The Economics of Ecosystems & Biodiversity

MEASURING WHAT MATTERS IN AGRICULTURE AND FOOD SYSTEMS

A synthesis of the results and recommendations of TEEB for Agriculture and Food's Scientific and Economic Foundations Report

‘The Economics of Ecosystems and Biodiversity’ (TEEB) is an initiative hosted by the United Nations Environment Programme (UN Environment), and coordinated by the TEEB Office in Geneva, Switzerland. ‘TEEB for Agriculture & Food’ (TEEBAgriFood) encompasses various research and capacity-building projects under TEEB focusing on the holistic evaluation of agriculture and food systems along their value chains and including their most significant externalities. This report serves as a synthesis of the ‘Scientific and Economic Foundations’ report, which is supported by the Global Alliance for the Future of Food.

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The full ‘Scientific and Economic Foundations’ report, including images, artwork and promotional materials, is available for download at: www.teebweb.org/agrifood/home/scientific-and-economic-foundations-report.

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Alexander Müller and Pavan Sukhdev

PREFACE

Alexander Müller & Pavan Sukhdev

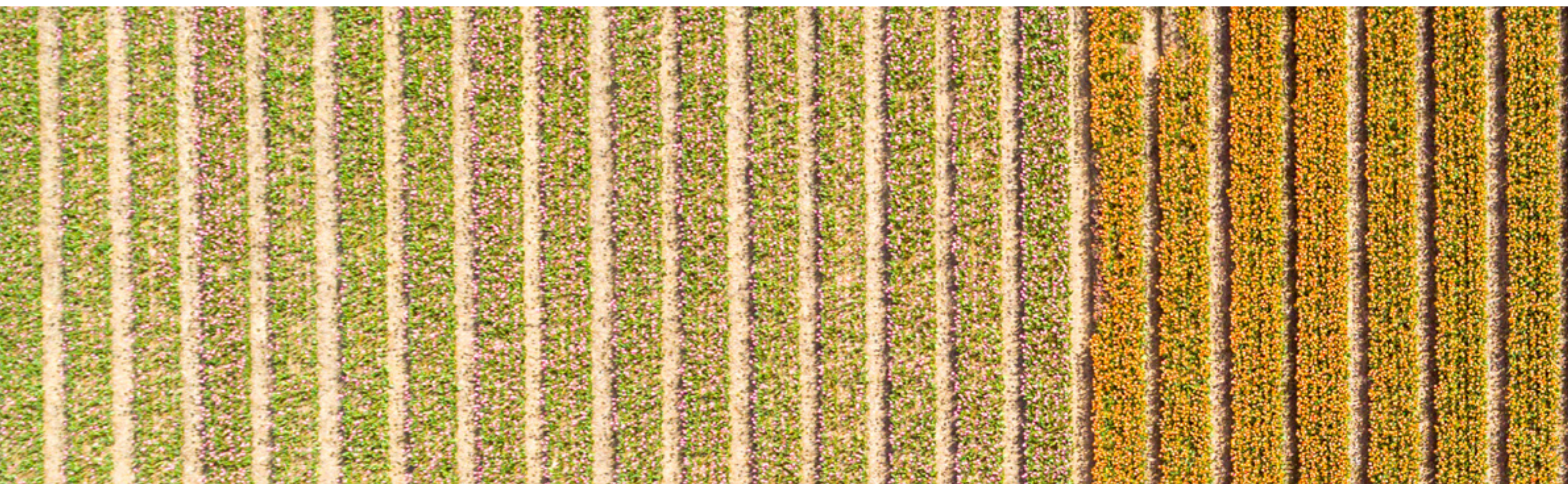
There is increasing evidence that today's agriculture and food systems are broken[1]: our diets have now become the main burden of disease[2], more than 815 million suffer from hunger[3], over 650 million suffer from obesity[4], and malnutrition affects over two billion. Considering the full value chain of food including deforestation to clear land, processing, packaging, transportation and waste, our food systems account for an estimated 43-57 per cent of human-caused greenhouse gas emissions[5,6]. However, as our understanding of the complexity and far-reaching impacts of food systems continues to improve, we can never fail to be surprised at the continuing inadequacy of today's prevalent metrics for food system performance[7].

Evaluating agriculture and food systems requires understanding the vast and interacting complex of ecosystems, agricultural lands, pastures, inland fisheries, labor, infrastructure, technology, policies, regulations, institutions (including those involved in making policies, framing regulations and providing markets), cultures and traditions that are involved in growing, processing, distributing and consuming food. Evaluating such complexity with (for example) a yardstick as narrow as "per hectare productivity" of a single crop might appear naïve, and yet, exactly such dangerous simplification infects the dominant discourse on food systems.

"The Economics of Ecosystems and Biodiversity for Agriculture and Food" (TEEBAgriFood), a new study launched by UN Environment on the occasion of World Environment Day 2018, demonstrates how to capture the complex reality of today's diverse and intertwined "eco-agri-food" systems in order to evaluate their performance in a holistic manner to support decision-making, avoiding the risks and limitations inherent in simplistic metrics such as "per hectare productivity".

Two key differences between a conventional, "production only" approach for assessing agricultural performance and the systems approach favoured by TEEBAgriFood is that the former is limited to the 'production' segments of food value chains, and to those stocks, flows, outcomes and impacts that are observable in markets and hence reflected in standard economic statistics. The systems approach adopted by TEEBAgriFood looks along entire food value chains, revealing that there are significant but economically invisible (i.e. non-market) stocks and flows that must also be considered. Whilst these stocks and flows may be unpriced and are not incorporated in macro-economic modelling or the calculus of Gross Domestic Product (GDP), they are undoubtedly real stocks and flows that can be observed, described and measured, and indeed they are important drivers of success (or failure) of many of the SDGs as the eco-agri-food value chain significantly impacts climate (SDG 13),

1 Sukhdev, P., May, P. and Müller, A. (2016). Fixing Food Metrics. Nature, 540, 33-34.
2 International Food Policy Research Institute (IFPRI) (2016). Global Nutrition Report 2016: From Promise to Impact: Ending Malnutrition by 2030. Washington, D.C.
3 Food and Agriculture Organization of the United Nations (FAO) et al. (2017). The State of Food Security and Nutrition in the World 2017. Building resilience for peace and food security. Rome.
4 Ng, M. et al. (2014) Global, regional, and national prevalence of overweight and obesity in children and adults during 1980-2013: a systematic analysis fort he Global Burden of Disease Study 2013. The Lancet, 384(9945), 766-781.
5 United Nations Conference on Trade and Development (UNCTAD) (2013). Trade and Environment Review 2013. Wake up before it is too late: make agriculture truly sustainable now for food security in a changing climate. United Nations.
6 Grain (2014). How much of world's greenhouse gas emissions come from agriculture? https://www.grain.org/article/entries/5272-how-much-of-world-s-greenhouse-gas-emissions-come-from-agriculture. Accessed 28 May 2018.
7 Sukhdev, P., May, P. and Müller, A. (2016). Fixing Food Metrics. Nature, 540, 33-34.



freshwater (SDG 6), biodiversity and ecosystems (SDGs 14 and 15), human health (SDG 3), social equity (SDGs 5 and 10) and livelihoods (SDGs 1 and 8).

The TEEBAgriFood Evaluation Framework has three guiding principles – universality, comprehensiveness and inclusion. As a "universal" Framework, its elements are defined and described in a uniform, methodical and consistent manner, to be used in any geographical, ecological or social context, at the level of society, the firm, or the individual. The Framework is "comprehensive" in that it acknowledges all significant impacts or dependencies of the food system, be they economically visible or invisible, along any segment of the food value chain. A third guiding principle is inclusion. i.e. that the Framework should support multiple approaches to assessment. Although the 'accounting based' nature of the Framework directly supports analysis in line with economic theory and valuation of impacts on human well-being in monetary 'value addition' terms, this is neither possible nor appropriate for all aspects of human well-being. Qualitative, physical, or non-monetary terms can provide important insights, as can a plurality of value perspectives and assessment techniques. These three guiding principles result in a Framework design and approach that can truly represent a holistic perspective of any food system. They anchor the Framework by recognizing and valuing the roles of all four forms of capital stocks (i.e. produced, natural, human and social capital[8]) deployed in eco-agri-food systems. They lead us to undertake a mapping and recording all major flows emanating from these stocks, be they economically visible or invisible, recognizing and evaluating the outcomes and impacts of these flows.

We are encouraging researchers to test our proposed Evaluation Framework in different ecological, farming and business value chain contexts, through a series of "Framework-testing studies" on various applications of the Framework: policy scenario analyses, farming typology comparisons, dietary comparisons of different food plates, product impact comparisons, etc.

It is our ambition that they will draw lessons from these Framework-testing studies and evolve the Framework further over time to become a new orthodoxy, eventually replacing simplistic yardsticks such as "per hectare productivity".

Agri-food policy makers, agri-businesses, farmers and civil society organizations will be able to use the information revealed by such "Framework-testing studies" to better manage risks associated with degradation of natural, social, human and produced capitals affecting eco-agri-food systems.

Fixing food metrics is a crucial part of the transformation needed to provide nutritious food for all people without damaging ecosystems, exacerbating climate change, and damaging human health. We believe that TEEBAgriFood is a major milestone in this defining journey towards sustainable development.

Signed by the authors,

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8 This capital base is comprehensive, comprising all four classes of capital, following the widely used lexicon of environmental economics, which has also been adopted by the UNU-IHDP and UNEP "Inclusive Wealth Reports"

A MESSAGE FROM THE TEEB FOR AGRICULTURE & FOOD STEERING COMMITTEE

Our goals are bold and ambitious: to contribute a framework approach for better understanding and managing the impacts and externalities of agriculture and food value chains, and to incite a global network of scholars and decision-makers dedicated to disclosing and valuing those impacts.

Without a doubt, the complexity is daunting as we embrace, holistically, the interconnectedness of agriculture and food production issues with which we must grapple. Yet we choose not to simplify our study, rejecting from the onset the reductionist, silo-oriented impulse that has dominated much of modern agricultural thought and action. Instead our collective effort to understand the true cost of food has left us energized, as we are certain that this is an essential step forward toward the kind of new policies, practices, science, and community engagement necessary to achieve our goals, particularly in the context of the Sustainable Development Goals.

Agriculture and food systems must evolve if we are to survive as a planet. Our report seeks to shine a light on the pathways forward and to generate new thinking and strategies that might lead to a more sustainable food future. Herein, you will find comprehensive, systems thinking approaches to evaluating 'eco-agri-food systems', an innovative Framework along with methodologies and tools to support robust evaluation of current production practices, and a theory of change describing how this all fits into the bigger picture.

We are honored to be a part of TEEBAgriFood and stand alongside so many contributors as we unveil this report. There is strength in numbers and it is impressive to note that over 150 scholars from 33 countries representing a wide range of disciplines, backgrounds and perspectives have contributed in some meaningful way. For this reason, we are convinced that this document is a beginning, not an end. We have seeded a powerful global network to carry on and further delineate externalities of agriculture and food value chains.

We invite you, the reader, to join us and invest in the collective effort to raise awareness of our dependency on the invisible benefits provided by natural, human, and social capital as well as the hidden costs that undergird our 'eco-agri-food systems'. We must alter our current

course and design better agriculture and food value chains and policies that support healthy people and a healthy planet. We must bring everyone to the same table to use a common approach that supports the change we seek. This is what TEEBAgriFood offers.

Signed,
TEEB for Agriculture & Food Steering Committee

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>
> **-WERNER HEISENBERG**

CHAPTER 1

The challenges of agriculture and food systems in the 21st century: five different perspectives

Nourishing 10 billion people by 2050, achieving all dimensions of food security (FAO 1996), employing over 1.5 billion people, developing rural societies and reducing large impacts on climate, ecosystems and environment: the global and national agendas of eco-agri-food systems are indeed packed with challenges. Yet there is no consensus on a holistic way of evaluating them. Instead, we seem to be in the world of "blind men and the elephant" with different expert perspectives (of the agronomist; the environmentalist; the sociologist; the economist; the health expert) competing for attention. Chapter 1 describes these five specialist perspectives, illustrating how they are good to answer only the specific question addressed by the expertise in question, with little recognition of the others, thus framing the central challenges for TEEBAgriFood: to adopt a systems perspective of the challenges and to agree on a holistic framework for evaluation.

1.1 INTRODUCTION

In the opening remarks for his acceptance speech in 1979 for the Sveriges Riksbank Prize in Honour of Alfred Nobel (i.e. the Economics Nobel Prize), Prof. Theodore Schulz said:

"Most of the people in the world are poor, so if we knew the economics of being poor, we would know much of the economics that really matters. Most of the world's poor people earn their living from agriculture, so if we knew the economics of agriculture, we would know much of the economics of being poor."

Schulz's insights, almost forty years later, remind us in three ways of our rationale for developing "The Economics of Ecosystems and Biodiversity for Agriculture and Food" (TEEBAgriFood) and its innovative Evaluation Framework for evaluating food systems and their complex linkages to the environment, society and human health.

First, TEEBAgriFood is about the economics of 'eco-agri-food systems' and places the economics of agriculture in a systems context, within complex and extensive value chains - from supporting ecosystems, to productive farms, to intermediaries such as aggregators, wholesalers and retailers, to food and beverage manufacturers, to distributors and consumers. Waste is important at all stages of these value chains. In other words, the economics of eco-agri-food systems can only be revealed through whole systems thinking, a feature of TEEBAgriFood that is described in Chapter 2.

Second, the true economics of agriculture can only be understood after recognizing and accounting for all significant "externalities"[1] along these eco-agri-food value chains. These externalities include the huge but hidden costs and benefits of agriculture and food systems, which need to be unravelled, understood, and evaluated if the world is ever to be able to work out how to feed and nourish billions of people in a manner that provides everyone with adequate nutrition, in an equitable manner, without seriously damaging ecological security or environmental sustainability. Chapter 3 of this Synthesis develops a realistic picture of today's eco-agri-food systems in their richness and complexity, recognizing their most significant externalities.

Third, Schulz correctly surmised that "if we knew the economics of agriculture, we would know much of the economics of being poor," because more than a billion people work as smallholder farmers or landless workers, the majority of whom are poor and live in developing countries. This staggering number is an order of magnitude larger than the number working in any other industry in the world. No governance framework, policy prescription, or economic strategy for "sustainable development" can truly succeed without recognizing and adequately rewarding the role of smallholder agriculture in providing rural livelihoods, particularly for people at the bottom of the economic pyramid. In other words, achieving the Sustainable Development Goals (SDGs) may remain a dream unless policy makers address this challenge of creating economically stronger smallholder farms through policies and incentives that lead to higher yields, lower risks and fairer prices for the small farm. But how can we bring this challenge and other major policy challenges into sharp focus without a holistic evaluation lens, as against a narrow lens such as "per-hectare productivity" which glosses over concerns about poverty, equity and environmental sustainability, central threads that run through so many of the SDGs? Indeed, this is the purpose of TEEBAgriFood's Evaluation Framework, which is described in Chapter 4.

The TEEBAgriFood discourse on food systems and their externalities aligns well with the overall TEEB initiative, as discussed by Hussain and James (2018). The final reports of TEEB (2010; 2012) highlighted the implications of the economic invisibility of nature in decision-making, and shed light on the sizeable but hidden contributions of biodiversity and ecosystem services to social and economic well-being. Extending this environmental-economic perspective, TEEBAgriFood now considers other hidden stocks and flows, including significant impacts on human health, social equity, livelihoods, poverty, climate change, freshwater scarcity and soil fertility, all in the context of our food systems.

1 *Externalities* are defined as the third-party costs (or benefits) of bilateral economic transactions whose counterparties have not accounted for these costs (or benefits) when undertaking their transaction.

This chapter 1 of the synthesis report of TEEBAgriFood shows how different disciplines are dealing with one of the most important challenges of the 21th century: the triple challenge of how to achieve food and nutrition security for a growing population, how to maintain or regenerate environmental integrity for the life supporting services provided by the ecosystems of our planet and how to ensure that the ongoing transformation of global food systems supports social equality and equity and leaves no one behind.

The world's eco-agri-food systems lie at the nexus of these challenges; decisions affecting one element will have positive or negative impacts on the other challenges. Some of these impacts are economically visible i.e. reflected in the accounts of society (such as the System of National Accounts, and its bellwether indicator, GDP) or reflected in statutory accounts of firms (such as the firm's Profit & Loss Account), but most of them are invisible.

The world's eco-agri-food systems are facing a number of unprecedented challenges, which we see as a starting point for our analysis:

1. Providing healthy diets to a growing population with some 10 billion people by 2050 in a more and more urbanized world. Population growth will take place mainly in developing countries!

2. Ensuring equitable, just and ethically based food systems, from production to consumption, including food waste management.

3. Drastically reducing food systems' significant impacts on ecosystems (water, land and biodiversity) while adapting to climate change and mitigating greenhouse gas emissions. This requires also increasing resilience and dealing with increased numbers and more intensive disasters and emergencies.

4. Improving livelihoods for over 1.5 billion people currently working in agriculture, many of them poor and many of whom go to bed hungry. The task is to fight rural poverty, through higher and more stable incomes, better health and education and other avenues for improving inclusion in society.

5. Ensuring that well-functioning markets can distribute food to all consumers at affordable prices, with the understanding that unduly low prices could drive even more farmers into poverty and that higher food prices will negatively impact poor consumers.

6. Addressing hunger, deficiencies of nutrients, overweight, obesity, diabetes and other food related diseases, which are on the rise – sometimes in the same country, community or even household. Both the absolute and the relative numbers of hungry people are increasing (FAO *et al.* 2017). 815 Million people have been hungry in 2016; at the same time malnutrition and diets have been identified as the far biggest risk factors for the global burden of disease (IFPRI 2016). And all countries in the world are affected.

There is growing consensus that none of these challenges of achieving food and nutrition security, environmental integrity and social equity can be tackled successfully in isolation as they are interlinked. However, there is not, or not yet, any consensus on the best pathways towards addressing all simultaneously or how to best appraise and improve the performance of different efforts.

The ancient parable of the "blind men and an elephant" is illustrative. The parable tells the story of five blind men who touch an elephant for the first time. Each blind man touches a different part (the tail, or the trunk, etc.), and based on his experience of the part that they touched, describe what they perceive an elephant to be. Despite each part being expertly described, their descriptions are vastly different from one to the next, and they fundamentally disagree on what an elephant is (and in some versions of the parable, even accuse each other of dishonesty). In a nutshell, the moral of the parable is that one's partial experience does not represent the actual whole.

The TEEBAgriFood version of the parable goes as follows: the agronomist declares 'the problem is crop yields.' The environmentalist says 'the problem is loss of biodiversity.' The sociologist says 'the problem is rural poverty.' The economist insists 'this is a failure of markets.' The health specialist says 'the issue is malnutrition combined with obesity.' As the light turns on, all experts see the full picture and realize each perspective was incomplete. Recognizing that each expert's experience is valuable but inherently limited by a deficit or inaccessibility of information leading to "silo thinking", they decide to collaborate in order to address the many challenges of the eco-agri-food system.

Specialized knowledge is powerful but reductive. It needs to be balanced and completed with a new way of doing science that recognizes the need to manage the whole, a perspective that is essential to sustainability. With advances in information and communication technologies of our digitalization age, including the extraordinary connectivity of mobile-based solutions, the three millennia old parable shows that we no longer have excuses to a fragmented and non-systemic perception of the world.

The agriculture and food system, as viewed and experienced by the agronomist, environmentalist, sociologist, economist, and health specialists, along with their dominant narratives, are briefly presented below, noting that even within disciplines, there are competing schools of thought and different levels of specialization, or sub-sector focus. Each perspective offers its own different yet fundamental contribution. We must bring these communities closer together in order to have maximum impact.

1.2 THE AGRONOMIST PERSPECTIVE: FEEDING A GROWING POPULATION

Issues at stake: The world population keeps growing and the aggregate food demand is expected to increase from 2789 kcal/capita/day in 1999/2001 to 3130 kcal/capita/day in 2050 (Conforti 2011), with average meat consumption per capita expected to increase from 37 to 52 kg/year. A world freed from hunger remains a prime concern.

Past achievements: Between 1961 and 2011, global agricultural output more than tripled (Alexandratos and Bruisma 2012). The share of undernourished people fell from 24 per cent in 1990-91 to 10.8 per cent by 2013 but this downward trend has since reversed, with the prevalence of undernourishment being highest in Sub-Saharan Africa, affecting an alarming 22.7 per cent of the population in 2016 (FAO *et al.* 2017), the increased number of hungry people in the last years was mainly due to political instability and conflicts.

