, and to demonstrate that the economic environment in which farmers operate is distorted by significant externalities, both negative and positive and a lack of awareness of dependency on natural capital. The Food and Agriculture Organization of the United Nations (FAO) together with its partners, the International Rice Research Institute (IRRI) and Bioversity International as well as Trucost has applied the TEEB approach to the rice farming sector.

Rice production is essential to the food security and livelihood of around 140 million rice farming households and provides a range of ecosystem services beyond food production alone. At the same time, rice production has been linked to a range of different environmental impacts such as high GHG emissions, air and water pollution as well as a steady increase in water consumption. As these challenges are not independent, but rather interlinked, reaching them is likely to require trade-offs, and policy makers will need to make decisions on how to address them. The TEEB rice study has set out to inform policy by identifying which rice management practises and systems can help to reduce costs and increase the benefits linked to rice farming. Making the invisible benefits and costs visible will facilitate this decision-making process.

Suggested citation: Bogdanski, A., R. van Dis, Gemmill-Herren, B., Attwood, S., Baldock, C., DeClerck, F., DeClerck, R., Lord, R., Hadi, B., Horgan, F., Rutsaert, P., Turmel, M.S. (2015) Valuation of rice agro-ecosystems. TEEB Rice. Final report. UNEP/FAO, unpublished project report for The Economics of Ecosystems and Biodiversity (TEEB) global initiative for Agriculture and Food.

See the full publication here: www.teebweb.org/agriculture-and-food/rice

## LIVESTOCK

The study aims to provide evidence that will help to identify policy options for the transition towards increased food security with sustainable livestock production systems (poultry, beef and dairy), with particular emphasis on the role of smallholder farmers. Two separate methods were used: a 'top-down' approach focussing on the externalities of end products to identify the most material externalities and geographical hotspots worldwide; and a 'bottom-up' approach, focussing on ten livestock production systems and looking at natural capital/human systems linkages for one of the selected livestock production systems (pastoralism in Tanzania) in a holistic manner with a regional approach. The main conclusions are:

- The livestock sector is a major contributor to the global ecological footprint.
- Climate change, the loss of ecosystems and water pollution are examples of material unpriced externalities. Most of these impacts are related to beef production.
- Livestock systems are highly context-dependent, and thus difficult to compare.
- Smallholder dairy systems tend to have relatively high stocking rates and low animal productivity, leading to substantial environmental impacts (high GHG emissions, high emissions to water). Due to the land use, their impact on biodiversity is much larger compared to pastoralist systems.
- The case study of the Maasai steppe in Tanzania showed that pastoralism can conserve measurable ecosystem services and natural capital value, especially if the alternative is farming that will eventually lead to land degradation. However, productivity in terms of food per unit of land is low.

The message is clear: growth of the livestock sector presents many risks for natural capital, but there is much that can be done to face these risks. It is possible to produce animal products for the world population without losing this form of wealth, if the right path is followed. Efficiency improvements and the implementation of good agricultural practices represent opportunities to move in that direction. Second, a single livestock production system alone cannot supply animal products to the whole world. Finally, livestock systems are key components of agro-ecosystems and under specific management practices can enhance the provision of ecosystem services.

Therefore, mechanisms have to be developed to internalize external costs and incentivize good practices, which do not affect food security for the poor. Internalization will help market forces to steer the food sector towards a more sustainable track, where natural capital is leveraged to create wealth for current as well as future generations.

Baltussen W.H.M., T. Achterbosch, E.J.M.M. Arets, A. de Blaeij, N. Erlenborn, V. Fobelets, P. Galgani. A. De Groot Ruiz, R. Hardwicke, S.J. Hiemstra, P. van Horne, O. A. Karachalios, G. Kruseman, R. Lord, W. Ouweltjes, M. Tarin Robles, T. Vellinga, L. Verkooijen (2015) Valuation of livestock eco-agri-food systems: poultry, beef and dairy, 119 p, Wageningen University and Research center, Trucost & True Price, The Hague.

See the full publication here: www.teebweb.org/agriculture-and-food/livestock

## AGROFORESTRY

This study determined quantitative values of provisioning, supporting and regulating ecosystem services in agroforestry systems compared to conventional agricultural practices in sub-Saharan Africa, and the ramifications of changing these systems under different scenarios. Three case studies were used: cocoa agroforestry compared to full sun cocoa in Ghana, coffee agroforestry compared to maize in Ethiopia, and Ngitili compared to maize in Tanzania. Agroforestry provides scope for halting the conversion of forests to agriculture by enabling simultaneous production of provisioning and regulating services.

Compared to alternative options, agroforestry systems provide substantial amounts of provisioning services mostly from cash and food crops and tree products. The most important provisioning service from agroforestry systems is from cocoa and coffee cash crops in addition to which a variety of food values are generated. In addition, agroforestry systems provide almost half of the biodiversity services found in intact forests and store substantial carbon stocks with potential to generate revenue from the REDD+. Regulating and provisioning ecosystem services in agroforestry systems, although mostly in consumptive and non-market form, far outweigh those in alternative agricultural practices in the coffee and Ngitili cases. Therefore, strong opportunities exist for increasing the total carbon stocks and food security values in these systems by increasing tree cover to moderate shade level, provided that this is followed by efforts to enhance income. The reverse is true for cocoa agroforestry where tree cover results in substantial reduction in yield and revenues although the productivity of the full sun system is short-lived compared to the agroforestry alternative.

Recently, there has been a surge of interest in agroforestry as a candidate for REDD+ land use, and it has also long been recognised as a practice with strong potential for optimizing carbon sequestration, livelihood and food security concerns. Despite this, there has been a strong push from many governments as well as adoption decisions from many smallholders towards more simplified cash crop systems in lieu of more multifunctional agroforestry systems. This points to the need for strengthening policy and incentive mechanisms for promoting agroforestry and the ecosystem values the practice provides. REDD+ provides national level scope for investing in agroforestry carbon sequestration values with potential to bring together other policy and incentive mechanisms aimed at safeguarding ecosystem services in farming landscapes. Beyond carbon, various policy and incentive mechanisms can be applied to promote agroforestry, including strengthening of certification, use of fiscal instruments (tax exemptions or input subsidies), strengthening land and tree tenure rights and PES schemes.

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See the full publication here: www.teebweb.org/agriculture-and-food/agroforestry

## INLAND FISHERIES

The study developed a holistic assessment of different production and management scenarios in the inland capture fisheries and freshwater aquaculture sectors taking into account the impacts, externalities and dependencies between fish production, environment, social and economic systems. Three case studies in North America (Columbia River, CR), Asia (Lower Mekong Basin, LMB) and Africa (Lake Victoria Basin, LVB) provided an analysis of the economic value of the provisioning, regulating, supporting and cultural services of inland capture fisheries and freshwater aquaculture under existing and alternative water management scenarios. The ecosystems in the case studies support a wide array of ecosystem services. Fish production – through commercial capture, tribal, recreational and small-scale capture, as well as through aquaculture, is one of the most important provisioning services of these ecosystems. However, fish production is in competition with other water uses and is impacted by how water is managed.

Key competitors addressed in the study were hydropower generation (CR and LMB) and use and transformation of wetlands (LVB) for agriculture and urbanisation. The case studies demonstrated significant trade-offs between fish production and the other uses of these aquatic ecosystems. Externalities generated by hydropower generation and the unsustainable use of wetlands are substantially affecting fish production service in all cases.

Considering inland fisheries and freshwater aquaculture from an ecosystem services lens is necessary for informed management. Although inland fisheries and freshwater aquaculture provide much more than fish, their value is under-estimated. It is imperative that water management decisions recognize and encompass the services supplied by both aquatic ecosystems and inland fisheries and freshwater aquaculture. Thus, an ecosystem approach should become standard practice for the formulation of policies on water management and land use to ensure optimum benefits from the wide range of ecosystem services provided by aquatic ecosystems.

Brugere, C., Lymer, D. and Bartley, D.M. (2015) Ecosystem services in freshwater fish production systems and aquatic ecosystems: Recognizing, demonstrating and capturing their value in food production and water management decisions. TEEB Agriculture & Food, 272 pp, UNEP, Geneva

See the full publication here: www.teebweb.org/agriculture-and-food/inland-fisheries

## PALM OIL

The aim of the report is to demonstrate the relevance of hidden environmental and social impacts in palm oil production to businesses and policymakers. This is done by quantifying and placing monetary values on the negative impacts associated with the production of palm oil and palm kernel oil.