Prevailing paradigm: The 1960s high rate of population growth and total fertility rates, coupled with insufficient food productivity, are at the roots of the agricultural mind-set that combines technological advances and public policies to raise outputs in order to match food supply and demand. Building on the success of the Green Revolution in increasing agricultural yields, and in view of a world population growing to 10 billion in 2050, along with rising incomes that are currently shifting diets to more protein rich food, agronomists seek to double food production by 2050 (as compared to 2012) through sustainable intensification, intended as more yields with less resources; this latest incarnation of the productivity focus is as an attempt to square environmental concerns with the imperative to grow more food (IPES-Food 2015). While the chemical revolution provided the main tool in the past decades, advances in genetic manipulation, coupled with targeted use of agricultural inputs (e.g. precision agriculture, applied robotics) and agro-ecological knowledge, represent the current promise for providing food to the increasing world population.

Externalities: Agronomists' prioritization has led to unplanned and sometimes unexpected (though well documented) ecological and human health damages. The remarkable gains in yields of the past were accompanied by degradation of natural resources and pollution of water, air and food by chemical agricultural inputs.

Challenges (within the sector): Agricultural specialization and increasingly global supply chains resulted in a narrow range of commodities, with efficiency being preferred to resilience of food and agricultural systems. Although 90 per cent growth in future crop production is expected to result from increased cropping intensity, growth of yields has been steadily slowing down (and despite increased input use in Asia); in fact, grain yields grew at an average of 2.1 per cent from 1950 to 1990 but since 1990, growth dropped to less than one per cent (FAO 2011). Further crop intensification seems very challenging and cannot be guaranteed; overall, increasing water scarcity constrains production more than land availability and coupled with climate change, the world's capacity to further expand food production appears severely limited. Agronomists suggest technological innovations, both gene manipulation (e.g. genetic modification, nanotechnology, gene editing) and ecosystem-specific technologies (e.g. conservation tillage, agroecology) and by exploiting the yield gap in Sub-Saharan Africa that production can be expanded. Whichever path is taken, the international agriculture community acknowledges the need for transformative change in order to meet the challenges posed by the evolving global environment (FAO 2017a).

Crossroad issues[2]**:** Income growth in low- and middle-income countries and higher food consumption (of

2 We refer to important cross-cutting issues, systemic

meat, fruits and vegetables, relative to that of cereals), the demand for crops for non-food uses (e.g. bioenergy, bioplastics), along with consumer shifts towards values-based food (e.g. organic, fair trade, local, seasonal) and millennials' preferences for plant-based meat alternatives, present uncertainties on how the nutrition transition (and consequent food demand) is evolving. Whatever happens, pursuing increased food supply must move away from the quantitative approach and place greater emphasis on access to nutritious food and human and ecological health. For agriculture, and even civilization, to survive in the long run, ecological boundaries and health imperatives cannot be compromised.

1.3 THE ENVIRONMENTALIST PERSPECTIVE: SAVING THE PLANET

Issues at stake: Agriculture, forestry and fisheries are the largest drivers of 60 per cent of biodiversity loss, putting genetic resources for food and agriculture at risk, 80 per cent deforestation, using 70 per cent of all withdrawals of freshwater, coral reefs collapse, 21 per cent of anthropogenic greenhouse gas emissions (FAO 2016) (including farming and deforestation but there are estimates that emissions could be up to 43-57 per cent if all phases of the value chain were considered [UNCTAD 2013; Grain 2014]). Planetary studies estimate that the 'safe operating space' for humanity has already been exceeded for genetic diversity as well as nitrogen and phosphorus flows (both essential for plant growth) – with agriculture being the major driver of this transgression (Campbell *et al.* 2017). The projected impacts of climate change range from falling crop yields in many areas (particularly in developing countries), significant decrease of water availability in many areas (including Mediterranean and Southern Africa), sea level rise threatening major cities, extensive damage to coral reefs and rising number of species facing extinction, to increasing intensity of storms, forest fires, droughts, flooding and heat waves. Agriculture is among the major contributors of climate change and at the same time, a prime victim of its effects.

Past achievements: Several international multi-lateral agreements (such as the latest Paris Agreement) and related national implementation measures have addressed environmental degradation, from bans on certain groups of pesticides (e.g. Persistent Organic Pollutants), through the establishment of terrestrial and marine protected areas (to protect biodiversity and ecosystem services), to emission restrictions that are triggering the shift towards greener technologies (e.g. fossil fuel-based inputs alternatives). One major achievement has been the elimination since 1990 of ozone-depleting substances (e.g. methyl bromide widely used as a fumigant in agriculture) (UN 2015). By June 2017, protected areas covered 14.8 per cent of terrestrial land areas and thanks to current national commitments, 17.7 per cent by 2020 (CBD website).

Prevailing paradigm: Environmental conservation seeks to safeguard long-term societal goods. These include wild species as well as areas that allow resource extraction, such as culturally modified landscapes and managed resource areas. The early ecologists' focus on the dynamic nature of the environment had often overlooked the complex dynamics of the users of natural resources. To address these issues and other competing land uses by different sectors, ecologists are designing landscape approaches that seek both ecosystem conservation and sustainable development of local communities.

Externalities: Conservation defeats its own purpose when the connectivity with people, agriculture and the broader landscape mosaic is not considered. The traditional top-down approach of protected areas that often did not admit local and indigenous communities within conservation areas created islands within a network of different land uses that inevitably contributed to the failure (to both people and biodiversity) of conservation efforts. In particular, agricultural management, not only in corridors but also in the whole landscape matrix, plays a key role in biodiversity patterns. Earlier agri-environmental policies experienced similar failures, with landslides and fires becoming frequent on land set-aside in the absence of good land management, in addition to loss of livelihoods for local communities.

Challenges (within the sector): Developing countries' twin challenges of reducing poverty and maintaining environmental integrity continues to be relevant; concepts like the green and inclusive economy development agenda launched in Rio in 2012 offer new solutions. However, there is still a long way to go before effectively establishing ecologically-proofed interventions and technologies. For example, for the global challenge to limit the planet to a 1.5 to 2°C

pressure points, potential turning points and significant potential systemic changes in the foreseeable future collectively as "Crossroad issues" temperature increase, current mitigation techniques and commitments are not sufficient. A debate has started if humankind will need CO_2 removal technologies. Geoengineering technologies (e.g. bioenergy with carbon capture and storage) are increasingly proposed to close the greenhouse gas emission gap by mid-century but any large-scale Earth system intervention is inherently risky and the transboundary nature of operations leaves many open questions, such as inequitable distribution of negative effects. In the meantime, the drive for a carbon-friendly future has fuelled the search for fossil fuel alternatives. The last 10 years have seen an increased use of cereals and oilseeds as substitute of petrochemicals. This shift to bioenergy has serious implications on food, feed and energy markets, as well as on food security, access to land and pressure on natural resources.

Crossroad issues: Environmental impact assessment (the dominant environmental planning technique) operates on a piecemeal, sectorial basis, often precluding issues arising with the multiple use of natural resources by a myriad of different actors. There are numerous examples of collective decision-making about nature, representing the oldest form of conservation efforts, and which are closely related to people's livelihoods, culture and identity (Pyhälä 2017). In fact, impact assessments increasingly include both environmental and social assessments, though to a limited extent. Re-establishing more realistic and resilient conservation networks must consider governance issues, such as indigenous peoples' land rights and partnerships with local people. Partnerships are required to estimate both the economic cost of damaged ecosystems and the regional economic benefits of conserving such systems, while managing competitive needs at a landscape level with policy instruments that cut across the jurisdictional lines of existing agencies.

1.4 THE SOCIOLOGIST PERSPECTIVE: SUSTAINABLE RURAL LIVELIHOODS AND SOCIAL EQUITY

Issues at stake: There are 767 million people living in extreme poverty worldwide, which means that almost 11 in every 100 live on less than US$1.90 a day (World Bank 2016), with 80 per cent of the world very poor found in rural areas. Agriculture plays a vital role in these areas; typically, it is the poorest households that rely most on farming and agricultural labour (IFAD 2011). 1.5 billion people work in agriculture. In most low-income countries, agriculture remains the major employer: employing 25 per cent of the population of low-income countries globally, and 42 per cent of such workers in Sub-Saharan Africa, 5 per cent in high-income countries. However, non-farm income sources are increasingly important across regions, and income gains at the rural household level are generally associated with a shift towards more non-agricultural wages and self-employment income. Undercapitalized family farms and landed peasantry, and marginal farmers and pastoralists facing insecure livelihoods are most often found in rural areas on fragile lands, where industrial export-driven farming is less common.

Past achievements: Over the last two centuries, global poverty has fallen dramatically. After industrialization, agricultural specialization and trade increased economic growth and living standards. Strong economic growth centred around urbanization is believed to be key to poverty reduction; should non-OECD countries transition to a higher growth path, the global poverty ratio would fall from 21 per cent in 2005 to less than 2.5 per cent in 2050 (Conforti 2011). However, rural areas are lagging behind on poverty reduction. Without pro-poor development, it is estimated that some 653 million people would still be poor and under-nourished in 2030 (FAO 2017a).

Prevailing paradigm: Promoting sustainable livelihoods as a route to poverty reduction has traditionally been pursued through agricultural growth and by connecting people to related markets and services, especially in high potential areas, with the assumption that economic growth would trickle down through societies. Different rural development paradigms now focus on inclusive rural transformation that prioritizes agri-food systems, while addressing problems of performance and equity within agriculture, so that non-monetary deprivations of rural people are reduced and their access enhanced to resources, services and participation (IFAD 2016).

Externalities: Economic growth forecasts rely on the neoclassical model, which accounts for changes in capital stock, labour force and technology – without accounting for resource constraints that cannot be met by technological solutions. In particular, the world's 500 million smallholder farmers risk being left behind as structural and rural transformations occur, as the agribusiness that dominates global input markets has little incentives to develop technologies for resource-poor smallholder farmers (FAO 2017b). Growth policies that subsidize increased agricultural yields (e.g. through subsidies on seeds, fertilizers, irrigation, power, credit and/or price) often lead to distortions to producer and consumer prices of key commodities, as well as to increased food losses, as it is more economic to leave produce to rot in the fields, rather than invest in infrastructures for better preserving and/or marketing it.

Challenges (within the sector): Traditionally, interventions addressing hunger and extreme poverty were sector-specific and looked at one or the other of the two problems. Agriculture interventions often target food insecure smallholders that have a potential productive capacity, that is, those who have some assets, leaving the extremely poor behind. On the other hand, the very poor are targeted by food distribution schemes that do not necessarily contribute to their own ability to build sustainable paths out of extreme poverty and poor health, whereas the poorest households also have productive potential when they are given the means to achieve it.

Population growth is expected to raise the overall number of people between 15 and 24 years of age from about 1 to 1.2 billion, most of which are expected to live in Sub-Saharan Africa and South Asia, particularly in rural areas where jobs will likely be difficult to find. Lack of employment in rural areas is fuelling migration to cities (and across national borders) and at least one third of urban slum inhabitants are rural migrants. In 2050, about 70 per cent of the world population will be urban; global urbanization could lead to a net addition of 2.4 billion people to towns and cities, which is more than the total global population increment of 2.2 billion people. This means that rural populations may see a net reduction of nearly 200 million people, including outflow and higher mortality rates in rural areas (FAO 2017b). Labour is the most critical production factor in agriculture, and urbanization and farmers ageing (even in low-income countries) have important repercussions on the fabric of the rural labour force, as well as on the domestic food supply capacity and agriculture production patterns.

Crossroad issues: The demographic transition (including ageing farmers, unemployed youth and forced migration) are resulting in depopulation of farm communities in some rural areas, and an ever-shrinking role of agriculture in the overall economy, along with an increasing vulnerability of agricultural assets to climate change and political instability. Overall, the decline in the share of agriculture in total production and employment is driving structural changes of economies. Rural poverty programmes typically focus on providing local livelihood opportunities while neglecting remote stakeholders, such as landowners and large corporate enterprises, who determine, respectively, land usufruct and labour networks. Poverty eradication strategies have so far invested in rural opportunities that focus on the asset base of the poor; pro-poor growth involves actions that resolve massive inequities and cut across both rural and urban areas, and chiefly, focus on an efficient reduction of inequality in income (World Bank 2016), as well as on supporting non-farm income, beyond agricultural support in the strict sense. Natural regenerative forms of farming present an opportunity for the very large population of smallholders who are mostly at the lowest rungs of the economic pyramid, seeking to improve their livelihoods by capitalizing on existing natural and human resources (instead of depending on external inputs) to improve yields, and sometimes also investing in remunerated quality (e.g. price premium on organic and fair trade goods) and taking advantage of government and other support related to the green economy (e.g. payments for environmental services). A territorial policy approach to rural policy that is able to integrate different sectorial policies at regional and local levels is currently been called upon in order to meet the SDGs (OECD 2016).

Social equity, justice and ethical considerations should be fundamental values of our food system and there is a need for policies that address key social equity and justice in the context of food systems and particular ethical considerations related to hunger, sustainability, human rights, safety, marketing, trade, corporations, dietary patterns and animal welfare among others.

1.5 THE ECONOMIST PERSPECTIVE: EFFICIENT MARKETS FOR CHEAP FOOD

Issues at stake: Historically, but more so since the 2007-9 food price crises and emergence of the Arab Spring and riots the world over, food production policies aim to provide the world with cheap and affordable food for all, or at least to reduce chronic price volatility by scaling-up food production and consumption subsidies. High staple food prices not only influence conditions of under-nourishment of poor people but also of obesity, as people opt for cheaper, less nutritious food.

Past achievements: The sharp decline of international food prices has traditionally benefitted from cheap oil and less expensive chemical fertilizers and transportation costs, despite oil price hikes, the appreciation of the US dollar, climate events and the food-competing growth of the biofuel industry. Typically, food prices move in the same direction as fuel prices, though with a time lag for the fuel costs to be incorporated into food prices. Between 1960 and 2007, the share of disposable personal income spent on food, on average, fell from 17.5 to 9.6 per cent in USA (USDA 2018). In low-income countries, household food consumption expenditures approach 40-50 per cent (World Economic Forum 2016). While acknowledging wide disparities between poorest and wealthiest households within countries, in general, household spending as a share of income usually declines as income rises even though eating outside the home and fast food addiction rises.

Prevailing paradigm: Economists seek to maximize human welfare within the constraints of produced capital stock, generally paying insufficient attention to the constraints of natural capital stock. Cheap calories have until now functioned as a *de facto* substitute for redistributive social policies that would allow all families, including low-income families, to have access to food (De Schutter 2017). 'Cheap' is the basic food policy mantra in most countries, with institutions maintaining this as the top most priority through complex manipulations of price mechanisms, trade rules and taxes. The economy of current food and farming profusely rewards producing more crops the cheapest way possible, in order to remain competitive on the global market.

Externalities: In its attempt to maximize the net welfare of economic activities, intra- and inter-generational equity is being challenged in market transactions aimed at economic optimization and efficient resource allocation. Farming sacrifices food quality and externalizes ecological and social impacts that perpetuate inequalities and contribute to the rise of food and agriculture-related diseases. In addition, most farmers of the world suffer from constant downward pressure on farm products pricing, making it almost impossible to make a living from agriculture.

Challenges (within the sector): In the past 50 years, agricultural research has focused on equipment productivity per hectare and industrial technologies for increased profits. This progress also brought more debt, with more farmers failing than those succeeding in maintaining net income. Modern (i.e. industrial) farmers run faster and faster to stay in business, expanding operations to keep the same income, as buying/renting more land/implements to increase production with the consequence of lower price per unit. According to USDA (2018), the total gross value of selling corn generates a profit of USD 40.08 per acre in the Northeast; however, when full ownership costs were added, including capital replacement, operating capital, land and unpaid family labour, the result was a loss of minus USD 48,95. In addition, USDA Farm Income Forecast of 2018 predicts a 6.7 per cent decline in net farm income[3], the lowest since 2006, and a minimum 50 per cent decrease from the 2013 net income. Chiefly, the industrialised agricultural sector as a whole is losing control of what to produce, how and at what price, with ever fewer input suppliers and fewer buyers of farm produce squeezing farmers from both ends. According to the World Trade Organization (2015, p.76), an estimated USD 1.765 trillion of agricultural products were exported, comprising a significant share of the USD 3.331 trillion of global value added (i.e. GDP equivalent) in agriculture (World Bank website). Currently, free trade agreements and the inclusion of agriculture under the General Agreement on Tariffs and Trade resulted in a global food system dominated by consolidated multinational corporations. In fact, just 6 corporate agrochemicals/seed companies control 75 and 63 per cent of global pesticide and seed market, respectively, with a combined 2013 research and development budget 20 times higher than that of international agricultural research (ETC 2015). Considering that up to 90 per cent of global grain trade is controlled by four agribusiness firms, a change in sourcing policy by a big player may become de facto regulation across the sector (IPES-Food 2015).

Crossroad issues. Economic cost-benefit analysis fails to account for the so far readily available and free natural resources, which undermines the resilience of ecological systems. Efficient pricing of scarce resources (such as water), or additional charges to cover external impacts or ecosystem services (such as cost-based fuel prices to cover health damage incurred by air pollution) are essential in order to reduce wasteful practices stemming from policy distortions. Systems of National Accounts are currently being adjusted to incorporate the so far neglected environmental impacts into measures of income and outputs. However, social externalities are lagging behind; farm and food workers are often heavily exploited, and when legally employed, they represent the largest group of minimum wage earners. If small farmers earned a living wage and farm workers were paid better wages, the price of food would invariably rise. Similarly, farm gate prices would rise if the loss of fertile soil was considered in household economics, or the cost of cleaning drinking water from agricultural inputs was factored into consumer prices. In addition, incentives for more sustainable production

3 Net farm income is "a more comprehensive measure that incorporates non-cash items, including changes in inventories, economic depreciation, and gross imputed rental income" (USDA 2018).

practices require markets and trading systems that function fairly through, for instance, protection of property rights and market mechanisms that ensure prices reflect the opportunity costs of environmental damage or resource exploitation (UN 2012).

1.6 THE HEALTH SPECIALIST PERSPECTIVE: HEALTHY DIETS

Issues at stake: As countries develop, the types of diseases that affect populations are shifting from primarily infectious diseases (such as diarrhoea and pneumonia) to primarily non-communicable diseases (such as cardiovascular diseases and obesity). The double burden of malnutrition constitutes a global health emergency through undernutrition affecting more than 800 million people, micronutrient deficiencies (both under- and over-nutrition derived deficiencies) affecting 2 billion people, including the status of being overweight or obese. Acute malnutrition is responsible for stunting 156 million children, while 99 million children are underweight and 52 million are wasted (8 per cent of children under five years of age), with irreversible impacts through their lives (FAO *et al.* 2017). Almost one third (33 per cent) of women of reproductive age worldwide suffer from anaemia, which also puts the nutrition and health of many children at risk. The cost of under-nutrition to the economy could be 5 per cent of global GDP, or USD 3.5 trillion a year (FAO 2013). In addition, child overweight and adult obesity are on the rise, including in low- and middle-income countries. In 2014, over 600 million people (or 13 per cent of adults over 18) were obese and 41 million children under the age of five were overweight or obese. Obesity is responsible for 4.8 per cent of deaths globally and 8.4 per cent in high-income countries (IFPRI 2016). Type 2 diabetes, which makes up 90 per cent of diabetes cases, has increased in parallel with obesity: in 2013, the number of people diagnosed rose to 368 million, compared to 30 million in 1985 (Gu *et al.* 1998).

Non-communicable diseases (NCDs) are recognized as the number one drivers of the global burden of diseases, affecting one in three people, with an economic loss of 11 per cent in Africa and Asia. Nutrition-related NCDs account for nearly half of all deaths and disability in low- and middle-income countries (IFPRI, 2016). The leading NCDs that are responsible for premature deaths include cardio-vascular diseases (37 per cent), cancer (27 per cent), respiratory diseases (8 per cent) and diabetes (4 per cent) (WHO 2014), all of which having important linkages with the food system.

Past achievements: Health care efforts of the past decades have halted or reversed global epidemics (e.g. tuberculosis, malaria) and between 1990 and 2015, the global prevalence of underweight among children aged less than five declined from 25 to 14 per cent (WHO website).