In the first stage of the study, there is a focus on the production of palm oil in eleven countries across Africa, Asia, Oceania, and South America. Impacts on human health and ecosystem functioning that arise from the emission of greenhouse gases, air, land, and water pollutants, as well as the use of water, and the generation of waste are quantified and then monetized. Some of the practices that are driving these impacts include the application of fertilisers and pesticides, as well as the type of land conversion. The second stage of the study quantifies and monetizes the negative impacts of different types of practices used in production processes in Indonesia. A number of scenarios were developed relating to: land conversion techniques; fertiliser application methods; whether methane is captured from palm oil mill effluent (POME) ponds and; social impacts arising from changing wages, salary, occupational health, and safety practices.

The main factors influencing the results in the study were the quantity and type of inputs used, the yield of fresh fruit bunches (FFB) per hectare, and the conversion rate of FFBs to palm oil. The results in the first stage provide businesses and policymakers with the magnitude of the impact in production locations, and also highlight the practices that cause impacts to human health and ecosystem functioning in each country. The study also provides intensity values which show the countries that have the greatest impact per tonne of palm oil produced. The second stage of the study showed that the choice of practices at various points of the production cycle can significantly influence the magnitude of the impact. For instance, converting rainforest to palm oil plantations can create significant human health impacts due to the formation of haze and inhalation of other air pollutants emitted during the land clearing process.

Shedding light on the hidden costs of palm oil production, and highlighting where costs can be minimised, shows that opportunities exist to redress the imbalance between private profit and public loss. Strong evidence is provided here to businesses and policymakers that urgent and decisive action is needed to make palm oil production a more sustainable food source for present and future generations.

Georgieva, A., Raynaud, J., Baldock, C., Fobelets, V. (2015) The business relevance for sustainability in palm oil production. Produced by Trucost and True Price on behalf of TEEB for Agriculture and Food.

See the full publication here: www.teebweb.org/agriculture-and-food/palm-oil

Photo: ©Flickr Farrukh

# APPENDIX II

# Valuation of rice agro-ecosystems

Photo: ©Thomas Sennett/World Bank

**Authors: Bogdanski, A., R. van Dis, Gemmill-Herren, B., Attwood, S., Baldock, C., DeClerck, F., DeClerck, R., Lord, R., Hadi, B., Horgan, F., Rutsaert, P., & Turmel, M.S.**

## Context

Rice production is essential to the food security and livelihoods of around 140 million rice farming households and provides a range of ecosystem services beyond food production. Five case study countries were selected that cover rice farming globally and represent a gradient from low intensified to high intensified production systems. Countries selected were: the Philippines and Cambodia in Asia, Senegal in Africa, Costa Rica in Latin America and California the US in North America. According to FAOstat[1], Cambodia was the least intensified country with 3.3 tonnes per hectare in Cambodia and the US had the most intensified production with 9.5 tonnes per hectare.

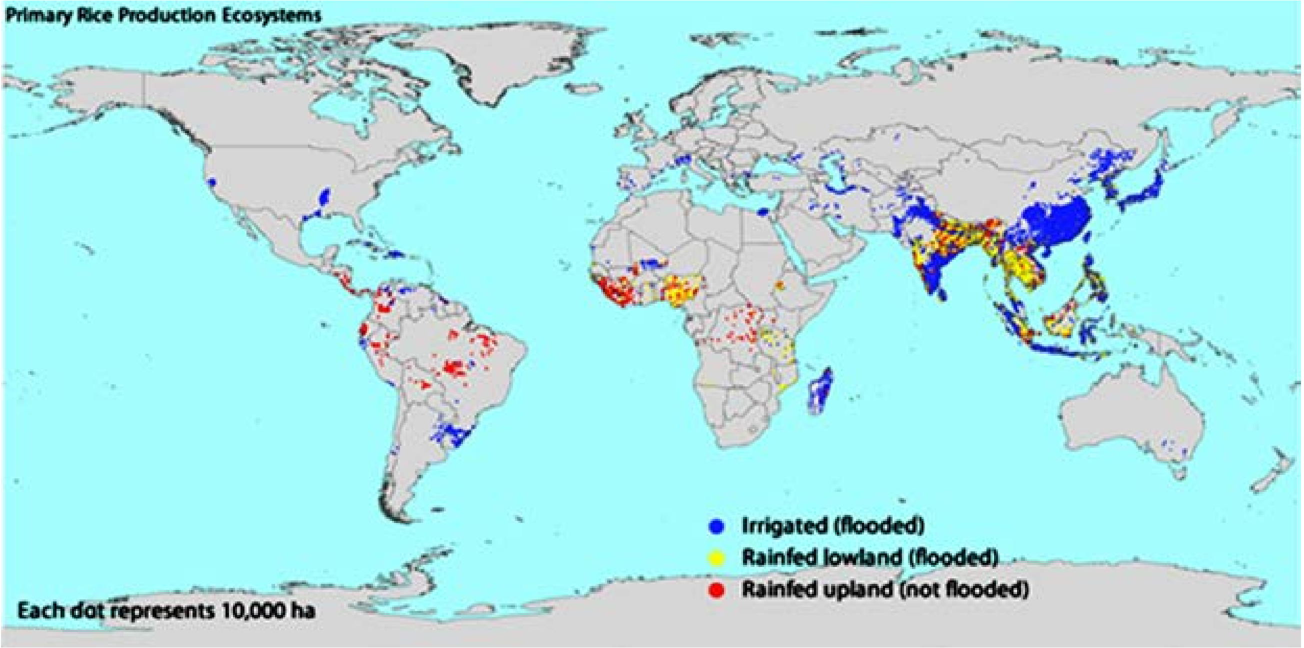
A rice production system typology was developed. Rice systems were distinguished by growing environments (Irrigated Lowlands; Rainfed Lowlands; and Rainfed Uplands) (Figure 1) and by management systems and practices.

The study has set out to identify farm management practices that offer the best options to reach synergies, and reduce tradeoffs between different management objectives. Several scenarios (Table 1) were applied to show the effect of the various farm management practices on different environmental and/or agronomic variables:

1. The baseline scenario describes a conventional management approach, for instance herbicide use to combat weeds.

2. The alternative scenario describes a farm management practice that is expected to decrease an environmental impact or to increase an ecosystem service. For instance, instead of herbicide use, hand weeding or biological control could be practiced.

Figure 1 Map of different rice production systems globally, showing the considerable extent of irrigated rice (blue)



Source: IRRI (2009) 'Rice Growing Environments', *Rice Knowledge Bank*, accessed on 18 November 2015 [http://www.knowledgebank.irri.org/submergedsoils/index.php/rice-growing-environments/lesson-2].

Table 1 Practice and system comparisons included in the rice study

| Management practices (Scenarios) | | |
|---|---|---|
| **1. Preplanting** | Land preparation | Dry tillage – puddling |
| | | Land levelling – no levelling |
| | | Minimum soil disturbance – conventional tillage |
| | | No tillage – conventional tillage |
| **2. Growth** | Growth | Direct seeding – transplanting |
| | | Dry seeding – wet seeding |
| | Water management | Low irrigation frequency - high irrigation frequency |
| | | Improved water management - continuous flooding |
| | Soil fertility management | Reduced mineral fertiliser use - high mineral fertiliser application |
| | | No fertiliser use – mineral fertiliser application |
| | | Organic fertiliser application - mineral fertiliser application |
| | | Organic fertiliser application - no fertiliser application |
| | | Mineral + organic fertiliser application – mineral fertiliser application only |
| | Weed management | No weed control - herbicide use |
| | | Biological weed control + hand weeding - herbicide use |
| | | Hand weeding – herbicide use |

| | | |
|---|---|---|
| | | Reduced herbicide use – higher herbicide input |
| | Pest and disease management | No pesticide use - pesticide use |
| | | Reduced pesticide use – higher pesticide input |
| **3. Postproduction** | Residue management | Winter flooding – no winter flooding |
| | | Straw incorporation – straw burning |
| | | Straw baling and removal – straw burning |
| | | Straw rolling – straw burning |
| **Management systems** | | |
| | | SRI – Conventional agriculture |
| | | Organic agriculture - Conventional agriculture |

These management practices (scenarios) and management systems were then mapped onto benefits and costs, as set out in Table 2.