Externalities: Dietary guidelines refer to diets in terms of calories and nutrient quantities, foregoing concerns about food and environmental quality, along with the implications of matching dietary trends patterns with changes implied for the food system. Mimicking Western diets increases the global demand for animal proteins; increasing supply of animal proteins has entailed a shift towards the production of food-competing feed for an unsustainable animal population, including increases of the incidence of food-borne diseases and prevalence of pathogens in flocks and herds, as well as over-fishing that affects 90 per cent of fish stocks. Considering that up to 80 per cent of greenhouse gas emissions of the food system are associated with livestock production (Tubiello *et al.* 2014), such aggregate dietary decisions have a large influence on climate change; in fact, some scholars argue that changing diets maybe more effective than technological mitigation options for avoiding climate change (Springmann *et al.* 2016).

Prevailing paradigm: Diets should provide safe and nutritious food but what constitutes a healthy diet is subject to debates and cultural sensitivities. Healthy eating recommendations vary from diets with reduced or no meat (e.g. Mediterranean, pescatarian, lacto-ovo-vegetarian and plant-based vegan diets), to constantly changing food pyramids specifying the daily serving quantity of different food groups (e.g. fruits, vegetables, cereals, meat, dairy), or percentage of calories from dietary fats, carbohydrates, free sugars and proteins.

Challenges (within the sector): Global dietary guidelines on healthy eating are not met by half of the world population, who also exceed the optimal total energy intake. Achieving global healthy diets that embody minimal global consensus on the consumption of a few major food groups require a 25 per cent increase in the number of fruits and vegetables eaten globally and a 56 per cent reduction in red meat whereas, overall, the human population would need to consume 15 per cent fewer calories (Springmann *et al.* 2016). Animal-based dietary choices have been referred to as ‘opportunity food loss’, as food can be recovered via changes towards plant-based diets (a rapidly rising trend among millennials in some parts of the world) permitting the reallocation of production resources from animal feed to human food (Shepon *et al.* 2018).

Crossroad issues: The evolution of food systems via cheap inputs is directly responsible for a substantial health impacts. Exposure pathways vary from access to food (or lack of), to individual dietary choices, quality of food (determined by the production, packaging and cooking processes), quality of the environment (determined by agricultural inputs in soil, water and air) and occupational conditions of farmers and workers. The global burden of disease accounts do not consider the whole food and agriculture system in determining disease causation or prevention measures. For example, the obesity epidemic is not only the result of dietary choices with high glucose/carbohydrate content, but also the consumption of refined wheat or sugar that triggers glycaemic peaks and ultra-processed foods and drinks containing sweeteners, as well as to 'obesogens' released in the environment by certain endocrine-disrupting chemicals. Finally, any healthy diet has a carrying capacity that must be considered: for example, the adoption of olive oil consumption worldwide would be impossible (in terms of supply and demand) and the substitution of ingredients such as sugar with high-fructose corn syrup, or of vegetable-based fats such as palm oil as source of cheap food ingredients are rather problematic in terms of both environmental degradation and human health implications.

1.7 THE TEEBAGRIFOOD PERSPECTIVE: SHEDDING LIGHT ON THE ELEPHANT

To take the 'five blind men and the elephant' parable narrated above one step further, one could easily imagine a scenario in which the agronomist worldview, with its primary emphasis on feeding the world, creates ecological and health damages. The environmentalist concern for conservation of nature created social exclusion in protected areas. The sociologist preoccupation with rural livelihoods led to well-intentioned subsidies that adversely affected food market prices. The economist's efforts to stabilize food price spikes generated a food economy that makes people ill. The health expert's focus on treatment overlooked prevention through healthy food and agriculture systems. Actually, causalities and effects are not necessarily in that order, nor binary, but these examples seek to point to some of the connections between the different scientific perspectives.

Indeed, eco-agri-food systems are struggling with several challenges: the dilemma of population growth and hunger; the demographic transition dilemma and the role of agricultural productivity; the environmental adversity dilemma of less favourable areas where agricultural research cannot solve inequities; the scale-positive dilemma that favours innovations to large-scale farmers; the sustainability dilemma and future generations' capacity to produce food; the maintenance dilemma to protect the gains from earlier crop advances; the optimist/pessimist dilemma about prospects of future food supply; and many other dilemmas - such as working at the system or process level (Evans 1998). We are all increasingly faced with demands, questions and planetary level challenges which require the understanding and interactions between agriculturists, environmentalists, economists, social and health care workers at all levels.

In a similar fashion, recent foresight exercises towards 2030-50 - including those of the FAO on world agriculture and IFAD on rural development, OECD on livelihoods and EU on global food security, as well as Agrimonde Terra and UNCCD's global land outlook – have all developed scenario narratives that integrate macro-economic and social drivers which converge on the common trends facing food and agricultural systems, despite the differentiated assumptions made by the different models.

Above all else, the universal challenge to which we all ascribe is to sustainably and equitably produce healthy food in a world of scarcity and uncertainty. In 1992, the global community collectively drew up Agenda 21 on Sustainable Development, followed by the development of sustainable development indicators for the various thematic chapters or clusters. As a result, the tendency today is to interpret the concerns of others through their own specialist lens, or to merely tack entire disciplines onto others, as if no impacts or dependencies existed across disciplines. At best, environmental or social concerns have so far been treated as 'add-ons' when problems became severe enough, leading to emphasis on treatment of ails, rather than prevention. Year 2015 brought the 2030 Agenda and its Sustainable Development Goals (SDGs) milestone, along with the Paris Agreement in 2015, echoing one key message: all disciplines are interlinked. Nowhere can this be better expressed than the tightly woven interplay upstream, within and downstream of agriculture and food systems - challenging nations to put in place trans-disciplinary structures for effective development policies.

The time has come to bring together the microscopic knowledge from each discipline/sector, as equal partners, around a common conceptual framework. The emerging new perspective is to see the eco-agri-food system as one of complex interrelations, synergies and trade-offs. It is the different constituent components and the interplay of the parts that must be analysed, while keeping sight of the big picture.

The goal of the TEEBAgriFood Framework is to introduce a macroscopic method of making and testing decisions in the eco-agri-food system and in the larger wholes in which we live. TEEBAgriFood empowers us to remove our blindfolds to see the whole 'elephant', from head to tail, as the whole 'eco-agri-food system', from production to consumption, and to bridge bridges between disciplines and knowledge bases toward achieving our common goals. With enough practice, it will become simply the way we automatically think and live, in a world that functions in wholes and co-create the common good.

The subsequent chapters of this report outline how the work of the TEEBAgriFood community genuinely shows the path to transdisciplinary science, policy and practice.

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> "THE WORLD AS WE HAVE CREATED IT IS A PROCESS OF OUR THINKING. IT CANNOT BE CHANGED WITHOUT CHANGING OUR THINKING."
>
> -ALBERT EINSTEIN

CHAPTER 2

Why eco-agri-food systems can only be understood with a systems perspective

To resolve the tensions and address the response challenges arising from 'silo' views of food systems, as described in Chapter 1, we need to move to a systems perspective. Little attention is typically paid to connecting the pieces of the systems jigsaw to achieve a comprehensive understanding of reality, but this is necessary. Without this perspective, human, social and environmental impacts along value-chains are not sufficiently considered, especially as they are usually economically invisible. Chapter 2 builds the case for a "systems perspective" to understand eco-agri-food systems: our chosen term "eco-agri-food systems" emphasizes entire value chains as well as the ecological, economic, social and human foundations of food. Chapter 2 outlines the means to understand food systems in their entirety: recognizing and responding to system boundaries and features such as non-linear relationships, feedback loops, rebound effects, time lags and delayed responses. Chapter 2 illustrates a high-level system view of eco-agri-food systems that reflects systems thinking to recognize all capital classes – natural, produced, human and social – and their associated value flows, both invisible and visible.

2.1 INTRODUCTION

The previous chapter pointed out the divergence in evaluations of food and agriculture arising from different specialized perspectives and their respective narratives of success. It helped us define the challenge of providing a comprehensive picture of performance that incorporates the multiple agronomic, environmental, social, economic and health objectives of the eco-agri-food system.

TEEBAgriFood tries to capture the reality of today's highly complex "eco-agri-food" systems. Diverse agricultural production systems grow our crops and livestock and employ more people than any other economic sector. They are underpinned by complex biological and climatic feedback loops at local, regional and global level. These natural systems are overlaid by social and economic systems, which transform agricultural production to food and finally deliver it to people based on market infrastructure and forces, government policies, and corporate strategies interacting with consumer and societal preferences. Furthermore, technologies, information and culture are continually re-shaping production, distribution and consumption, as well as the interactions among them. In the end, the state of many dimensions of human wellbeing, including the health of people and the planet, are determined by these diverse interlinked food systems and consumer choices made within these systems.

As the previous chapter described, most scientific research focuses on components or subsystems of these eco-agri-food systems. There is, however, too little attention paid to connecting the pieces of this puzzle to achieve a comprehensive understanding of reality. Social and environmental impacts along value-chains are not sufficiently considered or valued, especially if they are economically invisible. Economists and market champions place monetary value only on the pieces that can be readily identified, traded and monetized. Political decision makers place faith in best estimates, expert knowledge and hearsay. Even the so called "evidence-based" decisions often consider only some of the pieces of this vast systems puzzle that are well researched, generally ignoring linkages and feedback loops. This leads to an increasing number of policies, programs and strategies designed to address specific problems with 'silo' solutions but with consequences, trade-offs and impacts far beyond their intended effects.

To be clear, we have no objection to highly specialized science. However, when decision-making uses research organized in silos and focuses on maximizing only sectoral or silo performance, it may ignore side effects on other sectors and significant trade-offs.

By emphasizing the wide-angle lens of the TEEBAgriFood Framework (described in Chapter 4), Zhang *et al.* (2018) build the case for implementing a "systems perspective" for understanding eco-agri-food systems and providing responses appropriate for the complex and intertwined nature of these systems, taking into account positive and negative impacts and the relative unilateralism of respective narratives, as against the inter-twined policy challenges found in eco-agri-food systems. This chapter argues that the concurrent consideration of all those interactions helps reveal trade-offs and maximize synergies across all system components. This so-called 'systems thinking' has guided the development of the TEEBAgriFood's Evaluation Framework for the eco-agri-food system.

2.2 BEYOND SINGLE NUMERAIRES

The multi-functionality of agriculture has been profusely documented in the last two decades, including its multiple outputs (food, feed, fibres, agro-fuels, medicinal products and ornamentals), and its effects on many dimensions of human well-being, notably rural livelihoods and employment, human health, environmental services, landscape amenities and cultural heritage. De facto, the agriculture and food system has different meanings to different people, including income generation, calorie production, culinary and cultural heritage, community development and rural lifestyle. These diverse meanings reflect the diversity of community and individual values.

Single indexes, such as the "Gross National Product" for national economic performance, or "Profit and

Loss" for micro-economic performance, are far from appropriate to living systems such as food and agriculture. Their focus on produced capital stocks that have market prices by definition cannot capture multiple socio-ecological facets of human existence. As seen in the previous chapter, the agronomist narrative of 'productivity per hectare' therefore arguably externalizes ecological and social impacts.

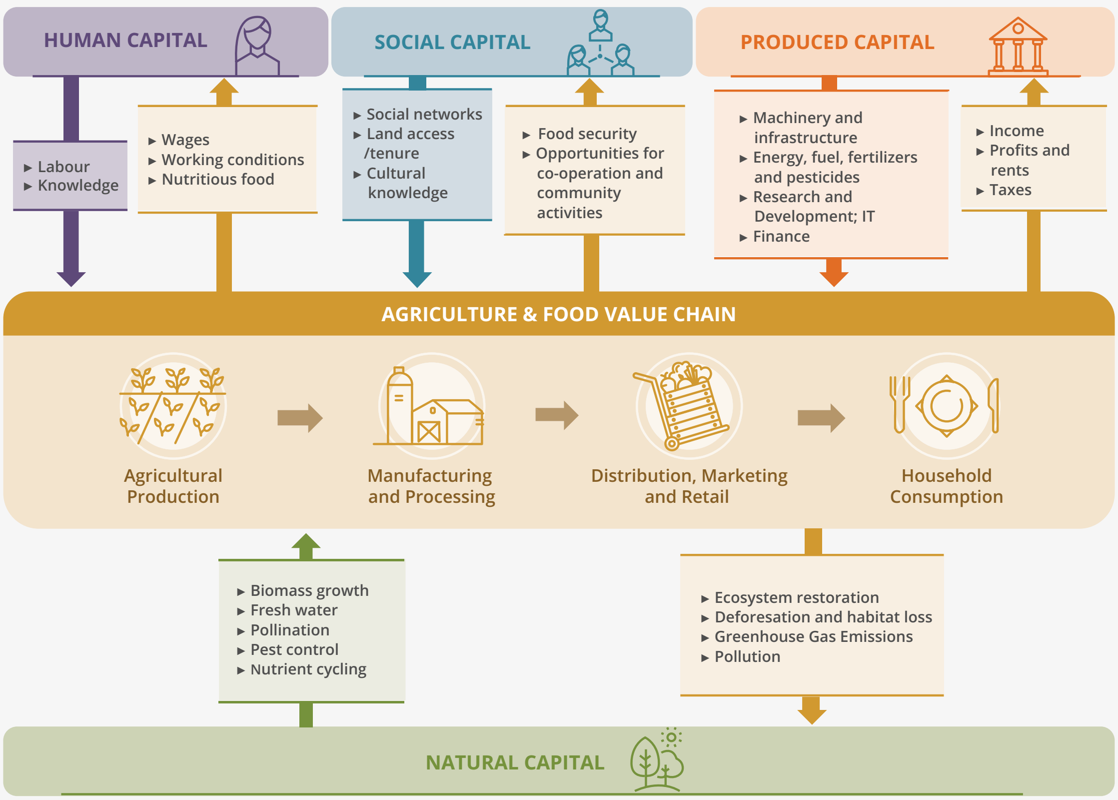
A more realistic appraisal of agricultural systems first requires the understanding their different constituent components, their visible and invisible impacts and dependencies, both up and down food value chains, while also considering time and scale, reflected in different stakeholder values.

2.3 WHY DID WE INTRODUCE THE TERM 'ECO-AGRI-FOOD SYSTEM'?

Why did we feel the need to introduce yet another new term in a field replete with terminology? *'Eco-agri-food systems' is our collective term for the vast and interacting complex of ecosystems, agricultural lands, pastures, inland fisheries, labour, infrastructure, technology, policies, culture, traditions, and institutions (including markets) that are variously involved in growing, processing, distributing and consuming food.* We felt it necessary to use this term (instead of 'food systems') in order to emphasize the importance of thinking in value chains and not in production silos, and equally to highlight the importance of recognizing the "eco" (i.e. natural ecosystem) source of some of the largest and most important but economically invisible inputs to most types of agriculture, delivered through ecosystem services such as pollination, pest control, freshwater provisioning, nutrient cycling, micro-climate regulation, flood protection, drought control, etc.

Furthermore, in referring above to *institutions,* our term "eco-agri-food systems" refers to the web of institutions and regulatory frameworks that influence, or are affected by, the eco-agri-food system: government, non-governmental organizations, financial institutions, businesses, research institutes and others who formulate, shape or implement

Figure 2.1 Capital stocks and value flows in eco-agri-food systems (Source: Hussain and Vause 2018)



actions that determine value chain performance through regulations, finance, policies, campaigns and innovations. Power imbalances, often stemming from economic inequalities within and across households, communities and firms, are a key factor in the way eco-agri-food systems operate. In particular, as the power held by private corporations greatly influences the governance of these systems, the knowledge politics and the political economy of food systems, from national to global level, must take centre stage. Thus, alongside economic, social and environmental sustainability, political sustainability, or the legitimacy of the governance of food systems and their guiding policies, should also be considered (IPES-Food 2015).

2.4 WHAT DOES AN 'ECO-AGRI-FOOD SYSTEM' LOOK LIKE?

Figure 2.1 is a high-level 'systems' diagram of an archetypal eco-agri-food system. View it bearing in mind that the world of food and agriculture comprises numerous different types of systems, or *typologies* as they are sometimes referred to. This illustration reflects a full value-chain perspective, including issues of human health and equity. It also reflects an inclusive conception of the underpinning role of capital assets for the value chain, with vertical arrows representing key flows: impacts and dependencies of each class of capital on the value chain.

The four capital classes depicted here (produced, natural, human and social) reflect mainstream literature in economics and environmental economics over the last half century[4] and are widely used, including most recently by the authoritative "Inclusive Wealth Report" (UNU-IHDP and UNEP 2014).

This diagram shows the typical flows from the four capitals to eco-agri-food value chains, and conversely, some of the most important impacts (both benefits and costs) flowing from eco-agri-food value chains back to these capitals. All of these significant dependencies and impacts need to be captured and incorporated in a holistic description of any eco-agri-food system.

2.5 THE IMPLICATIONS OF SYSTEM BOUNDARIES

No farm is an island when water flows through watersheds upstream and downstream and the wind blows across territories. Even farms that attempt to create closed nutrient and energy flows are not 'closed' as such, because they interact with human systems, and all human activities are hosted on a spaceship called Earth[5]. The current global concerns with climate change, wherever one is located, is further proof, if any were needed, that spatial boundaries are not the farm gate, nor the nation's border, but the planet.

The 'planetary boundaries' concept was introduced by Rockstrom *et al.* in 2009, who demonstrated that human development should remain within the 'safe operating space' between a socially equitable 'floor' and an environmentally safe 'ceiling', if it is to avoid disastrous consequences. In other words, eco-agri-food systems, which greatly contribute to pressures to transgress several planetary boundaries (i.e. climate change, biospheric integrity, freshwater use, land use change, phosphorous and nitrogen) have to respect ecological constraints or face potentially devastating consequences for the basic conditions for human life on earth, when crucial earth systems – climate, freshwater cycle, nitrogen cycle, etc. – cross respective tipping-points and enter states which are much less hospitable for humans. The Planetary Boundary concept was expanded by Raworth in 2012 to develop the idea of a socially acceptable 'floor' further, to include social justice requirements underpinning sustainable development, thus promoting the broader idea of a 'safe and just operating space' (see **Figure 2.2**).

One of the undercurrents of the work on 'planetary boundaries' is that some of them might be 'planetary time bombs'. There are thresholds or "tipping points" both at regional and global scales in many of these earth systems, and we may be much closer to tipping points in some boundaries in some regions than in others (Steffen *et al.* 2015). Indeed, some of the most urgent regional "threshold" effects already being observed (e.g.: flooding of Pacific Small

4 The works of senior economists including Theodore Schulz, Kenneth Arrow, Partha Dasgupta, Karl-Goran Mäler, David Pearce, and others from the 1970s onwards have consistently referred to these four broad classes of capital (see Chapter 4 for definitions and details)

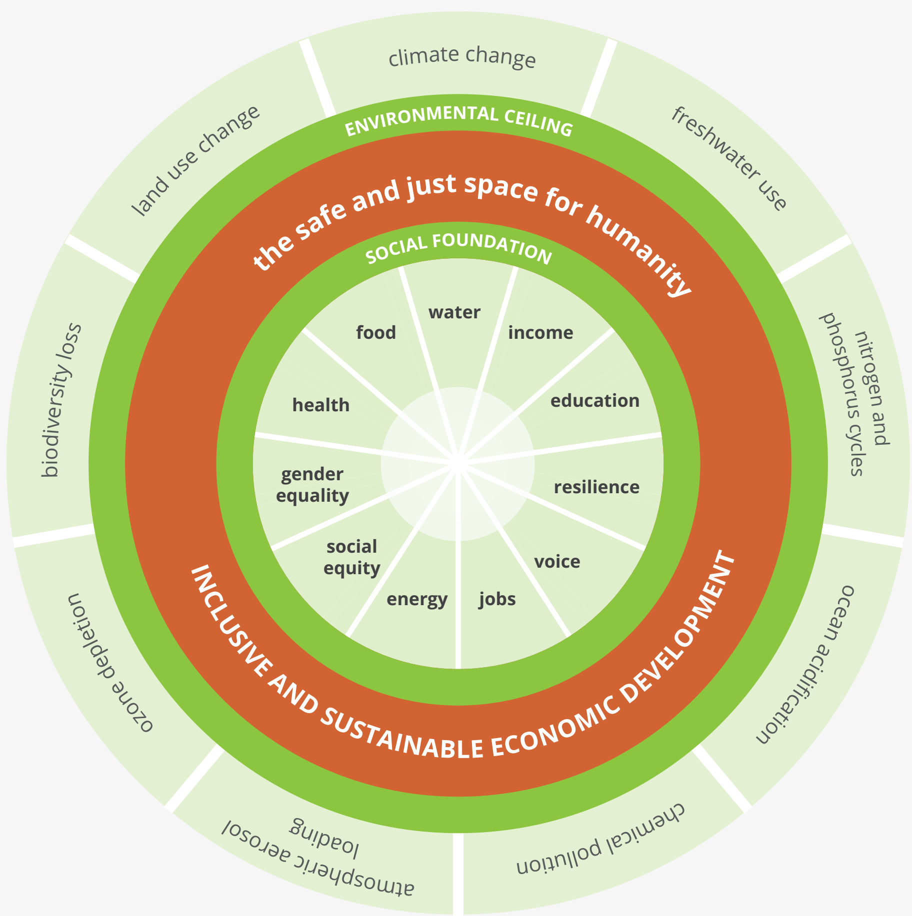
5 A metaphor coined by Henry George in his book "Progress and Poverty" (1879), used by several other authors, and popularized by Kenneth Boulding's essay "The Economics of the Coming Spaceship Earth", 1966

Island Developing States due to climate change) or feared to be imminent (e.g.: warming of polar ice caps; disruption of thermohaline circulation in the Atlantic; etc.) are related to either climate change or the loss of biospheric integrity, the two planetary boundaries now acknowledged (Steffen *et al.* 2015) as foundational to all other boundaries. Systems thinking requires that the differing contributions of various eco-agri-food systems in driving humanity's trajectory towards various planetary boundaries need to be considered when evaluating these systems. Conversely, the relative contributions of various eco-agri-food systems towards *meeting the requirements* of socially just human development must also be taken into account.