**Table 2 Benefits and costs related to rice cultivation**

| BENEFITS | COSTS |
|---|---|
| **Rice grain (Producer price of food)** | Water pollution |
| **Rice straw (Nutrient value)** | Air pollution |
| **Rice husk (Energy value)** | Land pollution |
| **Pest control** | Water consumption |
| **Nutrient cycling and soil fertility** | GHG emissions |
| **Carbon storage*** | Labor |
| **Ecological resilience (pests)** | Fertiliser |
| **Recreational and tourism opportunities** | Pesticides |
| **Flood prevention*** | Fuel* |
| **Water recharge*** | Capital costs (e.g machinery)* |
| **Habitat provisioning** | Irrigation water* |
| **Dietary diversity** | Seeds* |

[*=could not be covered due to data limitations]

Academic literature review coupled with biophysical modelling was used to estimate impacts on both human health and ecosystem functioning for the baseline versus the alternative scenario. One limitation of the rice study is that this assessment was limited to those impacts outside the farm gate, i.e. the emission of air, land and water pollutants, and changes in water availability.

In the last methodological step, management practices were upscaled from field to country level. All results – costs and benefits – are given on a per hectare basis. Knowing the rice farming area in each country and the percentage of irrigated lowlands, rainfed lowlands and rainfed upland systems, it was possible to calculate the production area in each rice growing environment. Multiplying this area by the difference in impact between two management practices allowed the estimation of aggregate gains, losses or savings.

**Box 1 Scenario analysis: SRI versus conventional management**

The System of Rice Intensification (SRI) includes intermittent flooding as part of the production package. The system advises transplanting of young (eight to ten days old) single rice seedlings and applying intermittent irrigation and drainage to maintain soil aeration. In addition, the use of a mechanical rotary hoe or weeder to aerate the soil and control weeds is encouraged.

If Senegal was to change all of its irrigated lowland systems from conventional management to SRI, 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 – a clear synergy. If the Philippines were to change all their rainfed lowland systems from conventional management to SRI, the rice producer community would gain a total of US$750 million through yield increases. No water consumption costs result from this farming system as it is dependent on rainfall only.

If Cambodia was to change all its rainfed lowland systems from conventional management to SRI, the rice producer community would gain a total of US$801 million through yield increases. Like the Philippines, the Cambodian system is only rain-fed and thus there are no water consumption costs. While the concept of SRI was originally developed under irrigated conditions, these systems have also been adapted to rainfed lowland paddies. The SRI in rainfed lowland systems differ from the conventional management system in several parameters, but the focus of included research studies is on modified water and nutrient management. In these studies, SRI fields are moist during transplanting and drained several times during the growing season. Trade-offs are likely to occur between $CH_4$ emissions when the fields are flooded and $N_2O$ emissions when fields are drained.

Data collected in rainfed lowlands systems in Cambodia led to a value of rice production of US$1099 per hectare when conventional management was practiced and US$1422 when SRI was implemented[2, 3, 4, 5, 6]. The monetary valuation for GHG emissions in Cambodia's rainfed lowlands paddies resulted in an average cost of US$690 per hectare of rice production for conventionally managed systems and US$586 for SRI – a reduction in costs of 15 per cent. If all rice farmers in rainfed lowlands systems in Cambodia would change to SRI, they would increase the producer price value of rice by US$801 million. At the same time, society would incur lower GHG emissions costs (US$258 million).

## Results

### *1. Increasing rice yields versus reducing water consumption*

Worldwide, about 80 million hectares of irrigated lowland rice provide 75 per cent of total rice produced. This predominant type of rice system receives about 40 per cent of the world's total irrigation water and 30 per cent of the world's developed freshwater resources. The dependence on water of the rice farming sector is a huge challenge as freshwater resources become increasingly depleted due to competing water uses from the residential and industrial sector and as rainfall is increasingly variable due to climate change. More efficient water use is necessary, yet it carries a number of tradeoffs, as this study has shown.

The study sought to assess and evaluate trade-offs resulting from irrigation management, soil preparation and crop establishment on rice yields, on the one hand, and water consumption, on the other.

The study analysed the change in yield and water consumption under continuous flooding, alternate wetting and drying, during aerobic soils production and the system of rice intensification (SRI). The study further compared dry tillage to puddling, and direct seeding to the transplanting of seedlings. Figure 2 shows the effects of SRI and conventional management on irrigated (IL) and rainfed lowland (RL) system in Senegal, Cambodia and the Philippines.

### *2. Increasing rice yields versus reducing GHG emissions*

Global estimates attribute about 89 per cent of rice global warming potential to $CH_4$ emissions which are due to flooding practices in irrigated and rainfed lowland systems (RL)[7]. To a much smaller degree, the production and application of N-fertilisers contributes to the rice global warming potential. Emissions from rice straw burning impact global climate change. In addition to rice production being a major emitter of GHGs, rice systems also sequester carbon via soil organic carbon in topsoil. Yet overall, rice production is a net producer of greenhouse gas emissions.

This study sought to assess and evaluate the trade-off resulting from irrigation water management, residue management, fertiliser application and the choice of rice varieties on rice yields on the one hand, and GHG emissions on the other. The value of rice production was estimated on the basis of the country specific producer price received per ton of paddy rice. Primary data on GHG emissions as reported in the peer reviewed studies was used to model the GHG emission costs. The cost of GHG emissions was valued following the Trucost GHG methodology which provides a valuation coefficient for $CO_2$ equivalent emissions based on the social cost of carbon emissions.

Figure 3 shows the effects of SRI and conventional management on the producer price of rice and GHG emission costs in RL systems in Cambodia.

Figure 2 Comparison of the effects of conventional management and SRI on the revenue and environmental and health costs of water consumption per hectare in irrigated lowland systems (IL) and rainfed lowland systems (RL)

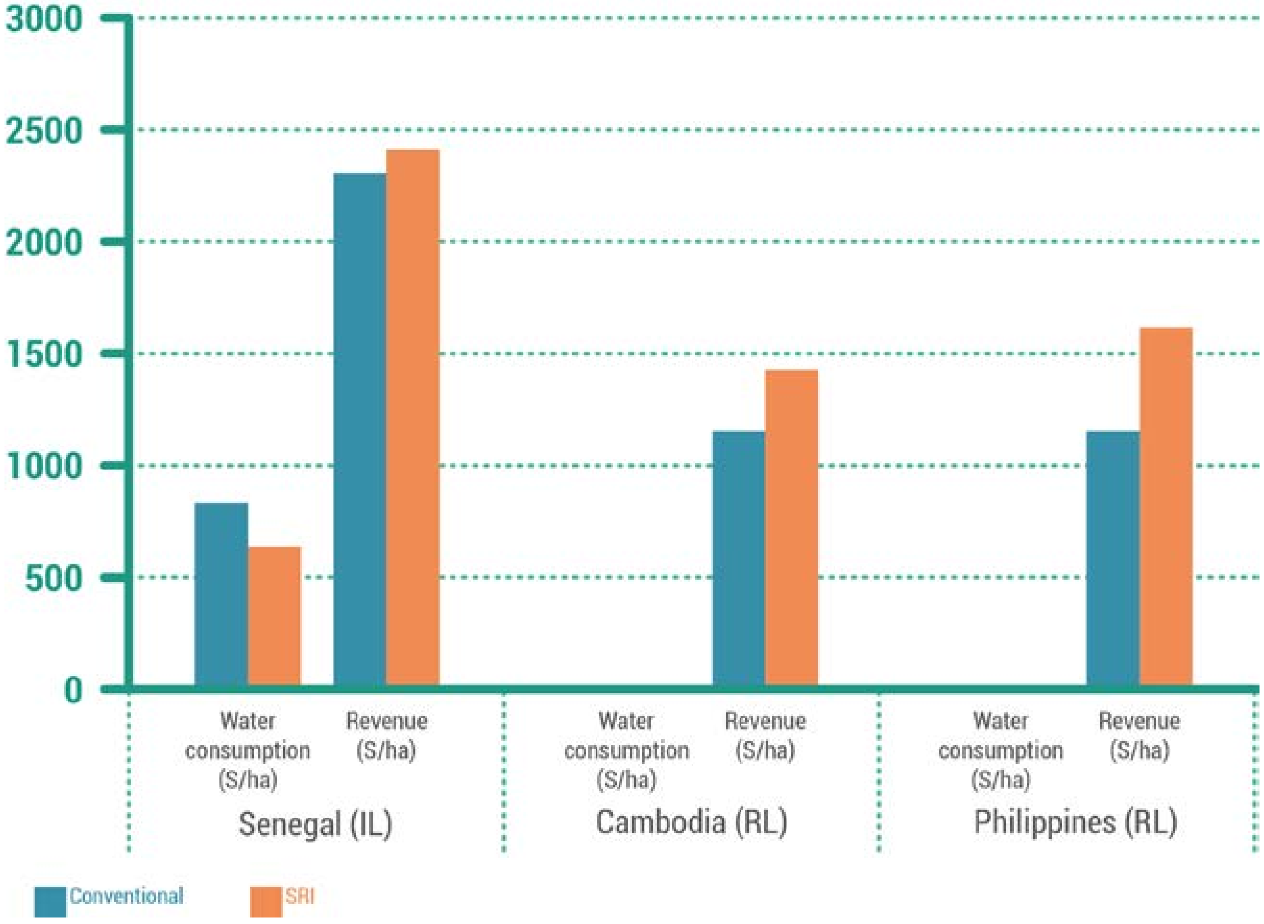
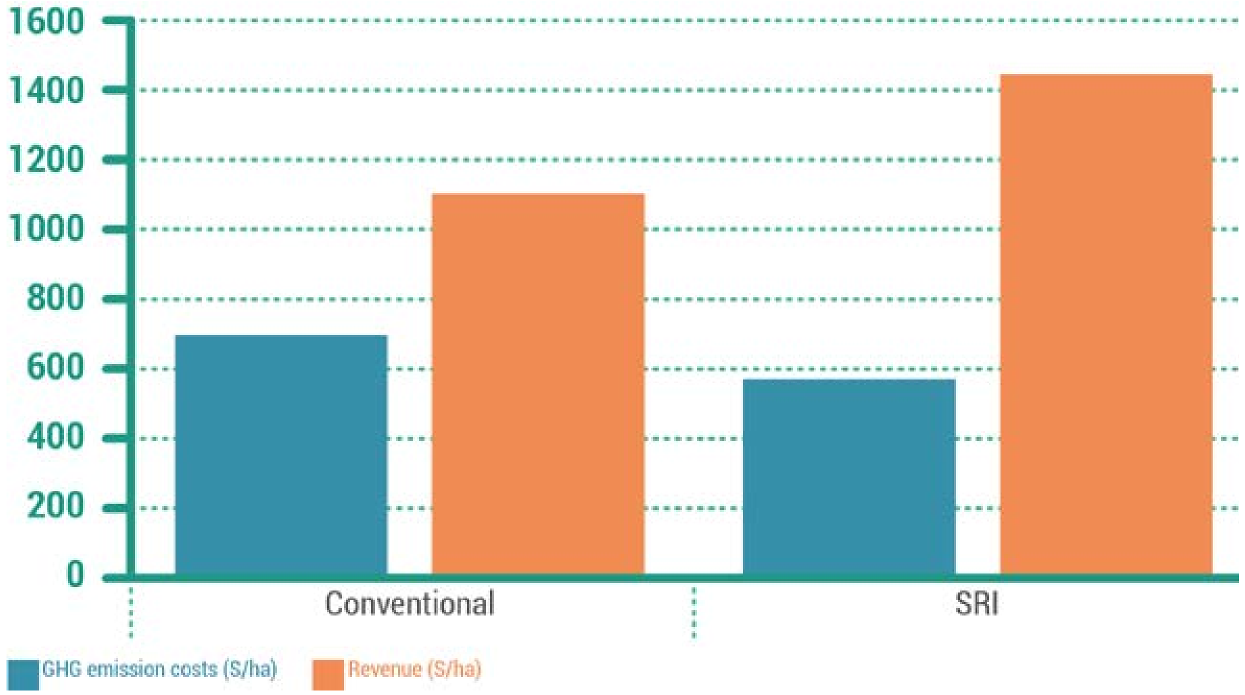


Figure 3 Comparison of the effects of conventional management and SRI on the revenue of rice production and social costs of carbon emissions per hectare in rainfed lowland systems



### Lessons learned

The results show that the development of a solid typology is key to valuing externalities from the agriculture and food sector. Farming is very diverse, and so are the environmental impacts and ecosystem services that are linked to each type of production. Typologies therefore need to zoom in on management practices and systems as much as possible to reflect the reality of (rice) farming and the diversity of its values. It would be illusionary to think that there is one farming sector that leads to one specific set of positive and negative externalities.

The study results further confirm that a tradeoff analysis is mandatory if the study is to inform policy. Focusing on environmental impacts or ecosystem services alone without considering the impacts on food production, for example, would fail to provide a sound basis for decision making. One therefore needs to value all potential benefits and costs at the same time, providing a holistic assessment of a farming system.

This requires that experimental studies provide a comprehensive data set that goes beyond food production alone as is typically the case in agronomic studies. Likewise, ecological and environmental studies need to record agronomic values, including yields, and widen their often restricted focus on natural resources and biodiversity alone. Furthermore, there is a need to enhance models that can mimic agro-ecological processes where specific data points are missing, and where field studies are not feasible.

There is also a need to improve current valuation methodologies, as there is a clear lack of those that can value agroecosystem benefits as opposed to costs. Furthermore, one needs to better adapt current models for monetary valuation to the realities of developing countries. Last but not least, there is a need to link economic valuations to market costs, and avoided costs for the farmer.

While these challenges still need to be addressed before the food and agriculture sector can be valued holistically, there is the potential to link the valuation results to the System of Environmental-Economic Accounting (SEEA) for Agriculture. While ecosystem valuations usually focus on the local level, ecosystem accounting methods aim to aggregate information to produce statistical results at the national level. Since both areas of expertise are still in its infancy, it is timely to join forces now in order to follow a coherent approach in the future.

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[4] Ly, P., Jensen, L., Bruun, T., Rutz, D & de Neergaard, A. (2012) 'The system of rice intensification: adapted practices, reported outcomes and their relevance in Cambodia', Agricultural Systems, 113, 16-27.

[5] Ly, P., Jensen, L., Bruun, T. & de Neergaard, A. (2013) 'Methane ($CH_4$) and nitrous oxide ($N_2O$) emissions from the system of rice intensification (SRI) under a rain-fed lowland rice ecosystem in Cambodia', Nutrient Cycling in Agroecosystems, 97(1-3), 13-27.

[6] Satyanarayana, A., Thiyagarajan, T. & Upholf, N. (2007) 'Opportunities for water saving with higher yield from the system of rice intensification', Irrigation Science, 25(2), 99-115.

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Photo: ©Tri Saputo/CIFOR

# APPENDIX III

# Livestock ‘bottom up' assessment

Photo: ©Shutterstock

**Authors: Baltussen W, E. Arets, A. de Blaeij, T. Vellinga (WUR) P. Galgani, O. Karachalios, A. de Groot-Ruiz (True Price)**

## Context

The livestock sector is of growing global importance. It is estimated that meat production will increase by 76 per cent between 2005/2007 and 2050[1], and that the sector contributes significantly to a broad set of issues (land degradation; loss of biodiversity; water scarcity; climate and water pollution) at the global level[2]. Livestock production systems differ markedly both between and within countries. A typology of ten ‘typical’ (yet hypothetical) livestock production systems were selected:

1. **Broiler production:** backyard production (Tanzania); family farm (Indonesia); and industrialised (the Netherlands)
2. **Beef systems:** pastoralism (Tanzania, India) and grassland-based system with feedlot finishing (Brazil)
3. **Dairy systems:** smallholder mixed systems (Tanzania, India, and Indonesia) and a highly specialized medium scale system (the Netherlands).

The research consortium attempted to characterize a particular eco-agri-food system in-country, but every farm is different. The idea is to develop a set of farm characteristics (yield, farm inputs etc.) and then evaluate the production system based on these characteristics (which may or may not be applicable across the country).

Therefore, using ‘Tanzanian backyard broiler production’ as a tagline for the system does not mean that each and every such system in Tanzania will have the modelled ecosystem impacts and dependencies. This is an important caveat that will apply equally in Phase II of the project. We cannot say that ‘Tanzanian pastoralism is better/worse than the Indian equivalent’ – only that the system as modelled based on our assumptions and data limitations is better/worse for one or more indicator.