This concept of a 'safe and just operating space' has of late been used to guide analysis of regional socio-ecological systems in a variety of situations and contexts (e.g. China water management [Dearing *et al.* 2014]). Therefore, whilst recognizing the limitations of our knowledge about the underlying ecological processes, functions and impacts of various systems, the social and natural foundations of sustainability do require that we investigate beyond narrow results (such as per hectare output) and consider the wider effects of individual activities, ideally also to act upon them through policy responses and choices made by enterprises and individuals.

Taking a systems approach, by definition, encourages policy makers to consider the relevant spatial and temporal boundaries, and thus also assess the impact of alternative systems on a broader set of policy considerations.

Figure 2.2 The safe and just space for humanity (Source: Raworth 2012)



2.6 THE NATURE OF SYSTEM RELATIONSHIPS

Any enterprise, including in the world of agriculture and food, relies on human, social and natural resources to thrive. The use of these resources by the enterprise drives numerous outcomes and impacts, some of which are planned, priced and accounted for in the operations of the enterprise, and others (the so-called ‘externalities’) are not. Unravelling the relationships within and between systems requires understanding the intended as well as the unintended effects created by interventions of the enterprise. It is a moot and ethical point whether some of these ‘unintended’ effects are in fact expected and predictable by the enterprise (e.g.: climate outcomes of GHG emissions; human health outcomes of animal antibiotic use) and simply ignored because our economic systems do not capture, measure or price them, or whether they are genuinely unexpected. The former could be seen as system design weaknesses (e.g., the lack of clearly defined “property rights”) which lead to social inequity or environmental damage or public health costs, whereas the latter could be seen as systemic risks or uncertainties which need to be acknowledged, researched, and better understood. In either case, these are all aspects of systems that need to be documented and mapped to achieve a proper understanding of the system being evaluated.

When we document and map the relationships that comprise any such system, we may often come across features such as non-linear relationships, feedback loops, delayed responses, rebound effects and cumulative effects. We comment briefly below on each of these features.

Non-linear relationships. Whilst documenting the various relationships that exist within and across systems, it is often observed that they are not expressible in simple proportions and ratios, i.e., they are not linear. Eco-agri-food systems involve numerous components or sub-systems which interact dynamically and in a non-linear manner, and also others which give rise to unpredictable properties that emerge at different levels of organization. Contrary to simple and linear systems whose behaviour follows a precise logic and repeats itself in a patterned way, complex and non-linear systems have feedback loops that may be difficult to predict and that generate an array of consequences.

Feedback loops The inter-dependence of the various components of the eco-agri-food system implies that interventions to improve one component (e.g. reducing environmental pressure) may produce impacts elsewhere (e.g. affecting employment, investments and earnings). Thus, actions or policies that seem reasonable in one sector, or at one temporal or spatial scale, can cause unintended adverse effects on other sectors, or across other temporal/spatial scales. Feedback is defined as a process whereby an initial cause ripples through a chain of causation, ultimately to re-affect itself (Roberts *et al.* 1983; Probst and Bassi 2014). Feedback loops are of two types: positive (or reinforcing) loops that amplify change and negative (or balancing) loops that counter and reduce change. When such feedback loops are identified, entry points for effective intervention, or policy levers, can also be detected.

Rebound effects. Caused by feedback loops and depending on the strength of the feedback loop, rebound effects may occur. For example, improved technology (e.g. high efficiency irrigation) affects economic productivity (e.g. water), which in turn will lead to system changes (e.g. more cultivations increasing water use) that create new equilibria (e.g. depressed food prices that inhibit further expansion).

Delayed responses. A snapshot approach to the eco-agri-food system is not representative of the dynamic interactions of its components. Some inter-dependencies might be poorly captured and others overlooked as they are deemed irrelevant because their effects become apparent only over the long-term. Since the eco-agri-food system is continuously evolving and adapting, there are limits to comparative static analysis. Considering that economic and political decision-making timeframes are relatively short (rarely exceeding five or ten years, i.e. one or two terms of political office) and that social and ecological changes have much longer time frames (measured in decades), a precautionary approach is advisable in case of uncertainties (i.e. lack of knowledge of possible feedback and rebound effects). Systems thinking includes the notion of ‘adaptive efficiency’ where the focus is on practices and processes that will enable a system to adapt to change. Therefore, preparing for the unexpected is paramount.

Cumulative effects. Especially in agriculture where a myriad of small decision-makers is involved, seemingly insignificant decisions accumulate and can result in undesirable outcomes. Further downstream in the food value chain, an accumulation of individual choices may have the ultimate effect of changing consumer preference functions themselves.

This is a feature of human behaviour that has of late been accentuated and accelerated by the growth and success of 'social media'.

2.7 MAPPING SYSTEM RELATIONSHIPS

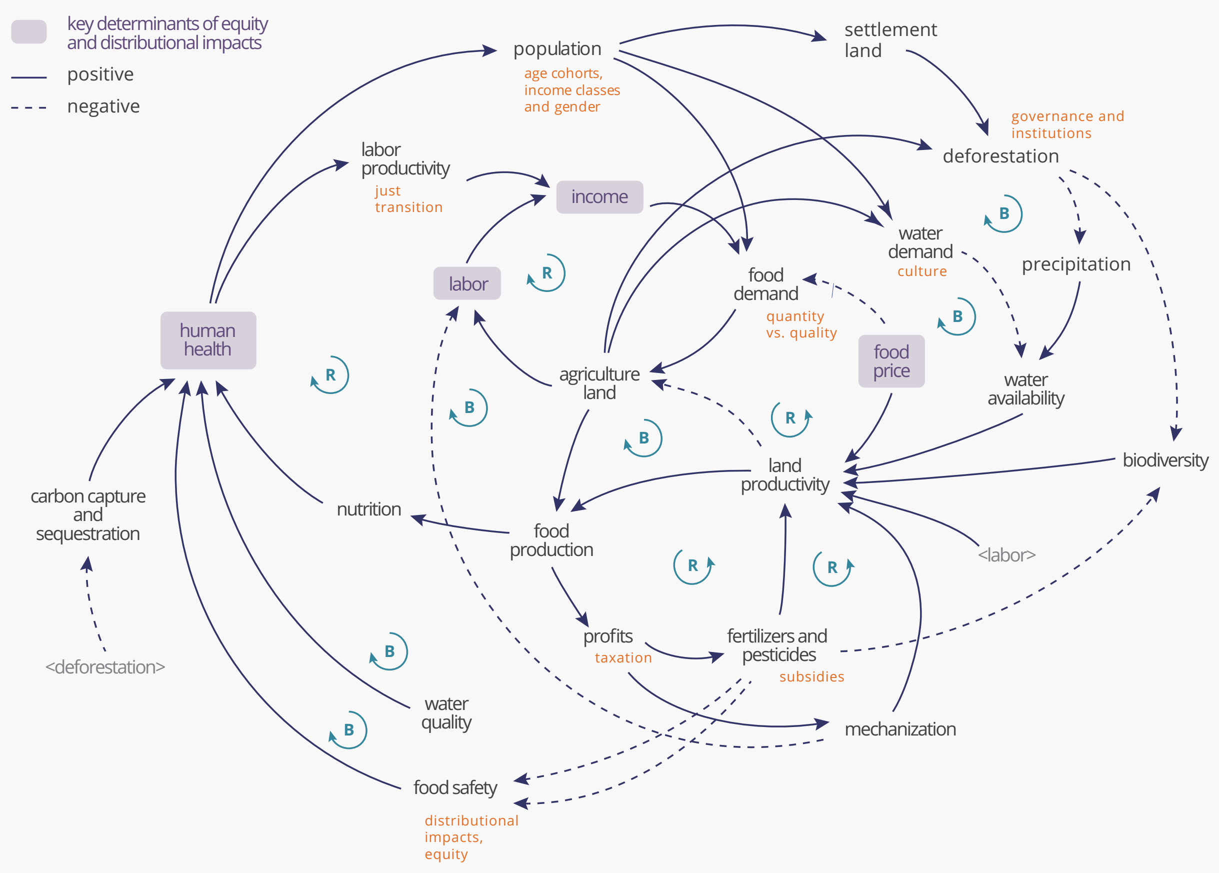
Often, it is the very system that we have created that generates problems, due to external interference or to a faulty design, and the causes of the problem are often found within the feedback structures of the system. A visualization of the system, its generic relations and its reinforcing and balancing feedback loops makes visible the emergence of side effects. Such evidence of the interconnectedness, particularly regarding public goods affected, can trigger coherence and synergies for a more balanced and equitable development approach. There are different ways of visualizing systems, and we illustrate one approach that is useful in practise.

Figure 2.3 presents a form of system map known as a 'Causal Loop Diagram'. It illustrates the complexity of the eco-agri-food system in order to shed light on how a system works. Causal Loop Diagrams make feedback loops visible, including reinforcing (R) feedback loops and balancing (B) feedback loops and facilitating a shared identification of entry points for interventions by several actors in a coherent way.

2.8 SYSTEMS THINKING FOR ECO-AGRI-FOOD SYSTEMS

Silo approaches are limiting our ability to achieve a comprehensive understanding of the interconnected nature of eco-agri-food system challenges. As a first step towards the paradigm shift called for by many scholars and thought leaders, it is crucial to re-assess how we conceptualize and interpret the global food system and how we choose the methods we use to analyse its problems.

Figure 2.3 Illustrative Causal Loop Diagram of a generic eco-agri-food system (Source: Zhang *et al.* 2018)



Systems thinking sheds light on the main components and relationships of eco-agri-food systems, including drivers of change as determined and impacted by feedback loops, delays and non-linear relationships, in the context of change along the value chain. This facilitates predicting the emergence of side effects and trade-offs, identifying winners and losers, uncovering synergies, and better understanding and forecasting the outcomes and impacts of policy decisions across sectors and economic actors, over time and in space.

With a view to establishing the building blocks of a theory of change, systems thinking empowers us to think beyond technical analysis and decision-tool development. Adopting systems thinking for eco-agri-food systems can aid the forming of a common ground for cultural changes by promoting more integrated approaches and collaborative spaces that cut across silos of expertise and selective interests. Only by making the invisibles (i.e. externalities) visible, society will be better positioned to take into account the full impacts of activities that were previously ignored and progress towards socially inclusive and environmentally safe progress: in essence, towards sustainable development.

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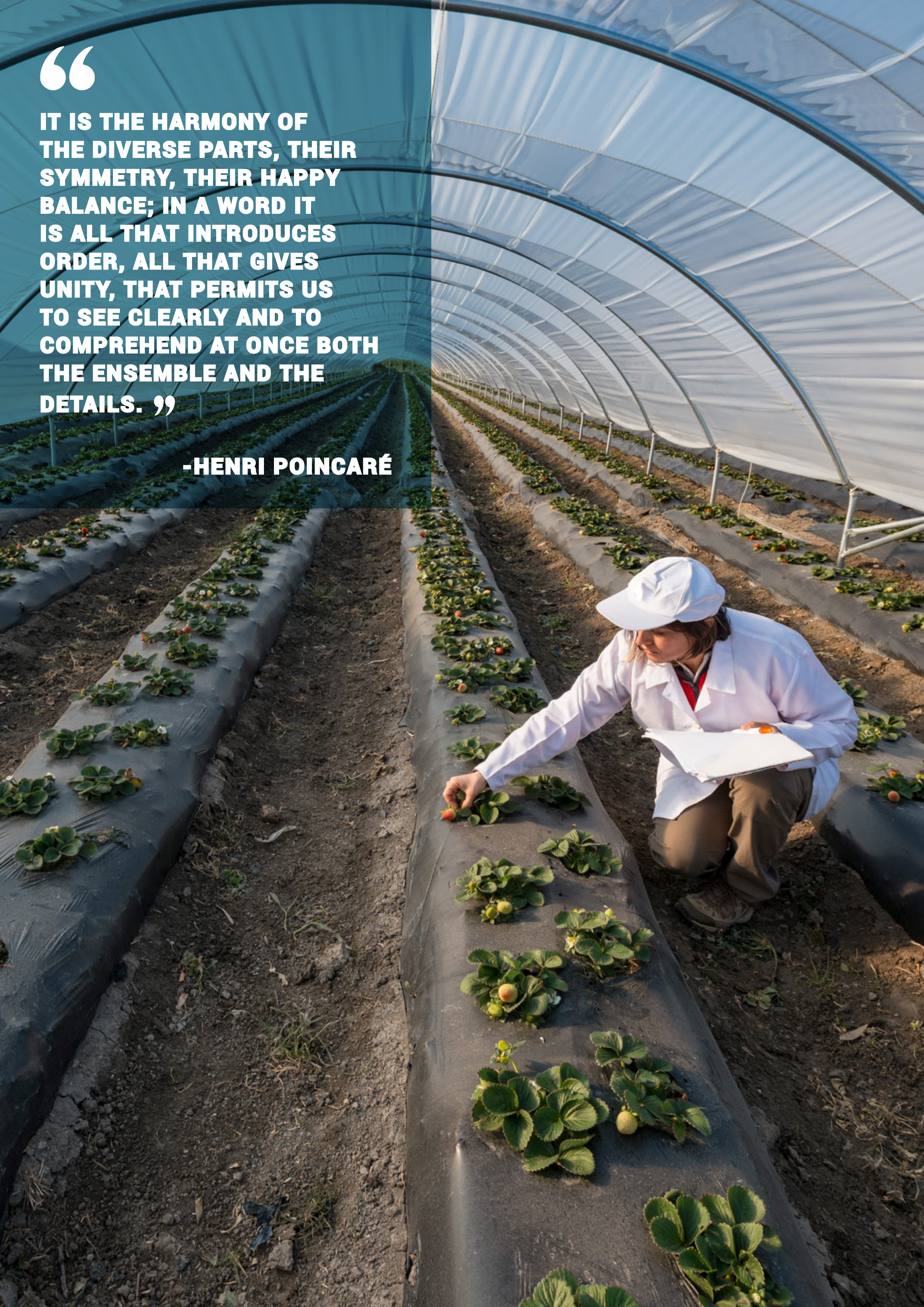


"IT IS THE HARMONY OF THE DIVERSE PARTS, THEIR SYMMETRY, THEIR HAPPY BALANCE; IN A WORD IT IS ALL THAT INTRODUCES ORDER, ALL THAT GIVES UNITY, THAT PERMITS US TO SEE CLEARLY AND TO COMPREHEND AT ONCE BOTH THE ENSEMBLE AND THE DETAILS."

-HENRI POINCARÉ

CHAPTER 3

The complex reality of eco-agri-food systems

Chapter 3 brings together key learnings from chapters 3, 4 and 5 of the TEEBAgriFood 'Foundations' report, outlining major elements of eco-agri-food systems in all their complexity, inter-connectedness and human significance, recognizing nutrition and health, livelihoods and equity as central to the underlying purpose of food systems. It describes the whole range of eco-agri-food systems – from modern to traditional to mixed, and, also across the various types of supply chains operating further along food value chains. The economic dominance of the private sector for inputs (seeds, fertilizers, pesticides) and processing (food and beverage) is palpable. This chapter describes various dimensions of eco-agri-food systems, including key drivers such as dietary patterns, food demand and technology as well as key outcomes and large impacts such as waste and greenhouse gas emissions, and significant impacts on human health and on food security and social justice. For each dimension, it lays out key interlinkages across the system, the consequences of 'business as usual', as well as some key societal transition points and aspirational scenarios depicting sustainable alternatives to 'business as usual'.

3.1 INTRODUCTION

There are many different types of agriculture and food systems, each with different contributions to global food security, impacts on the natural resource base and ways of moving food through supply chains. An improved understanding of the possible pathways towards sustainable food systems and the logic of intervention from different stakeholders around the world first requires a better understanding of this diversity.

Farming as an agricultural operation uses ecosystems (land, water, biodiversity) as substrate and crop and livestock as a factory building blocks. Any interaction of humans with the environment has consequences: farming can maintain, improve or degrade soil fertility; it can also create new biodiversity. The genetic resources for food and agriculture (GRFA) are a result of breeding efforts of generations of farmers over thousands of years – and can also destroy biodiversity, both wild biodiversity and agricultural genetic resources (Hunter *et al.* 2017). Management practices have an impact on organisms' susceptibility to diseases, requiring increasing or decreasing quantities of chemical interventions that can pollute water and air. Conversely, a regenerative form of agriculture (e.g. agro-ecological, organic, biodynamic, integrated) can provide a unique pathway to heal nature, restore and restock soils with carbon and microbiota and create ecosystems where diversity thrives.

Significant intangibles in global food trade remain as hidden costs that are largely not known or recognized by policy makers. It is such externalities and invisibles that are a focus of true cost accounting in agriculture and food system and that can be measured as "materials embodied in trade", "indirect flows", "hidden flows", "virtual flows" or "ecological rucksacks".

Human health is directly dependent on food and nutrition security. On the one hand, food systems currently provide more food than ever before, enough to satisfy the dietary needs of a population of 7.5 billion. On the other hand, six of the top ten risk factors driving the burden of disease are diet-related. Malnutrition impacts the quality of life for billions of people; in fact, 88 per cent of countries face the serious burden of two or three forms of malnutrition (i.e. micronutrient deficiencies, stunting/wasting, overweight/obese [WHO 2017]). Most efforts focus on direct food consumption and dietary composition, ignoring key risk factors such as environmental contamination from agriculture, food adulteration, risks to farmworker health by unsafe handling practices, or loss of nutrients resulting from the overall commodification of food. Eco-agri-food systems can either cause disease across generations (WHO and UNEP 2013) (e.g. endocrine-disruptor chemicals affect people in pre-natal phases), or provide a pathway to healthy lives (e.g. food with more polyphenols that strengthen the human immune system [EPRS 2016]), depending on a variety of conditions that determine what, how and how much food is produced, processed and consumed.

Quality of life, whether individual or global, requires equity in all spheres of human interactions, including across the eco-agri-food system. Certain agrifood systems secure decent livelihoods and equitably distribute benefits, while others exploit workers and deprive communities of healthy food and clean environments. In an equitable food system, all people have meaningful access to sufficient healthy and culturally appropriate food, and the benefits and burdens of the food system are equitably distributed. Creating an equitable food system requires actions ranging from improving people's access to productive resources (e.g. land, water, credit, technology), to ensuring labour rights and gender equality. Equal opportunities generate benefits to wider communities while alienation leads only to degradation throughout the agri-food system.

3.2 CHARACTERIZATION OF AGRICULTURE AND FOOD SYSTEMS

Inter-dependent sets of enterprises, institutions, activities and relationships collectively develop and deliver material inputs to the farming sector, produce primary commodities, and subsequently handle, process, transport, market and distribute food and other products to consumers (UNEP 2016b). Each stage of harvesting, storage, processing, packaging, marketing, trade transport, demand, preparation, consumption and food disposal requires inputs and generates, along with a wide range of governance systems, research and education, and varied other services (e.g. financial) around food provisioning. The heterogeneity of farming systems reflects, in many senses, the diversity of social, economic and ecological responses to changing adaptive conditions in different settings (Ploeg 2010). Clearly, various food and agriculture systems cannot but have different positive and negative externalities and impacts across the value chain.

Using a typology recently developed by the International Resource Panel of the United Nations Environment (UNEP 2016a) and adopted by the High-Level Panel of Experts on Food Security and Nutrition (HLPE 2017), Pengue et al. (2018) characterize the world's food systems as traditional, intermediate/mixed and modern, noting that they may overlap and intersect[6]. Each of these modes can be more strongly linked to natural capital and ecosystem service provisioning and to society as a whole. A more recent debate on the concept of agroecology implicitly raises the question of farming systems of the future (FAO 2018).

Traditional food systems. These are primarily low-external input systems based on natural processes and practices developed over generations, including farmers, pastoralists, forest dwellers and artisanal fishers providing staple food for about one billion people and contributing 50 per cent of global capture fisheries (i.e. excluding aquaculture) (Ericksen 2008). These systems are largely subsistence focused, using traditional cultivars and high labour, with no or very little application of external nutrients, no use of synthetic chemicals for pest and disease control, and high emphasis on on-site nutrient cycling. Compared to mechanized high input systems, productivity per unit is low and produce is sold largely unprocessed in local markets. While suffering from a lack of adequate storage facilities for perishables and lack of roads to access markets, a distinctive characteristic of traditional systems is the cultural element that permeates the system management.

Modern food systems. These are large high-external input systems strongly dependent on purchased inputs such as improved high-yielding varieties, synthetic fertilizers, pharmaceuticals, pesticides and fossil-fuel powered machinery with low labour intensity, based on capital (World Bank 2010) and technologies. These systems are designed to produce the highest output at the lowest cost, usually using economies of scale and global trade for financing, purchases and sales. Produce is commercialized in large, often transnational, food, feed and energy markets, including branded processed products, predominantly sold in supermarkets and food services and catering. Unlike traditional systems that integrate crops and livestock of different kinds, specialization results in eroding monocultures and feedlots. Modern biotechnology (e.g. genetic manipulation), ICT (e.g. satellite mapping) and artificial infrastructures (e.g. hydroponics) characterize attempts to increase production in the face of constraints such as weather events, soil degradation and water scarcity. Privileging a few high-yielding cereals has resulted in a loss of nutritional density of modern varieties of staple crops; declines of nutrient concentrations (protein, Ca, P, Fe, riboflavin and ascorbic acid) are documented for several crops (Davis 2009). Considering the rapid growing demand for fish (providing 6.7 per cent of global animal protein intake in 2013) and the decreasing capture of fisheries stocks, aquaculture is an increasing trend in modern food systems, growing in its sophistication and use of technology.

Intermediate (or mixed) food systems. The largest number of the world food systems can be classified as 'intermediate', providing food to around 4 billion people. Such mixed systems include different small and medium size producers that use combinations of traditional and modern system technologies. These systems require medium to high labour inputs (both manual and mechanized) and agro-ecological knowledge-intensive management. These systems have a partial market orientation, with both subsistence and commercial sale, the latter being in local, regional and global markets. A current trend in these systems is the growth of urban agriculture (mainly horticulture) on rooftops and public urban areas. Considering the source of food products, the supply chains involved in moving food products from growing and processing to the consumer, and various retail points that convey goods to the end user, intermediate/mixed systems could further be split into two types (Therond *et al.* 2017): traditional-to-modern; and modern-to-traditional. For instance, foods can be grown within the region and enter either a retail supermarket (traditional-to-modern). On the other hand, a highly processed product (e.g. soda) can originate via a global supply chain and end at a traditional market (modern-to-traditional).

Within mixed systems, there is a relatively small but steady growth of agro-ecological science seeking to

6 We are using this internationally agreed terminology knowing that the label "modern" is often questioned and it has been proposed to use "industrial" or "high-input" in order to avoid making a value judgment.

establish efficient food systems in terms of nutrient and energy flows. These take the form of the worldwide adoption of different forms of approaches, including permaculture of Bill Mollison (Australia), biodynamic farming of Rudolf Steiner (Europe), the 'one-straw revolution' of Masanobu Fukuoka (Japan), bio-intensive farming of John Evons (USA), no-tillage movement led by Ana Primavesi (Brazil), agroecology of Stephen Gliesmann (USA) and Miguel Altieri of SOCLA (Latin American Scientific Society of Agroecology), food sovereignty of MAELA (Latin America) and La Via Campesina, and the nowadays globally legislated organic agriculture market exceeding USD 80 billion retail sales.

Supply chains in mixed food systems are diverse, spanning from a simple straight line of firms, strictly guided by the focal company, to informal relationships among firms with almost no governance other than the market. Six different supply chain typologies can be distinguished, including those driven by (1) large retailers found across the world, mostly multinational companies (e.g. Wal-Mart, Carrefour, Tesco); (2) a global processing company usually governing the food chain in which they operate by buying raw materials and other inputs from a large set of producers who are in a quasi-captive position; (3) a cooperative with strong and stable horizontal coordination by farmers associations; (4) geographical indications (names) for traditional food that refer to the location where production takes place; (5) a focal company that is a small farm, processing firm, or small-scale retailer who privileges traceable and transparent short chains of raw material; (6) a specialized high quality retailer that offers high quality food (e.g. Eataly, iGourmet, Eat's Food Market, Wholefoods).

These are admittedly very broad categories but this typology represents a step forward toward understanding the differential contributions of diverse food systems, which is essential to appreciate global food and nutrient production and the diversity of agricultural landscapes. Herrero *et al.* (2017) documented that the majority of vegetables (81 per cent), roots and tubers (72 per cent), pulses (67 per cent), fruits (66 per cent), fish and livestock products (60 per cent) and cereals (56 per cent) are produced in diverse landscapes. Similarly, the majority of global micronutrients (53–81 per cent) and protein (57 per cent) are also produced in more diverse agricultural landscapes. By contrast, the majority of sugar (73 per cent) and oil crops (57 per cent) are produced in less diverse ones (less than 1·5 ha); these crops also account for the majority of global calorie production (56 per cent). The diversity of agricultural and nutrient production diminishes as farm size increases, but regardless of farm size, areas of the world with higher agricultural diversity produce more nutrients. Thus, it is evident that both small and large farms are important contributors to food and nutrition security, but very small, small and medium sized farms (thus largely traditional and mixed food systems) contribute the majority of production and nutrients in the most populous regions of the world.

Consumption patterns depend on historically evolving factors. Geopolitical, social, ecological and nutritional relations have shaped the concept of 'food regimes,' evolving from the 1800s family labour contribution to the growth of food markets and nations, through the extension of state systems agri-food forces to former colonies in the 1960s, to the current corporate control of agri-food multinationals. Predominant food regimes determine international divisions of labour and patterns of trade, relations between food systems, the environmental and social assets involved, and therefore, are responsible for tensions and contradictions. Food regimes can generate stable or consolidated periods (as well as transition periods) of capital accumulation associated with geopolitical power. Food regimes can support stability or contribute to instability in societies and region.

3.3 ADDRESSING MULTIPLE CHALLENGES

A prevailing economic logic has been in place for the last several decades, reinforcing forms of food production that neglect the contribution of nature while seriously impacting it, and also create effects on human welfare by creating widespread degradation of land, water and ecosystems, emitting greenhouse gases, contributing to biodiversity loss, promoting chronic over- and under-malnutrition as well as a number of non-communicable diseases, and stressing farmers' livelihoods around the world. The nature of international trade resulting from such forces and pressures has many ramifications for equity and sustainability. An emerging feature of global food systems is the existence of multiple, insidious forms of visible and invisible flows of natural resources. An increasingly dire context in addressing such challenges is the need for farmers and local communities to deal with the often-unpredictable impacts of climate change. Important decisions will have to be made based on a comprehensive approach to the eco-agri-food system: the challenge to accomplishing sustainable, universal food and nutrition security for a future with 10 billion people, predominantly living in urban areas.

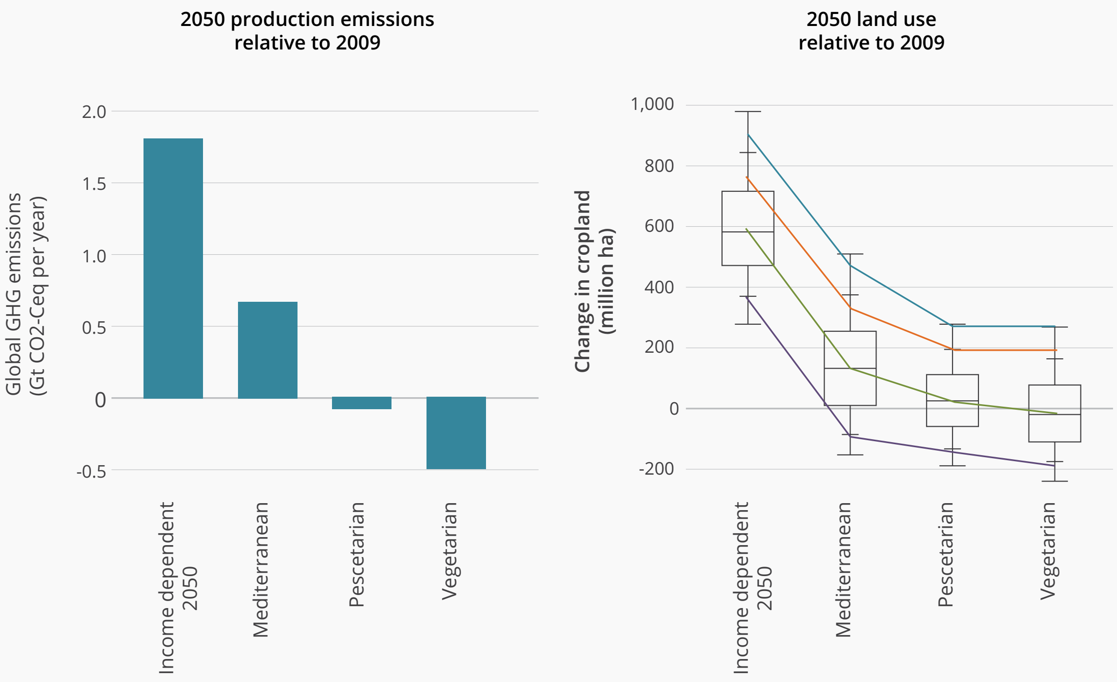
Based on work by Hamm *et al.* (2018) and Tirado von der Pahlen *et al.* (2018), seven main challenges to the sustainability of eco-agri-food systems are presented below by first highlighting some of the linkages between different aspects of agriculture and food systems, then summarizing business-as-usual outcomes, based on existing projections towards 2030-50. Lastly, we spell out what an aspirational scenario for a better future could look like, as expressed by the Sustainable Development Goals, should connections be visible enough to trigger adequate policy responses and changes in practices. Acknowledging that the narratives are neither comprehensive nor based on any modelling, the intent is to demonstrate that moving from business as usual to a positive transformation in the food system will depend on the recognition of interrelated developments.

3.3.1 Dietary patterns and food demand

Linkages. Current dietary patterns, especially excessive consumption of animal products in high-income countries, are not sustainable and would be environmentally deleterious if expanded globally (Garnett *et al.* 2015). Excess calorie and/or protein consumption that characterizes current dietary patterns constitute a form of resource waste: in more than 90 per cent of the world's countries, the average person had daily per capita protein consumption exceeding estimated dietary requirements in 2009 (Ranganathan *et al.* 2016). On average, the more animal products and processed food consumed per capita, the more land, fertilizer, and water required for production, with severe repercussions in terms of greenhouse gas emissions and other forms of degradation and pollution. Broad patterns in diets are changing globally in fairly consistent ways, linked to increases in income and urbanization over the last half-century. The last few decades have seen a shift towards poor-quality diets, excess caloric intake and low levels of exercise, which led to a rapid increase in obesity and other non-communicable diseases, closely related to the food system type in which food consumers exist, besides changes in income status and lifestyle. For example, industrial agriculture has had impacts on nutrient content of crops, through its objective to produce large quantities of relatively inexpensive energy-rich, nutrient-poor food. Demand is rising for meat, as well as "empty calories" derived from refined sugars and fats (Tilman and Clark 2014).

Business-as-usual into the future. Assuming the same faster pace of output growth attained over the past

Figure 3.1 Effects of diets on GHG emissions (Source: Tilman and Clark 2014)



10 years, FAO projections indicate that a 50 per cent increase in gross agricultural output is needed by 2050, compared to 2012. Despite such increased food supply, the number of undernourished in 2030 is estimated to be 637 million people in low- and middle-income countries (FAO 2017a). Asian diets are in striking dietary transition, led by China and its population's urban migration, rising incomes, and growing middle-class.

The global dietary transition - and its future trajectories - is one of the greatest challenges facing the world. The total greenhouse gas emissions from agriculture are highly dependent on the composition of diets: it is calculated that global average per capita dietary GHG emissions from crop and livestock production would increase 32 per cent from 2009 to 2050 if global diets simply continued along current trends (Tilman and Clark 2014).

Aspirational scenario. If adopted globally, alternative diets such as the Mediterranean diet and other meat-reduced diets would reduce emissions from food production substantially, below those of the projected 2050 income-dependent diet with per capita reductions (see **Figure 3.1**). These estimations also suggest that shifts in global diets could substantially decrease future agricultural land demand and land clearing. The eco-agri-food system will need to find solutions to the "diet-environment-health" trilemma aiming for healthier diets with low GHG emissions, rather than singularly seeking to minimize GHG emissions alone. Alternatives include revising diets for a healthier and smaller level of meat consumption, as well as focusing on meat production that requires less reliance on feed grains, which occupy large parts of agricultural lands and are often shipped from long distances. Diversification of production and hence, market supply of enhanced diversity for healthier diets, requires the correction of distortions to farm- and market-level incentives, with investments in greater use of agricultural biodiversity, as compared to current investments in bio-fortification that compensate for only one or two micronutrients per crop.

3.3.2 Human health and food ecology

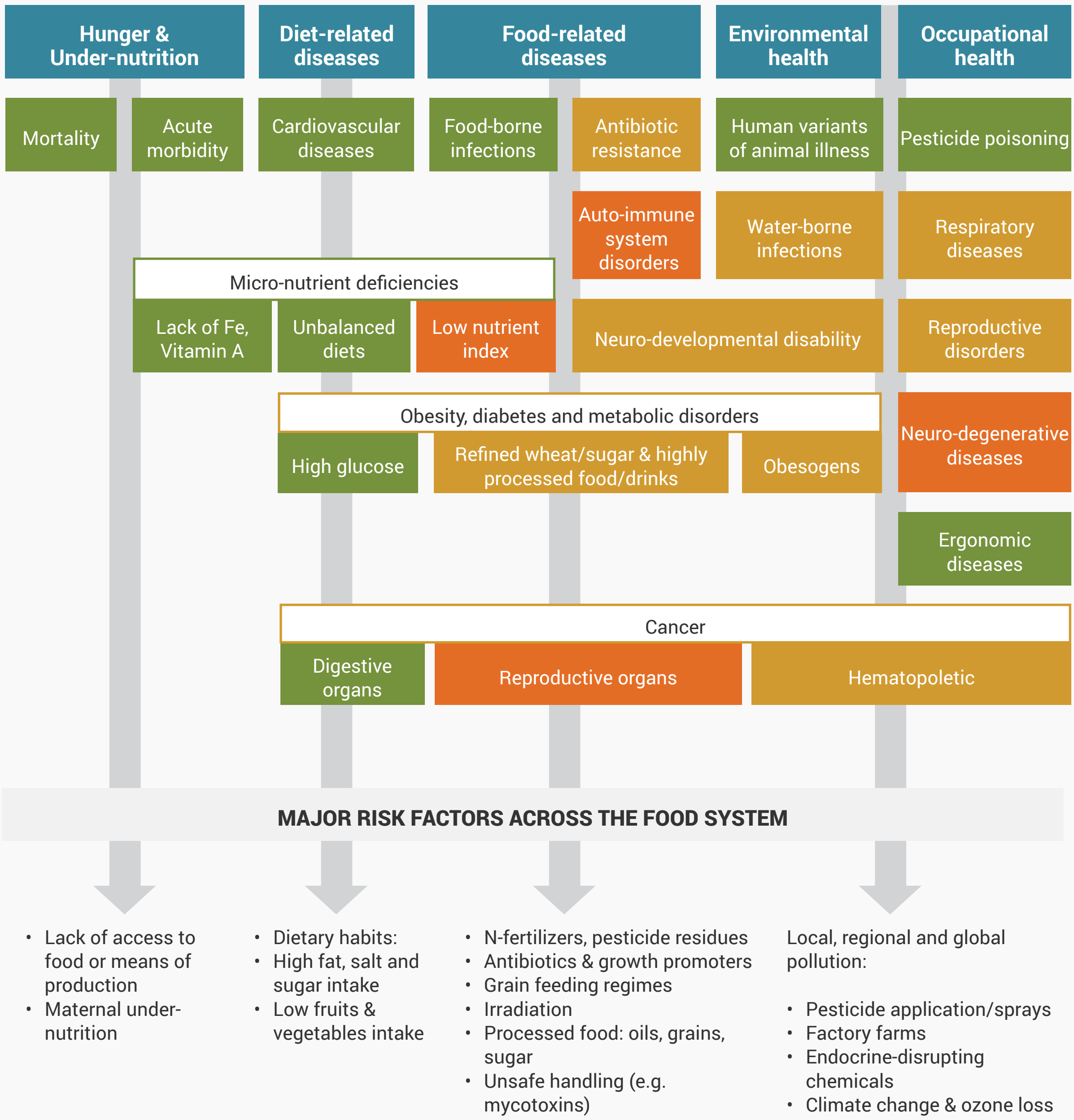
Linkages. Although life expectancy has increased worldwide, mainly due to improved healthcare, 'years lived with disability' also increased, due to the rapid increase of non-communicable diseases. The average dietary pattern in the world is not conducive to optimal health, and food systems determine human health to a great extent. In fact, access to resources, agri-environmental quality and occupational supply chain contexts can be major risk factors or determinants of health. Areas for improvement include the use of nitrogen fertilizers and pesticides that yield crops with fewer nutrients and micronutrients (e.g. polyphenols [EPRS 2016]); factory farms that produce products low in Omega-3 and other anti-oxidants; cumulative pesticide and veterinary drug residues in food; hygiene and appropriate storage conditions in post-harvest handling and storage (resulting in aflatoxin or other microbiological contamination); irradiated and refined products with reduced vitamin and mineral contents; (ultra)processed food and beverages with many additives; and packaging, coated cans and non-stick cookware that include endocrine-disrupting chemicals (e.g. phthalates and bisphenol A). **Figure 3.2** illustrates how human health has multiple causal links with the food ecology[7].

A new study published by the *German National Academy of Sciences Leopoldina* assesses the problem of pesticides as "a systemic problem" (Schäffer *et al.* 2018) and concludes that "pesticides have to be viewed in conjunction with the presence of many other substances which humans and the environment are exposed to (pharmaceuticals, biocides, fertilizers, industrial chemicals). The combined effects of multiple substances that have a simultaneous or successive effect on an organism, such as in the cases of tank mixtures or through sequential applications (spray sequences) of pesticides, are systematically neglected in the risk assessment. This gives rise to a systematic underestimation of the risks posed by chemicals."

Business-as-usual into the future. Currently, two-third of the world's population lives in countries where being overweight and obese kills more people than being underweight (WHO 2016). If this trend continues, by 2025 the per centage of overweight and obese children under five will reach 11 per cent, with serious consequences for future risks of non-communicable diseases (WHO 2014). The number of new cancer cases is expected

7 **Figure 3.2** brings together knowledge from nutrition science, environmental health and epidemiological, toxicological and clinical medicine under the common umbrella of food systems. The green coloured boxes refer to areas with sufficient scientific evidence, orange boxes refer to emerging evidence, while red boxes represent poorly understood or insufficiently documented links between health and the food and agriculture system. Clearly this Figure over-simplifies the complexity evident in real life, as no disease can be defined according to strict boundaries and everything is connected. However, one can manage only what can be measured and such representation is a first step towards building a more consistent framework for understanding food system-related health and working towards an attribution of causation method. It highlights the fact that disease outcomes follow different pathways and often respond to multiple risk factors throughout the food system.