For example, dairy systems can be compared with pastoralist systems that have a primary focus on beef production. All dairy systems considered specialize in milk production and also produce meat. Three out of the four dairy case studies are smallholders in Tanzania, India and Indonesia, each assumed to have five cows. In Tanzania and India, farms are assumed to rely heavily on crop residues or roadside grass/grazing, while in Indonesia relatively high inputs of synthetic fertiliser and concentrates are used and zero-grazing systems are common. The 'typical' Dutch dairy farm system is assumed to have 85 cows. It is 'land-based' in that a minimum of 80 per cent of roughage is produced on-farm (grass and sometimes maize), and it is a 'family farm' in that labour is predominantly from family members. It has high input levels (compared to the three smallholder systems) for fertiliser, chemicals, concentrates, artificial insemination, financial capital, machinery and medicines.

Although smallholders are often associated with low input systems, high stocking densities at farm level is becoming more normal. For the smallholder systems in scope, there were assumed to be two hectares of land per farm, but this farm size is already above average in many countries[3]. Due to the cattle to land ratio in the smallholder systems, the input of nutrients at farm level via external feed (grass from roadsides, by-products, concentrates, bought crop residues) is high, e.g. over 100 kg N per ha per year. Agricultural statistics show that fertiliser inputs are high in Asia and low in Africa[4], implying that the smallholder mixed systems in scope are relatively high input systems and comparable (in per hectare terms) to the high input levels in the Dutch dairy farm.

There is a strong contrast with the pastoral systems with stocking rates of 0.33 animals per ha against the mixed systems with 2.5 cows per hectare. The pastoral systems are indeed low-input systems with less than 1 kg N per ha (see Table 1).

**Table 1 Characteristics of dairy mixed feed livestock systems and two pastoralist livestock systems**

| Country | Type | Cattle (number) | Hectares (ha) | N-input feed (kg N /ha) | N-input fertiliser (kg N/ ha) | Total input (kg N/ha) |
|---|---|---|---|---|---|---|
| **Indonesia** | Mixed | 5 | 2 | 47 | 64 | 111 |
| **India** | Mixed | 5 | 2 | 137 | 100 | 237 |
| **Tanzania** | Mixed | 5 | 2 | 157 | 4 | 161 |
| **Netherlands** | Mixed | 85 | 40 | 108 | 150 | 258 |
| **Tanzania** | Pastoral | 300 | 1000 | 0.2 | 0 | 0.2 |
| **India** | Pastoral | 100 | 300 | 0.1 | 0 | 0.1 |

Given this typology of dairy systems, an analysis of ecosystem/social system/livestock impacts and dependencies was carried out, and Table 2 provides a synopsis.

**Table 2 The degree of valuation (not valued, qualitative, quantitative and monetised) per type of relation between livestock systems/ ecosystems and social systems**

| Relation from/to | Not valued | Qualitative | Quantitative | Monetised |
|---|---|---|---|---|
| **Livestock system/ outputs** | | 1. Raw materials<br>2. Agro tourism | | 1. Food |
| **Livestock system/ social system** | 1. Food security | 1. Health effects food<br>2. Zoonoses<br>3. Antibiotic resistance<br>4. Cultural heritage | | |
| **Social system/ livestock system** | 1. Biotechnology | 1. Breeding<br>2. Machinery<br>3. Pesticides and drugs<br>4. Labour | 1. Fertiliser as part of nutrient balance | |
| **Ecosystem/ livestock** | 1. Moderation of extreme events<br>2. Pollination | 1. Genetic variability<br>2. Water purification<br>3. Erosion prevention<br>4. Pest control<br>5. Carbon sequestration | | 1. Water irrigation |
| **Livestock/ ecosystem** | 1. Soil creation | 1. Soil erosion | 1. Manure<br>2. Nutrient recycling<br>3. Land use<br>4. Species reduction<br>5. Health externalities<br>6. Habitat encroachment | 1. Water pollution<br>2. Greenhouse gas emissions |

The exploratory studies were commissioned before the TEEBAgFood Framework was developed and contributed to the discussion on the final Framework. The rows in Table 2 provide categories of interactions within the eco-agri-food systems complex and although they broadly map onto the Framework, the mapping is imperfect. (This will be addressed in Phase II.) TEEBAgFood is concerned with the full gamut of impacts and dependencies, and some of these can only be expressed in qualitative terms, whereas others may be quantified and/or valued. Some are important but have not been assessed in this Phase I exploratory study (column 2 – ‘Not valued’).

The main global data sources come from FAOstat and inputs of the GLEAM model of FAO[5]. Country-specific data were used for valuing water pollution. In order to make like-for-like comparisons across systems, an appropriate functional unit is required. For the livestock study, this is one kilogram of animal protein.

## Results

Selected results from the evaluation of dairy systems are provided in Table 3.

**Table 3 Overview of quantified and valued impacts**

| Impact | Tanzania smallholder | India smallholder | Indonesia smallholder | Dutch family farm | Tanzania Pastoralist | India Pastoralist |
|---|---|---|---|---|---|---|
| **Number of lactating cows** | 5 | 5 | 5 | 85 | 300 animals | 100 animals |
| **Output** (kg of milk) | 7,500 | 5,000 | 7,000 | 700,000 | 1,125 | 21,250 |
| **Output** (kg of meat) | 640 | 550 | 815 | 15,800 | 12,676 | 3,665 |
| **Costs of GHG externalities** (USD/kg protein) | 12.80 | 18.20 | 13.60 | 5.40 | 34.50 | 41.30 |
| **Land use** ($m^2$ per kg of protein) | 1,231 | 275 | 59 | 23 | 10,913 | 5,574 |
| **Biodiversity weighted land use** (MSA.ha/ kg ) | | | | | | |
| **Pastures** | 0.005 | 0.003 | 0.001 | 0.001 | 0.05 | 0.08 |
| **Crop land** | 0.053 | 0.015 | 0.004 | 0.001 | 0.01 | 0.005 |
| **TOTAL** | 0.058 | 0.018 | 0.005 | 0.002 | 0.06 | 0.085 |
| **Nitrogen leaching** (kg N per ha) | 97 | 37 | 14 | 118 | 6 | 9 |

Erratum: Due to a copyediting error, the fourth row of Table 3 ('Costs of GHG externalities') has been changed from the print version to include a unit of measurement and correct figures.

### *Provisioning ecosystem services for direct consumption*

The output of the three smallholder snapshots with five cows is 7,500 kg of milk per year for Tanzania and 7,000 kg in Indonesia, but only 5,000 kg per year in India because of poor feed quality (a large proportion of crop residues) and periodically feed shortages. The Dutch farm produces about 700,000 kg of milk which is almost completely sold to the milk processing industry. In Tanzania much of the milk is for home consumption or sold locally on the informal market, whereas in parts of India the supply chain is better developed.

Besides milk, all four systems produce meat from slaughtered cows, male calves, and heifers not used for replacing cows. The amount varies per farm from 550 kg of meat in Indonesia to 15,800 kg in the Netherlands, where all the meat is sold to slaughterhouses. In Indonesia and Tanzania a proportion of the meat is used for home consumption. There is less beef consumption in India because cattle are considered sacred in the Hindu religion, leading to a very high number of unproductive cattle (but with high cultural value). Buffaloes are not considered as sacred and are slaughtered for consumption in India and for export.

For all smallholders systems in this study, dairy production is important for the diet of the family and local communities (with the exception of meat in parts of India). This is critically important as TEEBAgFood is not only concerned with yield levels but the distribution of benefits (and costs) from production. The opportunities for smallholder farmers to access and afford sources of animal protein may be limited out with the production from their own farms.

### *Biodiversity impacts*

Biodiversity impacts are assessed based on the indicator "Mean Species Abundance of Original Species", MSA, which is used within the GLOBIO3 modelling framework[6]. What is assessed in the biodiversity modelling is the (remaining) MSA for a given type of land use relative to a natural reference situation and the MSA loss (1-MSA). As a result MSA is a relative indicator between 0 and 1 and in simple terms might be described as an indicator of 'naturalness' in a certain location. Estimating first the number of hectares of a given land use type needed per kg protein, and then the MSA loss for each hectare of that land use type converted, allows the development of a biodiversity footprint. In order to allow comparisons between systems the indicator MSA.ha is used; 1 MSA.ha is equivalent to one hectare of land that has lost 100 per cent of its diversity.