Figure 3.2 Food ecology and health (Source: Scialabba forthcoming)



to rise by about 70 per cent over the next two decades, up to 22 million: about one third of all cancer deaths are due to behavioural and dietary risks (WHO 2015) and some cancers are related to exposure to chemical substances in the environment. The incidence of neuro-degenerative diseases (e.g. Alzheimer's, Parkinson's) is doubling every four years (WHO 2009), developmental disorders (e.g. IQ loss, autism, ADHD) and reproductive deficiencies are increasing and antimicrobial-resistant infections are reaching an alarming rate, jeopardizing public health (O'Neill 2014).

Although future population growth and population ageing will drive increases in the burden of mortality due to non-communicable diseases, it is anticipated that despite advancements in medical care quality, risk factors such as unhealthy diet and lifestyles (UN 2012) will pose serious health threats. By 2050, 66 per cent of the global population will be living in cities: increasing urban agriculture will contribute to the provision of healthy food. However, appropriate practices have to be applied to avoid health concerns e.g. through pathogen contamination (by using non-composted or polluted urban waste), disease transmission from livestock to humans (e.g. tapeworm) and higher occurrence of insect/disease vectors (Orsini *et al.* 2013).

Aspirational scenario. All nations have a goal to eliminate all forms of malnutrition by 2030 and to achieve low levels of obesity and chronic diseases (i.e. Sustainable Development Goals 2 and 3). By improving nutrition, particularly during a child's first 1000 days, many public health problems can be prevented (e.g. 15-20 per cent of all cancer deaths [Wolin *et al.* 2010]) and many obstacles to sustainable development can be overcome[8]. In addition, many cases of cancers can be avoided by simply changing diet and lifestyle; poor diet, lack of physical activity and obesity/being overweight are estimated to account for 25-30 per cent of cancers in USA (World Cancer Research Fund and American Institute for Cancer Research 2018). Nutrition-sensitive and health-promoting food systems require multi-sectoral efforts for the promotion of diversified agriculture and clean, nutrient-rich food adapted to different micro-climates and socio-cultural contexts, with special consideration for vulnerable groups and women's role as agents of change within households. To this end, appropriate technology and renewable materials/energy are promoted for the production, processing, storage and transportation of food. Industries supply primarily healthy processed foods and markets advertise healthy dietary patterns. Bold policies restrict the use of potentially harmful chemicals and adopt the precautionary principle to novel food, while addressing pathogens and hazardous working conditions (Schäffer *et al.* 2018). Strategies in agriculture, environment and trade explicitly point to healthy diets while simultaneously seeking environmental sustainability, livelihood security, growth or other development goals. This is imperative and achievable.

3.3.3 Social equity, justice and food security

Linkages. Social equity refers to 'fair' relations within societies in terms of distribution of resources, opportunities and services. In food and agriculture supply chains, human relationships should be fair at all levels and to all parties involved, with due respect to the rights of women and vulnerable people (e.g. access to education and training), farmers (e.g. access to land), workers (e.g. decent wages), suppliers and contractors (e.g. right to organize and bargain collectively), rural community (e.g. clean air) and the wider community of consumers (e.g. right to choose food) and nations (e.g. trade). Social equity issues are explored in **Figure 3.3.**

The agricultural sector is one of the most hazardous work sectors worldwide (ILO 2009), mainly due to use of hazardous chemicals and large machinery. It is estimated that every year 2 to 5 million people suffer acute poisoning and 40 000 die, and millions of injuries occur to agricultural workers, at least 170 000 of them fatal (Cole 2006), while workers in the food processing and catering sectors have the lowest wages and weakest workers' rights in nations' economies. Especially because of seasonal informal labour, using immigrants and other vulnerable groups, the sector harbours slavery, forced labour, human trafficking and gender-based harassment and discrimination (Anderson and Athreya 2015). There are an estimated 98 million child labourers engaged in farming, livestock, forestry, fishing or aquaculture, often working long hours and facing occupational hazards and higher levels of risk than adult workers (Eynon *et al.* 2017).

Besides these unjust food production conditions, the distribution of food is currently much more problematic than the absolute amount of food produced. In fact, the gains of international trade and specialization have not been equitably distributed and an unequal international ecological exchange (of natural resources, environmental services and ecological impacts) in the global trade matrix (Prebisch 2017) exacerbates inequalities. In fact, upstream flows used to produce imports and exports (known as 'materials embodied in trade' [Hoekstra and Wiedmann 2014], e.g. 'virtual water' traded through food) create disconnects in production systems across borders, resulting in the inefficient and inequitable use of materials (Lassaletta *et al.* 2016) and natural resource degradation or scarcity. For example, the international trade of feed (the largest component of traded agricultural commodities) has profoundly affected the flows of nitrogen (Rockstrom *et al.* 2009) in the form of vegetable or animal protein between continents over the last fifty years.

Business-as-usual into the future. Although the Right to Adequate Food, enshrined in the 1948 Universal Declaration of Human Rights and reaffirmed in the Rome Declaration on World Food Security in 1996, is universally recognized as a basic human right, over 815 million people do not have access to food in a world of plenty. The highest number of hungry people live in food exporting countries (e.g. India). More than food availability, access to resources to produce or buy food, exacerbated by lack of access to sanitation (e.g. South East Asia) and political instability and conflicts (e.g. Sub-Saharan Africa) hinder food security.

8 See www.thousanddays.org – accessed 28 May 2018.

Global inequality, measured as the percentage of people living extreme poverty, is narrowing (from 37 per cent in 1990 to 9.6 per cent by 2015) but within-country inequality is rising in fast-growing developing countries (the income appropriated by the richest rose from 5 and 6 per cent in the 1980s to 8 and 10 per cent in 2010, in India and China respectively) and high-income economies (48 per cent in USA in 2010 [World Bank 2016]). Accelerated economic growth will neither be sufficient to eradicate poverty by 2030, nor to reduce inequality within countries. Also, as corporate businesses control what to produce and what to eat, lands are 'grabbed' by foreign investors, food and agriculture-related wages are the lowest of any sector, and women suffer from unequal access to resources within households.

Aspirational scenario. Social equity, justice and ethical considerations should be fundamental values of our food system. This requires policies that address food system's equity, social justice and ethical issues related to hunger, human rights, sustainability, safety, marketing, trade, corporations, dietary patterns and animal welfare, and effective, accountable and inclusive institutions at all level. It is likely that SDG 16 which targets unstable and conflict-prone institutions will not succeed unless we work to eliminate poverty, hunger, gender inequality, lack of access to health and education while reducing consumption of our planet's resources. For most people to enjoy healthy and culturally appropriate food produced through ecologically-sound methods and for food and agricultural workers to have secure and healthy work environments, overarching multi-sectoral efforts are needed to address economic, socio-cultural and legal factors that reduce vulnerability and exploitation. To this end, governments pursue pro-poor investments in productive activities within and around sustainable food systems, including extending labour rights through the informal economy and improving migration governance (ILO 2017). In particular, the decades ahead need to address the distress of migration, both within and across countries, by increasing access to social protection (in the face of climate change, natural disasters and protracted conflicts) and employment opportunities to the 1.2 billion young people by 2050, especially in rural areas of Sub-Saharan Africa and South Asia (FAO 2017a). International development policies support agriculture in countries where the poor rely heavily on agriculture for incomes and

Figure 3.3 Social equity issues in the food system (Source: Tirado von der Pahlen *et al.* 2018)

nutrition and ensure that food importing countries have social protection programmes to offset vulnerabilities and absorb volatility in international food markets. Malnutrition is tackled with governance that allows improved access to food along with more equitable income distribution and public investments in enhanced earning opportunities. In particular, addressing women's status in society unleashes tremendous human development potential – much of it directed at food production and/or food system livelihoods. Other policies that contribute to equitable food systems include advancement of education (rural education, as well as sustainable consumption policies), economic diversification to rural non-farm income generating activities, local food procurement incentives, payments for ecosystem services using fairness criteria, connecting local food systems to growing urban markets through contractual arrangements with mutually beneficial terms, using taxes and food subsidies to improve the quality of people´s dietary choices, etc. Such daunting tasks will need to be supported by international cooperation and mechanisms, from financing inclusive food and agriculture development, to addressing shortfalls in the multilateral trading regime for agri-food systems.

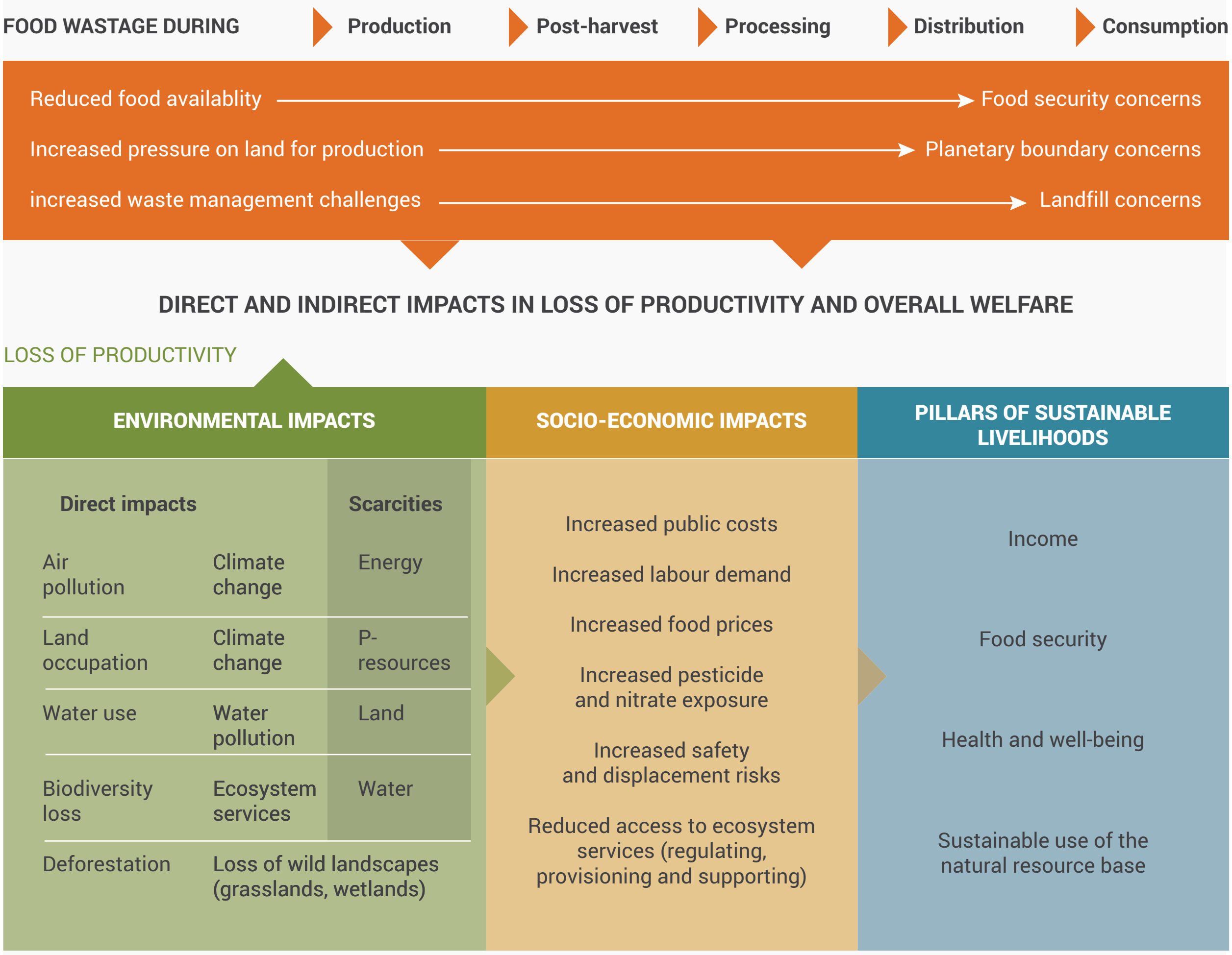
3.3.4 Food wastage and overall welfare

Linkages. The multi-faceted issue of food loss and waste (or wastage) is easily understood when considering what causes it. Food loss is due to lack of investments and poor infrastructure in harvesting, storage (e.g. lack of cold chain facilities), packing and transport (poor roads), or by market requirements (e.g. grading conformance) and food trade quotas and stringent sanitary requirements that favour letting foot rot in the field. Also, food waste by retailers or consumers may be caused by rigid or misunderstood date marking rules, poorly planned buying practices or the utility derived from choice: consumers gain utility from lots of choice on the market shelves or in their pantries, with unavoidable food waste consequences. Food wastage is intrinsically linked to the way food systems function technically, economically and culturally. Globally, 32 per cent of the food volume produced for human consumption, the equivalent of 24 per cent of all food calories produced, never makes it to the mouth of the consumer (FAO 2011). Food wastage does not only represent a lost opportunity in terms of economic return and food availability but also causes substantial societal impacts. **Figure 3.4** illustrates the full landscape of food wastage impact. Using data from 2011 Food Balance Sheets, the carbon footprint of food produced and not eaten, including land use change, was 4.4 Gt CO2 equivalents, or about 8 per cent of global anthropogenic greenhouse gas emissions. Squandered natural resources also include a vain annual occupation of almost 1.4 billion hectares of land (or 28 per cent of the world's agricultural land area), and use of about 250 km^3 of freshwater, let alone biodiversity loss. The direct social wellbeing costs inflicted by environmental degradation caused by food wastage include increased risk of conflicts due to soil erosion, loss of livelihoods and adverse health effects (toxicity) due to pesticide exposure in drinking water. Combining these factors, the magnitude of the economic (including both food prices and wasted OECD subsidies), and environmental and social costs of food wastage totals USD 2.6 trillion annually (FAO 2014).

Business-as-usual into the future. Generally, the economics of reducing food wastage are cost-prohibitive, involving tackling poverty and sustainable resource use. Preventing pre- and post-harvest food losses requires ensuring, respectively, that the actual output prices are higher than harvesting costs, and that the cost of improved storage facilities does not exceed the expected marginal revenues from reduced food losses. The consideration of food as a cheap commodity prevails: disposing is cheaper than reusing food in industrialized food chains and food wastage proportions continue to grow in parallel to increasing production and consumption (at least one third of the 3070 kcal/person/day estimated for the 2050 population [Alexandratos and Bruisma 2012]). People's attitude towards food abundance - from the all-you-can-eat buffets at fixed prices, through over-sized restaurant portions and "buy one get one free" stores, to over-packed large fridges in homes - are all conducive to massive food waste, especially in urbanized environments. Unfortunately, such trends are growing in the food service sector of the populous Asian countries, creating even more pressure on natural resources.

Aspirational scenario. Cutting waste significantly across the globe has significant impact on food security and future production needs. Considering that the 2050 food production will need to increase by 50 per cent to meet global food demand, eliminating the current 32 per cent of food wastage seems a logical response to improving food availability. It is estimated by Lipinski *et al.* (2013) that a realistic 50 per cent reduction of global food wastage by 2050 would save 1 314 trillion kcal per year, or roughly 22 per cent of the gap in food availability needed in 2050, with avoided ecological damage. For example, the impact of reducing food wastage by half by 2030 would lead to a reduction of the carbon footprint of 1.4 Gt CO^2e per year (FAO 2015a). To this end, increased investments in financially feasible post-harvest loss technologies are made and markets internalize environmental and

Figure 3.4 Food wastage impacts (Source: FAO 2013)



social costs, so that letting food spoil is no longer economic, nor culturally acceptable.

3.3.5 Technology and agriculture

Linkages. OECD (2011) lists a number of science and technology policy tools for a green growth strategy in agriculture, including public research to promote eco-efficient agriculture (including organic agriculture), research and development of agricultural biotechnology, alternative farming systems and related training. New technologies in agriculture can help increase crop production and can be used to improve practices that benefit sustainability and food security for current and future generations. However, questions about the safety of these new technologies and their ability to address issues of poverty, malnutrition and loss of biodiversity remain. For instance, modern biotechnology enables rapid changes to plants and animals. There are many gaps in the understanding of how, for instance, gene technologies may impact the target organism, the environment and subsequent generations. It is also essential to consider how gene drives will propagate throughout a population and affect not only the target species, but also its entire ecological community (Grassroots Foundation 2016). Furthermore, the extension of intellectual property regimes (primarily patents and plant breeders' rights) have withered public breeding programmes and facilitated resource grabs (e.g. arable land, traditional bulk commodities and generic plant material for biomass feedstocks) in the quest for raw material, especially in developing countries.

Business-as-usual into the future. Innovation is generated through high investments, with greater corporate concentration and patent protection, thus exacerbating inequalities as monocultures prevail in the agricultural landscape. The role of the public sector is limited to updating regulatory frameworks whose applicability is constantly challenged by new genetic improvement techniques (EPSO 2015).

Nanotechnology seeking to reduce raw material demand and manufacturing costs, synthetic biology seeking to decrease fossil fuel-based inputs, and geo-engineering seeking to sequester greenhouse gases, affect every aspect of the food system from production to processing, packaging, transportation, shelf life and bioavailability. The health impact of nanomaterials in food and feed is of major public concern (Saura and Wallace 2017) and the herbicide-tolerant genetically engineered crops promise for reduced inputs is continuously revised with novel products (gene editing) that perpetuate quick fixes that do not endure.

Aspirational scenario. Technological innovations include both environmental science (e.g. agroecology, marine multi-species dynamics and multitrophic aquaculture) and green inputs, meaning safe, environmentally-benign substances designed to maximize energy efficiency and minimize waste disposal. Their generation and exchange are orchestrated by a global agreement on green technologies for global common goods that builds on the technology transfer principles of the 1992 Rio Earth Summit (FAO 2012). An international technology evaluation and information mechanism is in place, based on the Precautionary Principle, to strengthen stakeholders' capacities to assess the health, environmental, economic and social impacts of new and emerging technologies, such as biotechnology, nanotechnology, synthetic biology and geoengineering. Appropriate technology development in service of producers in the food supply chain is in place as populations urbanize. In particular, enhanced agro-ecological strategies, coupled with improved labour-saving equipment and powered by renewable energies (50 per cent by 2050 and increasing to 100 per cent), long overdue, are addressed. Recycling becomes the primary form of raw material supply, leading to declining natural resource exploitation and greenhouse gas emissions.

3.3.6 Concentration and democracy in the agri-food chain

Linkages. In the past decades, developing countries 'structural transformation' meant following the path of developed countries in seeking high productivity per hectare. Globalization, deregulation and privatization gradually dismantled state-centred national agricultural development models. The information technology revolution, coupled with global market development, expanded the trade of fertilizers, pesticides, seeds and food, giving birth to a standardized technological package, with strong proprietary rights. Mergers and acquisitions in the input industry have led to concentrated control of almost the entire food system. The on-going contest for big data genomics commanded by the seed/pesticide companies and the big data sensor algorithms controlled by the machinery majors was set in motion in 1980 with patenting of life forms (biotechnology) and farm machinery companies started investing in satellite imagery in information management. Corporate consolidation and control over the first links of the industrial food chain have increased costs as natural processes are substituted with purchased inputs, reducing innovation by smallest industries who cannot compete due to economies of scale. This has cut farmer choices and diminished diversity, with negative impacts on smallholder livelihoods and their food security (ETC Group 2015). The food retail industry is no exception in terms of market dominance, with the top 10 large agro-industrial food manufacturers and retailers operating in just 65 countries accounting for about 10.5 cents of every grocery dollar spent worldwide in 2009 (ETC Group 2011).

Business-as-usual into the future. The big agrochemical corporations that dominate world markets of seeds and pesticides get bigger and faster in the context of increased food and meat demand and in the midst of climate change. With the on-going mega-mergers negotiations, 60 per cent of the world's commercial seed sales and 70 per cent of pesticides sales are controlled by 3 companies, a combined value of USD 96.7 billion in 2014. This will set-off a second round of mergers leaving farm machinery titans controlling all agricultural inputs worth USD 0.4 trillion. A third round of mergers may see farm insurance companies who are best able to influence what crops and varieties to sow, and what growing regimes and what monitoring capacities are required, controlling whether insurance is made available. If business-as-usual is not an option, governance-as-usual is not an option either (ETC Group 2016).

Aspirational scenario. International policy-makers bridge the current disconnect between food security, agriculture, environment and climate policy by establishing authoritative and innovative mechanisms. Integrated implementation of the Sustainable Development Goals, through the review of country efforts and thematic reviews[9] of selected topics establishes a global mechanism that leaves no one behind and moves development pathways towards sustainability. New institutions and innovative financing models complement the roles of the market and the state for managing the agri-food system as commons,

9 'Thematic reviews' is an agreed mechanism in the 2030 Agenda. So far only very few of these thematic reviews have been undertaken, no one so far on the implications of on-going concentration and market power on diversity of genetic resources for food and agriculture.

with both land and food embedded in an ecological, rather than an economic, framework. Public funds are dedicated to supporting common goods (nature stewardship), with producers and consumers cooperating in the food chain. Research funds are allocated to regenerative and no-waste farming. At last, nations and people democratically determine their own food and agricultural policies.

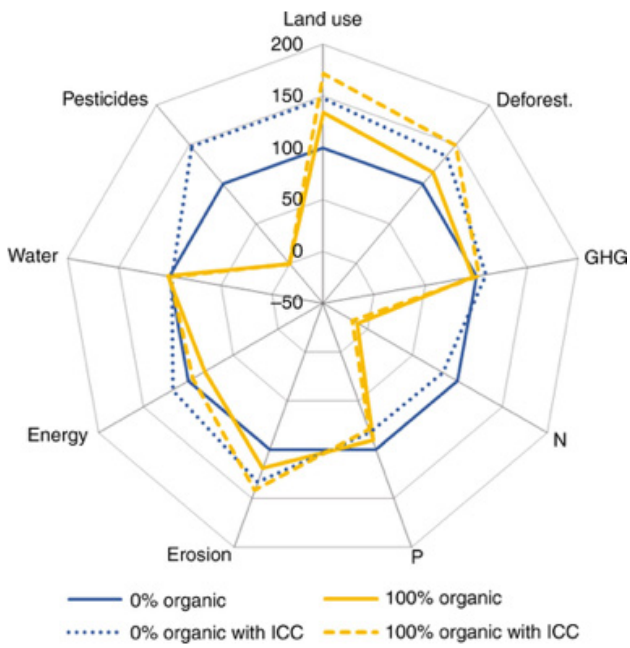
3.3.7 Climate change and food security

Linkages. Climate change and freshwater access will undoubtedly impact the ability of millions or even billions of people to maintain or enhance livelihoods. Poor households that incur injury and disability are hit harder, affecting their ability to work (their main asset). The disruption of livelihood systems due to severe and repeated crop failure results in further pauperization of households and communities. Between 2003 and 2013, natural hazards and disasters in developing countries affected more than 1.9 billion people and caused over USD 494 billion in estimated damage. Disasters destroy critical agricultural assets and infrastructure and cause losses in the production of crops, livestock and fisheries, with a total damage to crops and livestock of around USD 7 billion (FAO 2015b). Such losses can change agricultural trade flows and also cause losses in agricultural-dependent manufacturing sub-sectors, such as textiles and food processing industries.

Business-as-usual into the future. World average temperatures increase by 3-5° C by 2100, with intensified conflicts and international population movements. The Intergovernmental Panel on Climate Change warns that declining crop yields may already be a fact, and that decreases of 10–25 per cent may be widespread by 2050. Developing countries are expected to shoulder much more of the production burden, although regional variations in productivity are significant. Degradation of the world's soils has released about 78 billion tons of carbon into the atmosphere (FAO 2017b) and land demand (hence deforestation) for crop expansion is expected to unsustainably increase the carbon footprint of agriculture, while even running out of primary land before 2050. There is consensus that the productivity of crops and livestock may decline because of high temperatures and drought-related stress, but these effects will vary among regions. Undoubtedly, climate- and weather-induced instability will affect levels of, and access to, food supply, altering social and economic stability and regional competitiveness. It is estimated that climate change will result in 250,000 additional deaths between 2030 and 2050, that soil degradation will lead to the loss of 1– 2 million hectares of agricultural land every year, and that by 2050, 40 per cent of the world population could be living in areas under severe water stress (Horton and Lo 2015).

Aspirational scenario. By scaling-up agroecology, decreasing food losses, reducing feed production, adapting global dietary patterns to decreased livestock supply, disincentivizing all fossil fuel-based practices and accelerating adoption of renewable energy through

Figure 3.5 Environmental impacts of a full conversion to organic agriculture (Source: Muller *et al.* 2017)



nations' economies, global temperature increases are kept within 2ºc. Using today's technologies, the 2050 world population can be feed with positive outcomes on the environment and on climate (see **Figure 3.5**). This alternative strategy to achieve both food security and environmental integrity through a global conversion to organic agriculture is based on a 50 per cent decrease in food wastage and food-competing feed from arable land; this scenario entails a drop of animal product consumption from 38 to 11 per cent in total protein supply, a quantity that matches healthy diets (Muller et al 2017).

Year 2050 environmental impacts of a full conversion to organic agriculture. Environmental impacts of organic scenarios (100 per cent organic agriculture, yellow lines) are shown relative to the reference scenario (0 per cent organic agriculture, blue lines), with (dotted lines) and without (solid lines) impacts of climate change on yields; Calories are kept constant for all scenarios. Indicators displayed: cropland use, deforestation, GHG emissions (incl. deforestation, organic soils), N-surplus and P-surplus, water use, non-renewable energy use, soil erosion, pesticide use.

3.4 TOWARDS INCLUSIVE ECO-AGRI-FOOD METRICS

Applying today's 'productivity only' metrics in agri-food system assessments ignores outcomes such as degraded ecosystems and alienated communities, with alarming impacts on health and the poorest segments of society. This can be redressed by fixing the eco-agri-food system metrics.

As described in the first chapter of this Report, much progress has been made in disciplinary science on the different aspects of the eco-agri-food system. However, an overarching comprehensive analysis of this complex system is missing. The predominant indicator of success shown as "yields per ha" or 'delivery of kilocalories' is too narrow and does not analyse the advantages and disadvantages of different agricultural production systems. Health impacts are measured by health costs or Daily-Adjusted Life Years, without considering the linkages to production systems, and at best referring only to individual behaviour. The importance of equity or human capital is largely undervalued. Labour is only seen as a cost of production and the provision of livelihoods of 1.5 billion people is of minor importance. Only a comprehensive valuation of the whole system (see Chapter 2) can explain and value the different four capitals and their interlinkages. The contemporary scientific analysis of agriculture is fragmentary, focusing on economic interpretations of agriculture and trade, while disregarding broader relationships to the local and global environment and social organizations, as well as visible and invisible flows of material and energy. Many aspects are "missing in the frame", and those must be addressed in holistic assessments, such as the one promoted by TEEBAgriFood's Evaluation Framework (see Chapter 4).

Pathways to sustainability, going forward, must recognize and strengthen those forms of agricultural production that explicitly enhance ecosystem services and build the natural capital that underpins food systems, creating regenerative forms of agriculture and a food system that generates multiple positive externalities. Pathways to sustainable food systems must look at dependencies and interactions along the entire food chain.

Irrespective of the particular socio-economic, cultural and ecological context in which a particular eco-agri-food system is situated, there are always positive and negative externalities and impacts across the entire value chain, from production, through processing and transport, to final consumption. The question is thus not whether such externalities and impacts exist, but rather their extent, which agents in society are affected and whether we can promote a decision-making environment in which the positive impacts flourish and the negatives ones are mitigated.

Global society – whether taking the perspective of the private sector, governments or civil society - can identify the intangible and invisible stocks and flows that affect the integral processes and the complexity of the global food system. Greater insight into these processes can help the public to promote the sustainable use of the natural resources, biodiversity and environmental services that will lead to eco-agri-food chains with multiple benefits. Public policies, technology and investment possibilities can enhance the promotion towards sustainable food systems, creating opportunities for all farmers, consumers, corporations and countries.

This chapter shows that a different approach is not only possible but urgent. With the TEEBAgriFood Evaluation Framework presented in the next Chapter, we confide that improved understanding of connected societal issues will lead us to collectively say: yes we can and yes we should!

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“SELECTING THE RIGHT MEASURE AND MEASURING THINGS RIGHT ARE BOTH ART AND SCIENCE.”
-PEARL ZHU

CHAPTER 4

Framing and evaluating eco-agri-food systems

Chapter 4 describes the limitations of the dominant ‘narrow’ lens most often used to evaluate the food system (i.e. per hectare productivity) as well as the opportunities presented by the wide-angle lens of the TEEBAgriFood Evaluation Framework, with its emphasis on measuring all significant visible and invisible impacts and dependencies. It outlines the rationale and principles for choosing a universal, comprehensive and inclusive Framework, defining and describing its key elements: stocks, flows, outcomes and impacts (the “what and why” of evaluation). It outlines scientifically and economically sound methodologies – the “how?” of evaluation. And finally, it describes various opportunities for the Framework’s application to decision-making: on policies; on food plates; on farming typologies; on value chains; on the accounts of society – the “for what purpose?” of evaluation.

4.1 INTRODUCTION

This chapter describes how TEEBAgriFood frames and evaluates eco-agri-food systems in a manner that recognizes their complexity, brings out their true nature after recognizing and accounting for hidden costs and benefits, shows the pitfalls of continuing to view agriculture through any narrow lens (e.g.: per hectare productivity) and also shows the opportunity presented by using the wide-angle lens of TEEBAgriFood, or the so-called *"TEEBAgriFood Evaluation Framework".*

The two key differences between a traditional, "production only" approach to assessing agricultural performance and the *systems approach* favoured by TEEBAgriFood (see Chapter 2) is that the "production only" approach only considers the 'production' part of the overall value chain, and furthermore, is generally limited to those stocks, flows, outcomes and impacts that are observable in *markets* and hence are reflected in standard economic statistics. A systems approach looks all along entire food value chains, and also reveals many significant but economically invisible or *non-market* stocks and flows that must also be considered. Of course, while these stocks and flows may be unpriced and not incorporated in macro-economic modelling or the calculus of GDP because they are unrecorded inputs to production, or because they are "externalities", they are undoubtedly *real* stocks and flows that can be observed and described; they are important drivers of success (or failure) of many SDGs such as the eco-agri-food value chain impacts on climate (SDG13), freshwater (SDG 6), biodiversity and ecosystems (SDGs 14 and 15), human health (SDG 3), social equity (SDG's 5 and 10) and livelihoods (SDG's 1 and 8).

We wish to clarify here that some of the health hazards of eco-agri-food systems do not qualify as "externalities" in the strict economic definition of this term, particularly in the consumption stages of the process, such as over-consumption of products high in sugar and fats. This is because consumers *pay* for these products and make a conscious decision to consume them without being obliged to do so, i.e., these are not costs to *third-parties*. Nevertheless, such consumption is a social concern because of its harmful effects, including on publicly funded health services (Green *et al.* 2014). These are *demerit goods*[10]: goods or services that can have a negative impact on the consumer and society, and these effects may be unknown to or ignored by the consumer. The notion of merit and demerit goods thus extends the concept of *externalities*, and in this Synthesis Report, the term "externalities" is used to refer to *both* conventional externalities *as well as* demerit goods.

4.2 SHINING A LIGHT ON THE HIDDEN COSTS AND BENEFITS OF ECO-AGRI-FOOD SYSTEMS

The *hidden costs and benefits* in the way we produce, process, distribute, and consume food are rarely captured in conventional economic analyses, which usually focus on goods and services *that are traded in markets.* For example, one hidden *cost* of food systems is their climate footprint, estimated (along the value chain) at between 24 and 57 per cent of anthropogenic global GHG emissions (UNCTAD 2013; Grain 2014; UNEP 2016) on a 'cradle-to-grave' basis. A hidden *benefit* is that food systems (including especially small-scale agriculture) employ more people than any other economic sector. Chapter 1 highlighted that agriculture alone employs 1.5 billion people. Compare this to auto manufacturing which directly employs an estimated 9 million people worldwide (OICA), or to the steel sector, which employs around 6 million people worldwide (Worldsteel 2018). How many global steel, automobile, IT, and other such sectors would we need to create to provide "substitutes" for lost agricultural jobs, even if that were possible? Without retaining agriculture's huge employment capacity, it would be frightening to imagine the large-scale unemployment that might arise, together with rural poverty, widespread discontent, social tensions, migration challenges, fiscal stress, law and order breakdowns, and devastating consequences for peace and political stability around the world.

10 For a definition of merit goods and demerit goods see Musgrave (1987). Strictly speaking demerit goods are not externalities in the sense that their consumption harms a third party (e.g. if I smoke in my home with no one else around I am not generating an externality in the conventional sense, but I am consuming a demerit good insofar as overall social welfare is diminished by such consumption).

The two examples mentioned above are important *economically invisible impacts* of agriculture, as neither are measured or included in either *GDP* at the national or 'macro' level, or in *Profit & Loss* accounts of corporations at the 'micro' level. However, there are also *invisible dependencies*. For example, evapo-transpiration from the Amazonian rainforests forms clouds as it reaches the Andes and generates precipitation over the La Plata basin, the granary of South America (Marengo *et al.* 2004). The value of the output of this agricultural economy exceeds a quarter of a trillion USD (World Bank 2016), however, its most vital dependency on the Amazonian water cycle also remains economically invisible both at the 'macro' and the 'micro' level.

From an ecological perspective, there is little or no recognition of ecosystem *inputs* to agriculture (i.e. dependencies), including freshwater provisioning, nutrient cycling, climate regulation, and pollination (Millennium Ecosystem Assessment 2005). Similarly, key *outputs* of agri-food systems central to human health and well-being, such as impacts on food security, water quality, food safety and local communities, are often unaccounted for (TEEB 2015). Perhaps most significantly, conventional assessment systems do not capture the ability of ecosystems and supporting social systems to continue to deliver these critical goods and services over the long-run, i.e. their *resilience* in the face of climatic and other changes.

TEEBAgriFood's central aim is to make all such "economically invisible" costs and benefits visible, primarily by providing a *universal and comprehensive* Evaluation Framework (hereinafter referred to as "Framework"). This Framework comprises 'rules of the road' and guidance that can consistently and coherently answer the question *"what impacts and dependencies should be evaluated, and why?"*

The original 'TEEB for Business' report (TEEB 2011) highlighted the various environmental risks and opportunities that businesses should address in a resource constrained future, and described how businesses could measure, value and report their impacts and dependencies on nature. Several other works and initiatives have helped move this agenda forward, including the Global Reporting Initiative (GRI 2018), the World Business Council for Sustainable Development's Guide to Corporate Ecosystem Valuation (WBCSD 2011), and the Natural Capital Coalition's (2016) "Natural Capital Protocol" (NCP) which includes a sector guide for food and beverage businesses (Trucost 2016). From a broad governance perspective, the Integrated Reporting <IR> framework of the International Integrated Reporting Council (IIRC 2013a) developed the concept of reflecting impacts across capital classes and reporting *beyond* statutory reporting requirements. Integrated profit and loss <IP&L> statements and 4-D reporting (Environmental Leader 2015) statements now help to operationalize <IR> and express the impacts of a corporation across all capital classes. The TEEBAgriFood Framework builds upon this recent momentum in the private sector around the measurement, valuation, and disclosure of externalities.

4.3 TEEBAGRIFOOD FRAMEWORK: GUIDING PRINCIPLES

The Framework has three guiding principles – *universality, comprehensiveness and inclusion.*

It is a *'universal'* Framework because it can be used in any geographical, ecological or social context, at the level of society, the firm, or the individual. Its universality also entails that no matter what the entry point or application of the Framework, no matter what the context or the decision-maker, the same Framework can be used for assessing any eco-agri-food system. While each assessment may be different in scope and evaluation methodology, to assure completeness within - and comparability across - assessments, it is important that the *elements* considered and evaluated in each assessment are defined and described in a uniform, methodical and consistent manner.

The Framework is *'comprehensive'* in that it does not ignore any significant impacts of the food system, or any material dependencies, no matter whether they be economically visible or invisible. This comprehensiveness refers to the *entire value chain*, and to *all significant outcomes and impacts* within an agri-food system. A comprehensive Framework ensures that all hidden costs and benefits, including dependencies and impacts upstream and downstream, are part of each assessment over the entire agri-food value chain, covering both production and consumption. For example, various natural capital inputs to farming, such as freshwater, climate regulation and pollination come from beyond the "farm gate", likely at the watershed or landscape scale. Similarly, some hidden costs of farming may occur downstream of the farm gate, for example contamination due to use of fertilizers or pesticides. Although analyses that are limited to the agricultural area of a farm may have the virtue of simplicity, they must be considered partial and are potentially misleading.

Comprehensiveness also implies that systems are assessed in terms of observed economic, environmental and social flows, such as production, consumption, ecosystem services, pollution and social benefits, and in terms of the underlying capital base that both sustains the system and can be impacted by activities within the system. Consistent with this approach, the capital base used in the Framework is also comprehensive, i.e. it covers produced capital, natural capital, human capital and social capital.

A third guiding principle for the Framework is '*inclusion'.* i.e. it should support multiple approaches to assessment. Although the 'accounting based' nature of the Framework directly supports analysis in line with economic theory and valuation of impacts on human well-being in monetary 'value addition' terms, this is neither possible nor appropriate for all aspects of human well-being. Qualitative, physical, or non-monetary terms can provide important insights, as can a plurality of value perspectives and assessment techniques. A frequent concern about the use of monetary values is the implication that all asset classes are substitutable, and that so long as overall per-capita capital grows in a country, all is well. This is sometimes referred to as "weak sustainability" (Pearce *et al.* 1989). In reality, ecosystems and biodiversity are subject to major non-linearity such that some degree of substitution may be tolerated, but beyond a point, phase changes occur with significant consequences as entire ecosystems cross *thresholds* or 'points of no return'.

These three guiding principles result in a Framework design and approach that can truly represent a holistic perspective of any food system. They anchor the Framework by recognizing and valuing the roles of *all* four forms of capital stocks (*produced, natural, human and social capital*) deployed in eco-agri-food systems; on mapping and recording *all* important flows emanating from these stocks, be they economically visible or invisible; and on recognizing and evaluating the outcomes and impacts of these flows.

4.4 THE CONCEPT OF CAPITALS

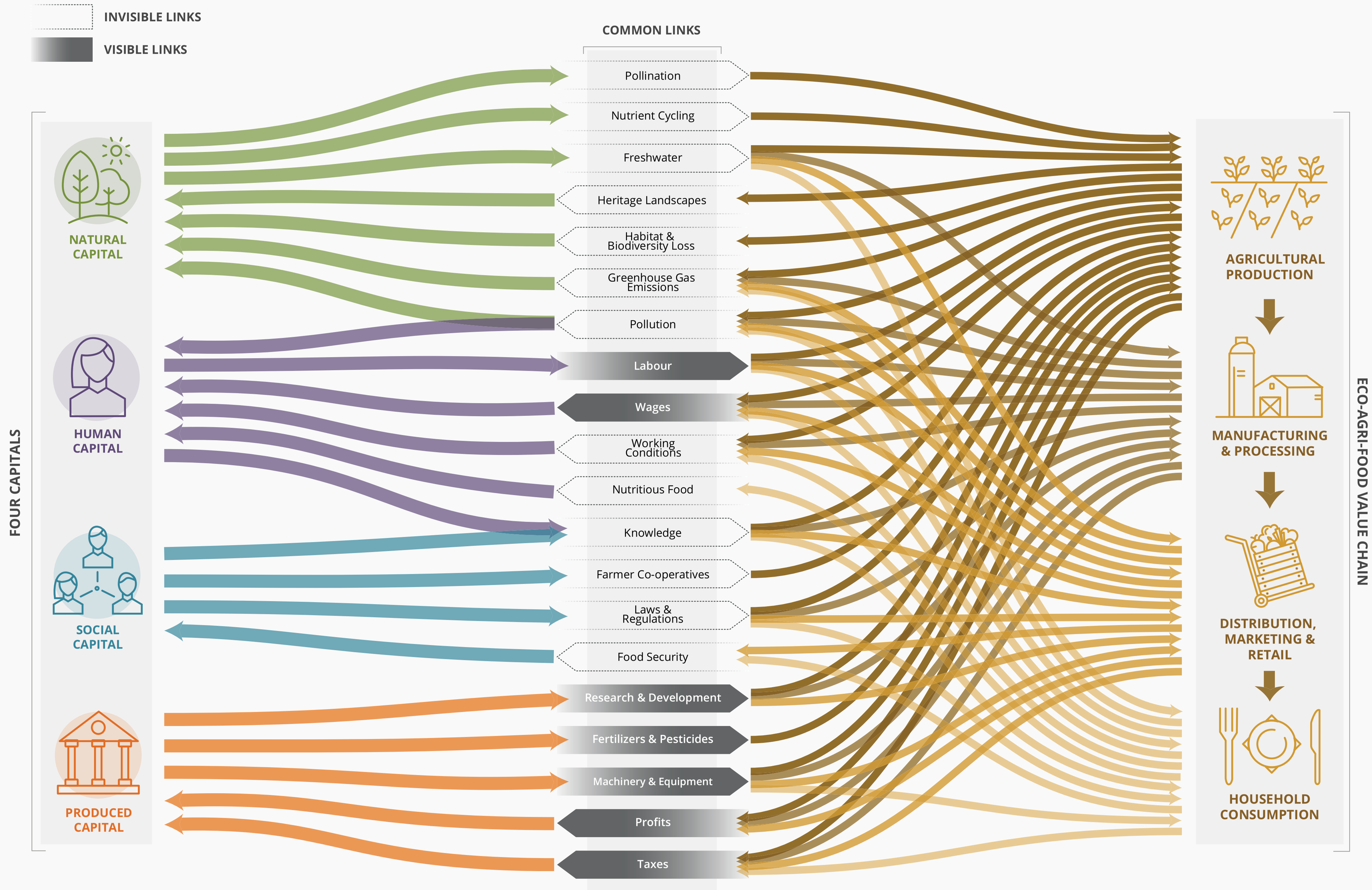
The term "capital" is an economic metaphor for wealth. Wealth can be owned privately (private goods) or by communities (club goods) or by society at large (public goods), and it can be found in many forms or classes. The concept of different capital classes as economic metaphors for complementary dimensions of human well-being is widely used nowadays both at the macro level (Engelbrecht 2015) and at the micro level (IIRC 2013b). These 'capitals' are foundational elements of our Framework for a few reasons. Firstly, eco-agri-food systems use as well as generate *all* classes of capitals along their value chains - from production to manufacturing to distribution and consumption. There are several exchanges or flows between them, both visible and invisible, which are integral to understanding the complexity of eco-agri-food systems, as illustrated by **Figure 4.1**.