Mixed dairy systems in Tanzania, Indonesia and India have a limited direct impact on biodiversity and ecosystems. Per unit of land used, these impacts are very small. The cows in the mixed dairy systems, however, are assumed to be kept indoors. Therefore the Indirect impacts– through production of feed – are substantial and depend on the location and intensity of crop production. Among the mixed dairy systems the MSA losses per ha used for feed production were found to be lowest for the Tanzania mixed system (note these are not presented in the summary Table 3). However the total amount of land and inputs needed per kg protein produced were also highest in the Tanzanian system (Table 3, land use). As a result the combined direct and indirect impact expressed as MSA.ha per kg of protein in the four mixed systems ranges from 0.002 in the Netherlands to 0.058 in Tanzania (Table 3).

The main differences between the dairy systems are caused by the impact on crop land and not on pastures. The low impact per area for the Tanzanian system (not presented in Table 3) indicates that these systems may better protect ecosystems functions and integrity locally, but at the same time the large areas needed for production has larger overall biodiversity impacts. Any shift in smallholder systems should try to combine the low impacts per ha with higher protein productivity.

### *Climate externalities of livestock production systems*

GHG externalities for dairy systems in the selected snapshots vary from 5.4 USD/kg protein for the Dutch situation to 18.2 USD/kg protein for the Indian situation. In line with recent evidence[7], the analysis also shows that GHGs released as part of animal husbandry processes are primarily associated with (I) enteric fermentation in dairy systems with ruminants, (II) organic and synthetic fertiliser and, to a lesser extent, (III) fossil fuels related to transport. The GHG emissions per animal are lower in the smallholder systems, but expressed per kg of animal protein, the common unit to compare these emissions, GHG emissions in the smallholder systems are higher compared to the specialised highly productive dairy system considered. The ranking across systems might change if mixed crop-livestock system were assessed, looking at the whole farm instead of just the livestock component.

### *Carbon sequestration*

In pastures, more carbon is fixated than in arable land. All dairy systems examined use a combination of pasture (in the case of Indonesia without grazing) supplemented with crop residues in smallholder systems and with concentrates in the Dutch system. Intensification of dairy systems often leads to a shift to relatively more crop (by-) products. Carbon sequestration will decline if pastures are partly replaced by crop production.

### *Ecosystem externalities of livestock production systems*

Land occupation varies from 23 $m^2$ per kg of protein in the Dutch system to 1231 $m^2$ per kg of protein in Tanzania. This difference is caused by differences in crop productivity (low crop yield and hence low yields of crop residues in arid Tanzania compared to managed pastures in the temperate climate of the Netherlands) and by differences in animal productivities (kg protein per cow). Land occupation per se should not be considered a negative externality. For instance there is considerable evidence[8, 9] that forcing pastoralists from communally-managed rangelands is detrimental not only to their livelihoods but also to ecosystem functioning (and also to cultural heritage).

Although the three smallholder snapshots use more land/kg protein, their nitrogen footprint is lower than the more intensive Dutch system. Nitrogen leaching varies from 14 kg per ha in Indonesia to 118 kg per ha in the Netherlands. Because the effects of nitrate leaching are local, the emissions per hectare are important and emissions per unit of produce are only part of the story.

## Lessons learned

The typical dairy system in a country is context depended (soil, water, climate, availability of capital, breeding, supply chain structure, etc.) and as such the substitutability of dairy systems is low. Copying one 'efficient' system to another region is difficult. The same dataset can give differing rankings across the systems depending on the unit of account, and in Phase II we will consider the best alternatives, particularly for mixed systems. The evidence suggests that smallholders can have a high impact on natural capital if they operate on a high input-low output basis per ha of land. The low feed efficiency and the lack of proper manure management leads to high externalities per ha and also per kg of animal protein produced. Smallholders can however perform better in terms of water pollution. Further, it is important to note that the protein produced is more likely to be locally consumed in these smallholder systems, and this has implications for food security that are not captured in the raw data.

The raw data for the pastoralist systems appears to indicate that the relative performance of these systems is poor but these data are based on externalities per unit of output, and this is arguably not the most appropriate unit of account to apply in the comparison. For instance, although the biodiversity impact MSA ha/kg of animal protein is high, the biodiversity impact per ha is amongst the lowest. This means that the ecosystems in which these systems are applied remain relatively intact and as a consequence are able to provide many other ecosystem services. Such systems are not geared to providing protein in large quantities to people outside the system, but they are well suited to meet local demand.

Although the comparisons in this case study are useful, the data collected and analysed does not include the social and risk uncertainty dimensions of the TEEBAgFood Framework (see Chapter 3). Thus the livelihoods dimension (the significance of livestock-based incomes is very high), the employment/migration dimension, the cultural significance of pastoralism etc. will need to be counterweights to milk and beef productivity statistics and these are not value components that can be assessed on a per unit of output basis.

It is for these reasons that in TEEBAgFood Phase I we commissioned a ‘deep dive' into Tanzanian pastoralism so as to be able to add to the results from the overall livestock study (this Appendix), and this is discussed further in Appendix IV.

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Photo: ©Dustin Miller

# APPENDIX IV

## Ecosystem services and pastoralism in the Maasai Steppe

Photo: ©Flickr/Harvey Barrison

**Authors: P. Galgani, O. Karachalios, A. de Groot-Ruiz (True Price)**

### Context

Herds of Maasai pastoralists graze in the Maasai steppe, one of the regions with the highest concentration of wildlife in Tanzania. This area hosts some of the most visited national parks in Tanzania. Traditionally, cattle and wildlife make use of the Maasai steppe for feeding, as both wild animal populations and pastoral systems are highly adapted to the extreme conditions of these arid grasslands. In the past 40 years, agricultural land cover has been expanding rapidly owing to both inward migration from other regions in Tanzania, and traditional nomadic local populations settling down to establish farms in the region. This transition is influencing the landscape of the region on several levels. Arable farming is gradually closing corridors to fertile grasslands for both wildlife and herders. Furthermore, today's farming practices have been shown to lead to land degradation[1], which is related to a reduction of stored carbon.

Policy makers face a critical trade-off regarding land conversion in the Maasai Steppe. Expanding sedentary agriculture may contribute to meeting immediate food needs but causes a shift in the region's landscape, and thus changes in key ecosystem benefits. These changes affect both local populations and the global community. TEEBAgFood investigated the projected values of different land conversion scenarios over time, to inform the trade-offs that policymakers face.

### Methodology

The case study focuses on the value to beneficiaries situated within the region studied, i.e. local communities (but also assessed changes in carbon sequestration and storage). What is critical for TEEBAgFood is to value the contribution that well-functioning ecosystems alone make to local livelihoods; we have to distinguish the role of ecosystems in value addition from that of labour and other inputs.

Local biophysical and market values are used if available; when local data were not available, the analysis exclusively uses data from comparable regions, such as other rural parts of Tanzania or the Maasai region in Kenya. The list of ecosystem services that are quantified and valued can be found in Table 1 below. The last column shows those that were considered potentially relevant but were not included due to research constraints.

Table 1 Ecosystem services in and out of scope

| Crops and livestock | Traded and subsistence products | Recreation | External benefits | Out of scope |
|---|---|---|---|---|
| **Beef** | Honey and beeswax | Tourism in National Parks | Carbon storage | Subsistence hunting |
| **Cow milk** | Gum | | | Recreational hunting |
| **Goat meat and milk** | Medicinal plants | | | Blood from cattle |
| **Maize** | Charcoal, firewood, thatch and poles | | | Water cycle regulation |
| **Beans** | Wild herbs and vegetables | | | |
| **Animal skins and hides** | Drinking water | | | |

The value of ecosystem services were calculated for three types of land use: rangeland, agricultural land and national parks. Three different scenarios of possible futures were developed in relation to land-use change:

1. Business as usual expansion of agriculture, leading to the conversion of all land available for farming within ten years [HI scenario]
2. Expansion of agriculture at half the speed of business as usual [MID scenario]
3. Lower land conversion rate with further conversion being halted within 20 years, below critical thresholds for ecosystem functioning [LOW scenario]

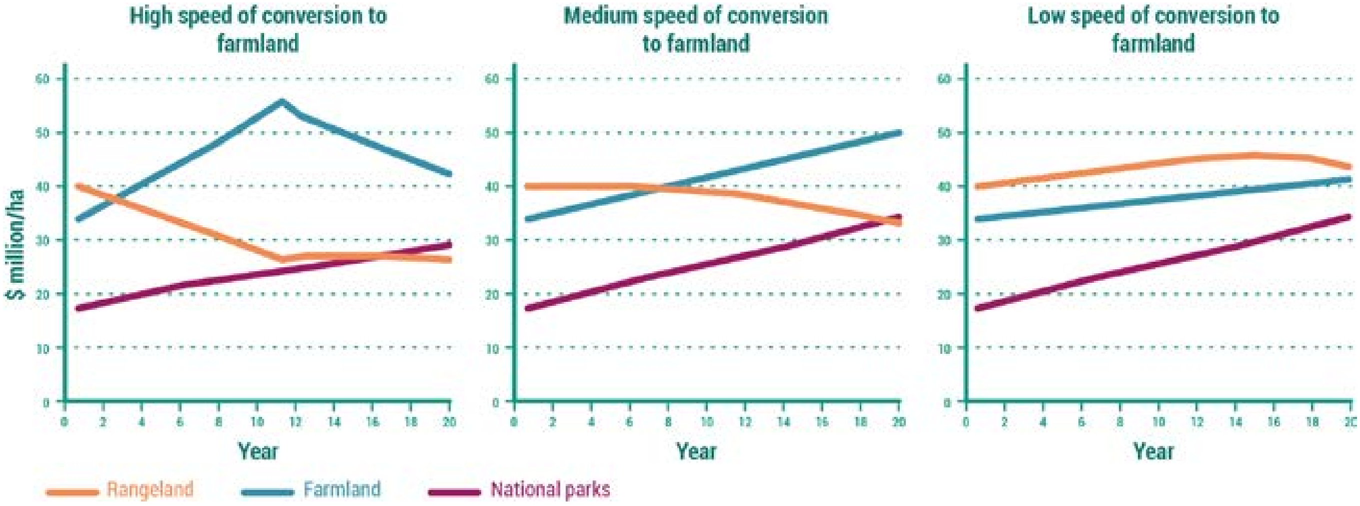
## Results

The analysis was over two time horizons: (i) 0-20 years when land use is assumed to change, and (ii) from year 21 onwards when land use is assumed in the model to be at a steady state. The results for the first period are summarized in Figure 1.

Livestock keeping in rangelands and crop production are the two main sources of ecosystem value in the Maasai steppe; in Year 0 (today) they account respectively for an estimated 31 and 27 million USD per year, or 28 per cent and 30 per cent of the total annual ecosystem benefits in the region.

Quantifying ecosystem value creation per hectare in Year 0, we find that using land for agriculture generates the highest ecosystem benefit value from natural capital, with ecosystem benefits above US$73/ha, as opposed to US$52/ha for national parks and US$18/ha for pastoralist rangelands. When we consider the whole Maasai region, rangelands supply the most ecosystem services because of their huge area.

**Figure 1 Projections of Ecosystem Benefits to local communities in the Maasai steppe, per year, adjusted for purchasing power parity (PPP)**



When land use change occurs, a high conversion rate of rangeland to farmland negatively affects wildlife and will reduce the increase in ecosystem benefits from national parks, compared to the medium and low conversion rates.

Farming practices will lead to a decline in soil quality, which in turn will negatively affect yield per hectare and hence ecosystem benefits of farmland. The increase in ecosystem benefits of farming in all graphs reflects the compensation of yield reduction per hectare by an increase in area. At the high conversion rate this is not the case anymore after year 11, and the total ecosystem benefits of farmland are decreasing. In the moderate and low conversion rates, the area of arable land increases during the whole period. The conversion to arable land starts at the most productive rangelands, which implies that the ecosystem benefits of rangeland decline at a higher rate than the decline area. Additionally, the ecosystem benefits per hectare of rangeland decline, due to fragmentation.

Population growth affects ecosystem benefits as well for those services that are exploited below the carrying capacity of the rangelands. This is for example the case for harvesting firewood and wood poles for buildings. This explains the slow increase in total ecosystem benefits of rangelands in the slow conversion scenario.

Turning to the second period (not in the graphs), the ecosystem benefits linked to national parks peak in year 20 for HI and then decline, reach an equilibrium for MID and continue growing for LOW. This is related to the effect of declining wildlife populations on the revenues of the national parks. The rangeland ecosystem benefits will remain constant as underexploited benefits will reach their carrying capacity. Arable land benefits will decline, due to the continuous process of land degradation. This process can be stopped if good farming practices were to be applied.

Additionally, the value of potentially lost carbon stocks (using the social cost of carbon) ranges from an estimated US$23 billion in the HI scenario and US$15 billion in the LOW scenario, considering land cover in year 0 versus land cover in year 20 across the scenarios. The external cost of potential losses in carbon stocks (CO2 emissions, borne by the global population) following agricultural expansion is even higher than the cost of lost ecosystem services for the local population.

## Lessons learned

The range of ecosystem services assessed in this study is partial, as some of the benefits of pastoralism have been left unquantified (the preservation of cultural heritage; the maintenance of social ties, traditions and household resilience; and biodiversity conservation that does not accrue tourist revenue). Furthermore this study has valued ecosystem services, but not assessed total food production. However the trade-off between higher food production on farmland on the one hand versus the existence of rangeland, with its high ecosystem values, appears clear. The challenge is to develop forms of agriculture that can co-exist with pastoralism and that can maintain higher soil carbon stocks to halt land degradation and maintain the numerous benefits for local communities over time.

TEEBAgFood needs to bring such evidence to bear on decision-making and present options for capturing the values of ecosystems and biodiversity.

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# APPENDIX V

# Modelling agroforestry systems

Photo: ©Tri Saputo/CIFOR

**Authors: Marieke Sassen and Arnout van Soesbergen (UNEP-WCMC)**

## Context

Agroforestry is a production system that generates a huge array of values from the local to the global scale. Agroforestry is an agricultural practice that integrates trees with crop and/or animal production on the same area of land. It encompasses a wide range of production systems, from shaded plantation crops such as coffee and cocoa, to treed rangelands or pastures, to timber or fruit tree plantations combined with seasonal crops. Agroforestry systems allow the diversification of farmer income and often provide additional products such as food, medicine and wood fuel important for (poor) smallholder farmers. Beyond the farm, agroforestry systems support the maintenance of ecosystem services at the landscape to global levels, such as carbon sequestration, water regulation, soil retention, biodiversity (including that which supports crop production) and landscape values.

Increased demand for food and/ or cash crops, tend to lead to a reduction of (shade) tree cover or the conversion of mixed agroforestry systems to monoculture cropping. These systems can produce higher yields[1]. However, they often require significant external inputs, provide fewer services or negatively impact on ecosystem services at farm-level and beyond[2, 3]. Yet, there is also scope for technology to support increased yield within shaded systems, which would help avoid conversion of additional natural habitats[4].

The study used modelling to evaluate the gains and losses in ecosystem services under different scenarios for three different agroforestry systems: coffee agroforestry in Ethiopia, cocoa agroforestry in Ghana and Ngitili agroforestry in Tanzania. The agroforestry areas were identified and mapped by ICRAF. The WaterWorld model[5] was used to analyse changes in tree cover and their implications for the following ecosystem services: freshwater provision and run-off, water quality, soil erosion and above ground carbon. By way of example, a map of study districts and of baseline modelled modeled run-off within sub-basins is provided for the Tanzania case study (Figures 1 and 2).

## Results and scenarios

1. **Conversion of all areas identified under coffee agroforestry to maize mono cropping system (maximum canopy cover five per cent) in the Ethiopia case study:** This scenario results in variable but small impacts on water yield between districts as tree cover is replaced by high water use crops. Overall, there is a cumulative loss of 12 million m$^3$ of water. Water quality decreases for all districts and cumulative total aboveground carbon stock decreases with 17.7 million tonnes. Soil erosion increases up to 76 per cent for one district.

2. **Conversion to a full sun/lightly shaded system where shade trees are almost completely removed from existing agroforestry (maximum canopy cover 30 per cent) in the Ghana case study.** This scenario leads to increased water availability due to reduced water use by trees, with a cumulative increase of 16 million m$^3$ per year across all districts. Total aboveground carbon stock decreases by approximately 533,000 tonnes of carbon while total cumulative soil loss increases by around 913,000 tonnes annually.

3. **Extended Ngitili agroforestry system with increased tree cover in areas identified as Ngitili agroforestry (minimum 20 per cent canopy cover)in the Tanzania case study:** This scenario leads to considerable increases in tree cover and thus a reduction in water yield totaling around 217 million m$^3$ per year for all districts. Water quality however increases and total carbon stocks increase with over 60 million tonnes of carbon overall. Soil erosion is reduced by around 210,000 tonnes annually.

**Figure 1 Ngitili agroforestry study districts, showing elevation within districts and location in Tanzania**

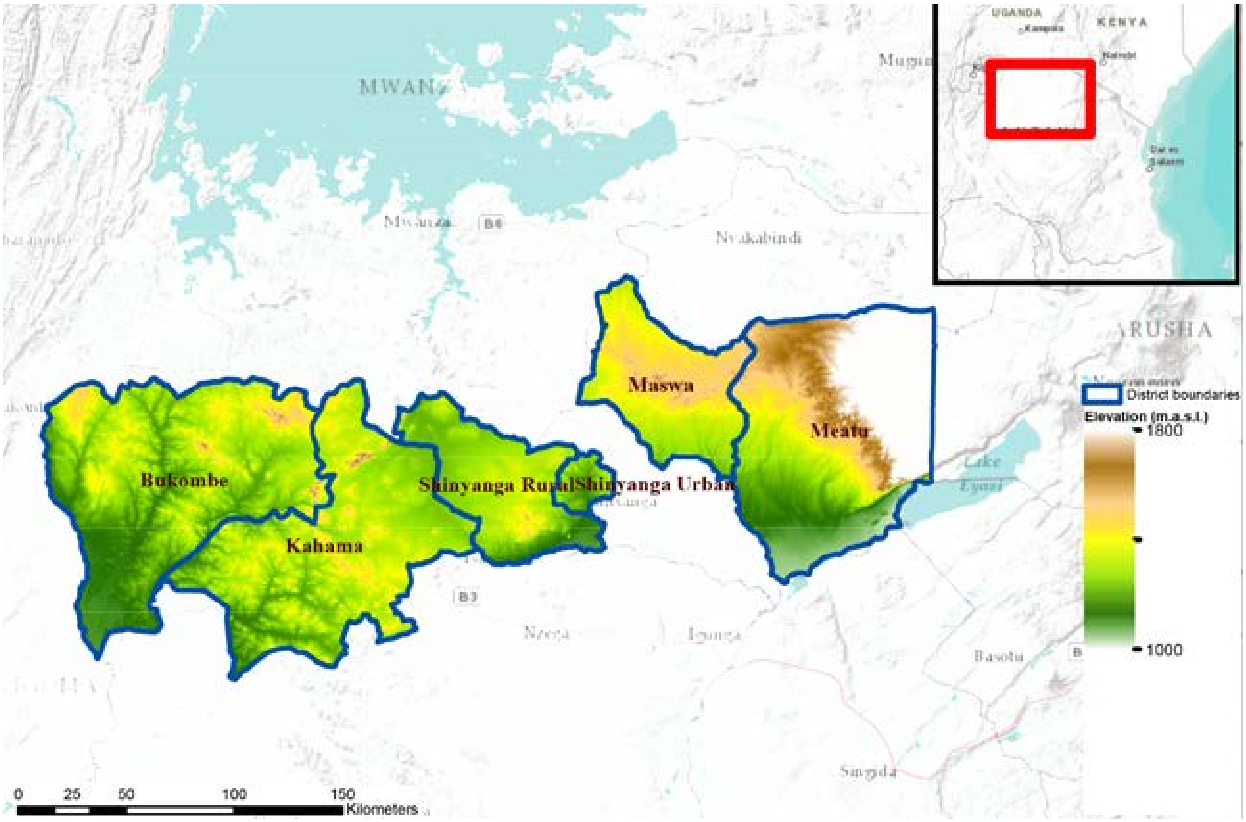
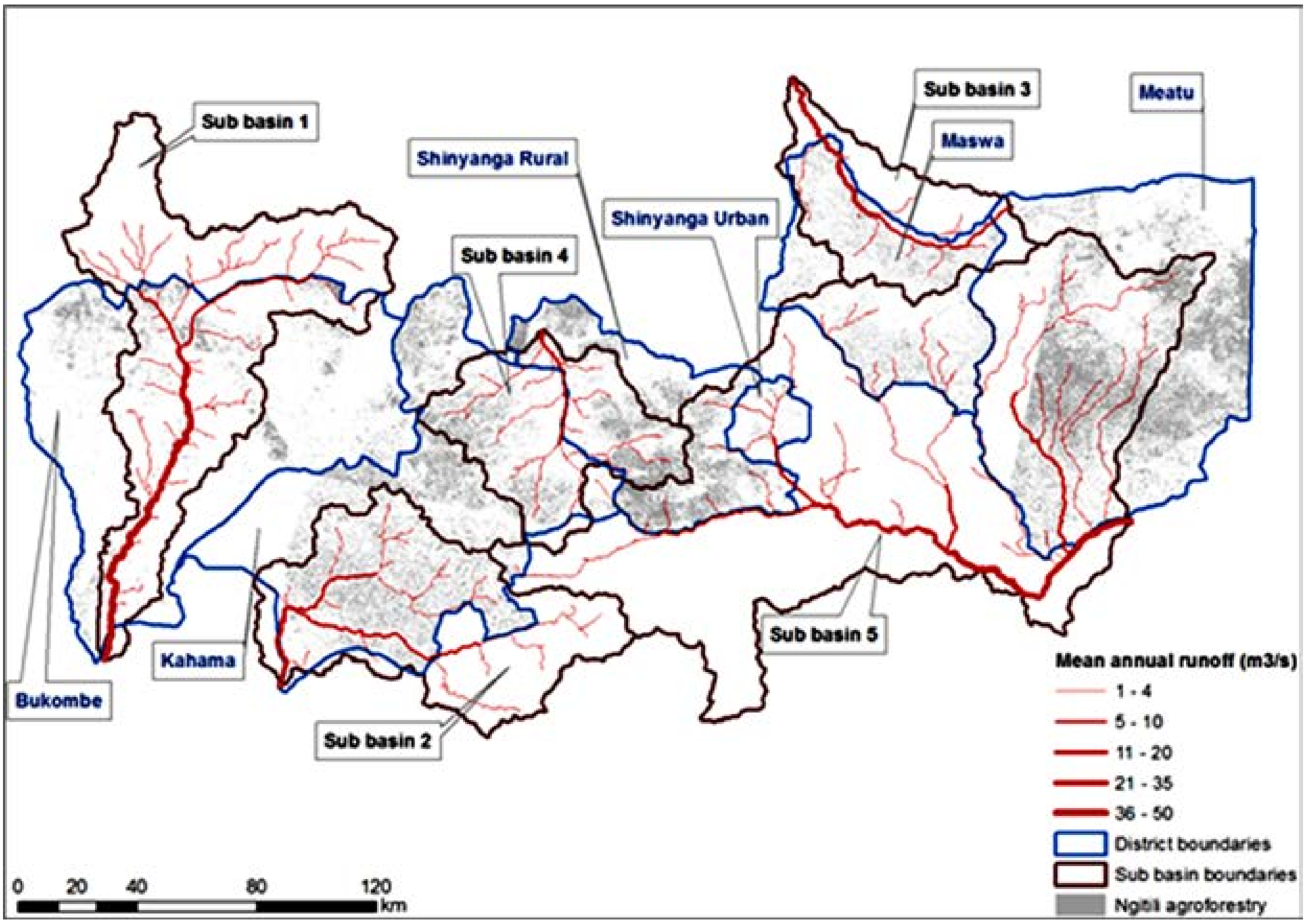


**Figure 2 Baseline modelled run-off within sub-basins overlapping the Ngitili agroforestry study districts in Tanzania**



## Lessons learned

Due to the complexity of agroforestry systems, identifying and modelling agroforestry using optical remote sensing is difficult without sufficient ground truth data. Definitions of agroforestry systems and criteria used to classify them should be made more consistent, including those criteria related to tree and canopy cover which can be assessed using remote sensing.

The interactions among ecosystem services and agriculture are complex. Spatially explicit models, such as WaterWorld and others, can help simulate and visualise these complex interactions and assess the outcomes of alternative future scenarios under which these interactions take place.

What the findings of the studies point to is trade-offs in certain scenarios, e.g. water yield decreases versus water quality increases in Tanzania, which may hold different values for different stakeholders at different spatial scales and distances from where the services or externalities originate. It is up to local decision-makers to determine the preferred options for their stakeholders, but TEEBAgFood has a role in providing the scientific evidence base and also guidance on appropriate policy instruments, i.e. demonstrating and capturing ecosystem values.

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Photo: ©Flickr Luis Ovalles

# Notes

# Notes

The Economics
of Ecosystems
& Biodiversity

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## Making nature's values visible