Secondly, information on the economic value of different capital stocks is key to understanding economic behaviour associated with the use of these stocks. For example, monetary values may help explain the extent of return on investment and inform on the level of financial resources required to maintain ownership and management of assets. There are real connections between the capital base, the flows that each class of capital produces, and the consumption of goods and services. All these flows act as "drivers" from which arise many "outcomes" each of which has associated "impacts" on human well-being (see **Box 4.1** for definitions). Historically, in the assessment of agricultural systems, the focus has been on the production of agricultural goods only, with limited connection to understanding the changes in the broad capital base or the broader outcomes and impacts of productive activity. The development and design of our Framework therefore aims to provide a platform for recognizing the breadth of dependencies and impacts within agri-food systems.

4.5 THE FOUR CAPITALS IN THE TEEBAGRIFOOD FRAMEWORK

In our Framework, the capital base is comprehensive, and comprises all four classes of capital, following the widely used lexicon of environmental economics literature, which has also been adopted by the landmark "Inclusive Wealth Report" (UNU-IHDP and UNEP 2014). These four capitals are: *produced, natural, human and social capital.* As noted in the forward to the report, the 'enabling' nature of social capital is important: social capital does not generate income of its own, but in its absence, the other three capitals are less effective in generating incomes and may thus diminish in value.

Figure 4.1 Links between four capitals and eco-agri-food value chain (Source: Obst and Sharma 2018)



Box 4.1 What are the "Four Capitals"?

Produced capital[11] refers to all man-made assets, such as buildings, factories, machinery, physical infrastructure (roads, water systems) as well as all financial assets. Human knowledge – sometimes called "intellectual capital" - is usually found embedded within produced capital (technology, software, patents, brands, etc.).

Natural capital refers to "the limited stocks of physical and biological resources found on earth, and of the limited capacity of ecosystems to provide ecosystem services." (TEEB 2010, p.33) For measurement purposes, following the SEEA, it incorporates the "naturally occurring living and non-living components of the Earth, that in combination constitute the biophysical environment" (UN *et al.* 2014, p.134). It thus includes all mineral and energy resources, timber, fish and other biological resources, land and soil resources and all ecosystem types (forests, wetlands, agricultural areas, coastal and marine).

Human capital: represents "the knowledge, skills, competencies and attributes embodied in individuals that facilitate the creation of personal, social and economic well-being" (Healy and Côte 2001, p.18). Human capital will increase through growth in the number of people, improvements in their health, and improvements in their skills, experience and education. Income-based measurements of human capital usually need to be supplemented with quality indicators such as 'decent' working conditions (ILO 2008)[12].

Social capital encompasses "networks, including institutions, together with shared norms, values and understandings that facilitate cooperation within or among groups" (OECD 2007, p.103)[13]. Social capital may be reflected in both formal and informal arrangements and can be considered as the "glue" that binds individuals in communities. More broadly, it can be seen as the form of capital that "enables" the production and allocation of other forms of capital (UNU-IHDP and UNEP 2014).

11 The term "produced capital" is used for consistency with the concept measured in UNU-IHDP and UNEP (2014). Other terms such as physical capital, manufactured capital and reproducible capital are also used, sometimes with a different scope from the definition used here.
12 ILO (2008) adopted a framework of Decent Work Indicators that was presented to the 18th International Conference of Labour Statisticians in December 2008. The Framework on the Measurement of Decent Work covers ten substantive elements which are closely linked to the four strategic pillars of the Decent Work Agenda, that is: (i) International labour standards and fundamental principles and rights at work, (ii) Employment creation, (iii) Social protection, and (iv) Social dialogue and tripartism.
13 Adapted from Brian (2007).

Figure 4.2 provides examples of these four capitals in the context of eco-agri-food systems. It should be noted that recording the class of capital is not the only relevant information; the nature of its ownership also matters, to determine how to set discount rates to value the asset, and to decide on the appropriateness of so-called trade-offs that affect one group of asset owners versus another, especially if they fall in different social strata, countries, locations or generations.

4.6 VALUE FLOWS INCLUDED IN THE TEEBAGRIFOOD FRAMEWORK

It is in the nature of capital *stocks* to produce value *flows*. Some of these flows are economically visible, i.e. market priced and accounted for based on market prices. Others are economically invisible and need a range of valuation techniques to estimate their *shadow prices*. One important aim of the TEEBAgriFood evaluation Framework is to ensure that all flows, and associated stocks, are made visible in decision-making. Intermediate flows (i.e. those which contribute towards the production of a good or

Figure 4.2. Capital Classes and ownership categories (Source: authors)

	Private Ownership (Private Goods)	Community Ownership (Public Goods)	Public Ownership (Private Goods)
NATURAL CAPITAL	Farm ponds Farm fields Private forests	Community Forests Grazing Commons	High Seas Fisheries National Parks/ Forests
HUMAN CAPITAL	Health Education Job Skills	Traditional Community knowledge	Public Databases Non-patent Knowledge
SOCIAL CAPITAL	Market design, rules and regulations Civil & Criminal Laws; Judicial systems	Farming community rules and regulations Community norms, customs, traditions, culture	Constitutions; Judicial systems; Law ℴ Taxation Social equity; Communal harmony; cultural diversity
PRODUCED CAPITAL	Bank Accts Farm Equipment Farming Licenses	Community Centers Farmer Field Schools	Country Roads Public Hospitals

service and its final value) are often invisible, in the sense of usually being ignored in decision-making. For example, while pollination services are intermediate flows that contribute to agricultural yields, since it is yields that are captured in the market, pollination services are often ignored. Therefore, while several intermediate flows will be embedded within final flows, it is important to recognize and capture the intermediate flows separately.

The four key types of flows mapped in our Framework are:

Agricultural and food production and consumption: these are the outputs of farms and the value-added by food processing and distribution. They are economically visible, hence corresponding to these flows recorded in physical terms there will be measures of income and economic value added recorded in monetary terms and measured at a 'country' level in national accounts (IMF 2007). It is recommended that these flows be recorded by type of commodity (e.g. wheat, rice, beef, etc.) and classified as appropriate by type of farm (e.g. type of production practice; size range of farm; etc.). Generally, this information would be recorded in tons or similar production equivalents. From this base data it would also be possible to convert and express these flows (using appropriate factors or coefficients), for example, in terms of the quantity of protein produced, or in terms of micro-nutrients produced. Such nutritional information may help in establishing food value chain linkages to outcomes for human health.

Purchased inputs to production: these are important to understand food value chains, including labour and *"intermediate"* goods, i.e. those used to produce food (e.g. water, energy, fertilizers, pesticides, and animal medicines). Knowing these inputs is important, as there are significant differences in inputs across alternative production systems for the same commodity (e.g. between intensive and extensive production systems) and hence potential trade-offs between the use of purchased inputs *versus* reliance on natural ecosystem services. The latter may provide the same kind of input value at lower environmental and human costs, for example, for water (e.g. through direct rainfall), for fertilizers (e.g. through managed natural inputs such as compost) and for pesticides (e.g. through biological pest control).

Ecosystem services: data on both inputs and outputs should be recorded, following the typology prescribed by the widely used 'Common International Classification of Ecosystem Services' (CICES webpage). By extending the logic and analysis above for purchased inputs, we could also consider respective changes in the underlying capital base (e.g. soil condition, pollinator diversity, off-farm water quality) across different production systems. This will allow a better-informed assessment of the social value and sustainability of alternative systems.

It is important not to limit analysis of ecosystem services and other inputs to the *flows* themselves, but to extend analysis to consider also changes in the underlying *stocks* or capital base of farm production (e.g. soil condition, pollinator diversity, off-farm water quality). This will allow an informed assessment of the capacity of farms and farming landscapes using different farming approaches. It should be noted that farms also *produce* ecosystem services such as climate regulation (e.g. via carbon sequestration), soil retention and cultural values, which will differ across farming systems. The services to be considered in scope of the Framework should align with those described in CICES. Since these ecosystem services are generally not for sale, being in the nature of 'public goods and services', their generation by farming areas will not be included in market valuations of production, nor will their decline or loss be captured in economic values of the underlying natural capital. Exceptions may arise when farmers can participate in payment for ecosystem services (PES) schemes, and indeed, this is a good rationale for such schemes.

Residual flows: These include various pollutants (GHG emissions, excess nitrogen and phosphorus emissions), harvest losses, wastewater, and food loss and waste along the eco-agri-food value chain. In the language of the SEEA Central Framework, residuals are "flows of solid, liquid and gaseous materials, and energy, that are discarded, discharged or emitted by establishments and households through processes of production, consumption or accumulation" (UN *et al.* 2014, p.26) These residual flows are drivers of some of the most serious outcomes that affect human well-being from the workings of the eco-agri-food systems complex, and it is vital that we record and measure them. Food waste can be captured most simplistically in tons; however, to dimension it properly, it needs to be expressed also in calories, nutrients and indeed, economic value. Harvest losses include pre- and post-harvest losses. The latter are particularly damaging in the context of poor communities, as their inability to afford storage and refrigeration leads to a vicious cycle of low farming returns and further poverty. GHG emissions are a significant externality of agriculture – an estimated 11 to 15 per cent of global GHG emissions (Grain 2014) are from agricultural production.

Mapping these various flows into, within and from eco-agri-food systems allows us to see how food systems really affect human well-being, not from a single perspective of either just 'production' or just 'climate', etc. (as described in Chapter 1), but from all of these important perspectives.

Box 4.2 Drivers, Outcomes and Impacts

Drivers: A collective term for all the above *flows* which arise from the activities of agents (i.e. governments, corporations, individuals) in eco-agri-food value chains, resulting in significant *outcomes* and leading to material *impacts*.

Outcomes: Change in the extent or condition of the four capital bases (natural, produced, social and human) due to value-chain activities

Impacts: Positive or negative contribution to one or more dimensions (environmental, economic, health or social) of human well-being

4.7 OUTCOMES AND IMPACTS IN THE TEEBAGRIFOOD FRAMEWORK

In addition to stocks and flows, 'outcomes' and 'impacts' as defined in **Box 4.2** are the other two important components of our Framework.

Recording stocks, flows and different types of outcomes provides a complete description of agri-food systems, but still does not provide a means of measuring changes to human well-being as a result of these outcomes. As we are comparing farm systems across economic, social, and environmental dimensions we find that using a common lens of *"value addition"* allows measurement of these different dimensions in a consistent and coherent manner that is practical and equitable, and can better inform both policy and business decision-making. In our Framework, we apply the principle of "value addition", which is at the heart of the System of National Accounts (SNA) of the United Nations, and reflects the idea that we can change the state (i.e. space, time, and characteristics) of a product to make it more valuable to humanity. SNA metrics incorporate the principle of "value addition" through what is known as the "income approach" of calculating the Gross Domestic Product (GDP), which calculates GDP as the sum of compensation paid to employees, rents paid, taxes paid less subsidies, and the profits of producers. However, as all these quantities generally ignore the *economically invisible* flows that form important components of the eco-agri-food systems complex, we broaden the "value addition" approach by also including the contributions of invisible flows to human well-being through their positive (or negative) impacts along the agri-food value chain. **Table 4.1** explains this concept, using several examples of outcomes and impacts from various flows along a typical eco-agri-food value chain.

It should be noted that these are selected and illustrative examples, as each flow usually results in more than one outcome, and each outcome can result in more than one impact:

Table 4.1 Examples of outcomes and impacts, as expressed by value addition (Source: Obst and Sharma 2018)

Example of a Flow	Example of one Outcome from the Flow	Example of one related Impact (in Value Addition terms)
GHG emissions from wheat, rice, beef, etc	Natural Capital Outcome: Higher GHG concentrations	Productivity & infrastructure losses through increased droughts, flooding, etc
Land Use Change from forests to farms	Natural Capital Outcome: Deforestation	Loss in relevant ecosystem services inputs, leading to productivity losses
Watershed repair & restoration expenditure	Natural Capital Outcome: Higher water yields	Improved crop yields due to increased water availability
Subsidy to grow farm-edge vegetation	Natural Capital Outcome: Improved condition of tree belts and hedgerows	Increased amenity values, pest control & pollination values
Excess N & P flow from fertilizers	Natural Capital Outcome: Eutrophication of water ways	Reduced income from fish catch
Investment flow to farmland aggregation	Social Capital Outcome: Loss of access to land/ displacement	Reduced income and qualitative indicators concerning equity, including gender equity
Investment flow to small farms in fragile lands	Social Capital Outcome: Increased access to food	Assessed health benefits and qualitative indicators concerning equity
Micro-credit flow to rural Self-Help Groups	Social Capital Outcome: opportunities to employ more women in rural areas	Qualitative indicators on equity and community networks
Pesticide use on farms	Human Capital Outcome: Ailments due to pesticide poisoning	Increased health costs due to higher disease burden
Subsidy for farm equipment	Produced Capital Outcome: Investment in agricultural machinery	Improved farm incomes and productivity
Declaration of a new Protected Area	Produced Capital Outcome: Loss of road infrastructure	Increased transportation costs and higher consumer prices

The appropriate response to our principles of universality and comprehensiveness, from an evaluation perspective, is to ensure a comprehensive assessment of all information (biophysical, qualitative and monetary) on all capitals is undertaken so as to understand the extent of substitutability between capitals in any given agri-food system and associated issues of thresholds in the use of capital. Collectively, fully mapping these various flows into, within and from the agri-food system allows a full articulation of the pathways by which an agri-food system impacts on human well-being.

Finally, putting together stocks, flows, outcomes and impacts, the Framework can be summarized by **Figure 4.3.**

4.8 MEASURING AND VALUING STOCKS AND FLOWS

In order to understand what society gains or loses from policy choices, or what society (instead of just the business bottom line) gains or loses as a result of business decisions related to eco-agri-food systems, we need to be able to estimate changes in stocks arising from such actions, and we also need to be able to *value* these changes. Thus it becomes important to be able to measure and value capital stocks. To do so, we need to know or be able to estimate the *flows of value* that are expected to be generated from capital stocks.

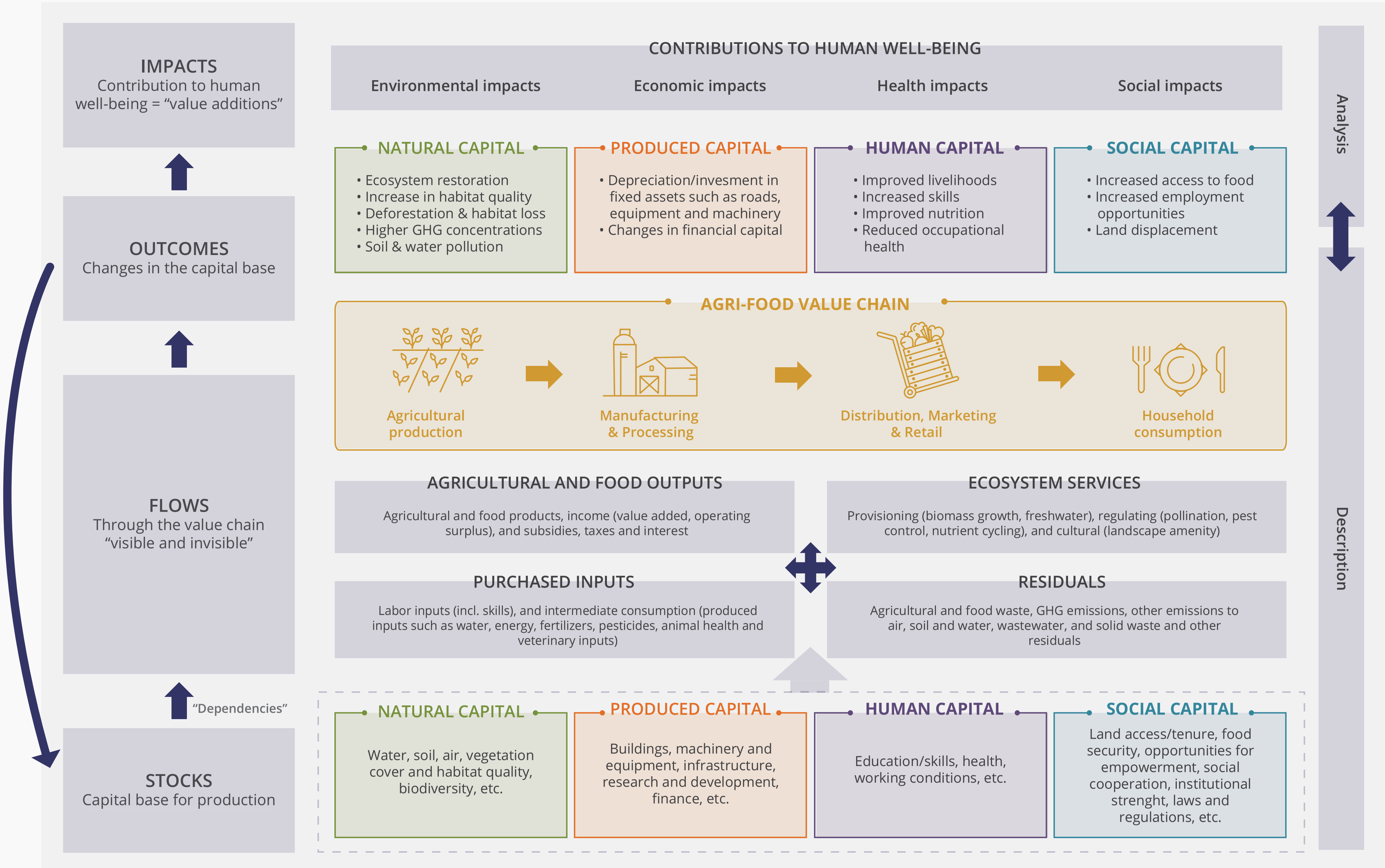
In general, capital stocks can be valued as the *net present value of their future returns.* In other words, the flows from capital stocks have to be estimated, together with costs for maintaining these stocks to be able to deliver those flows. Appropriate discount rates then need to be chosen to convert expected future returns to their present values. Such valuation is generally not very challenging for *private goods* or services flowing from *produced capital*, because flows are generally known and market-priced (e.g.: rentals minus maintenance costs for farm equipment, factory premises, etc.); interest rates can serve as a reasonable proxy for private discount rates; and most produced capital stocks are tradeable private goods and thus have market prices.

For ***human capital***, as it comprises of some components (i.e. skills and knowledge) that can be "leased" by people to firms for an economic return (i.e. their salaries and other remuneration), and other components (i.e. health) that cannot, such calculations can be complex and challenging. Future incomes (salary, bonuses, profit shares, etc.) can at best be *estimated*, and private discount rates (i.e. preferences for present versus future utility from a given income flow) are assessed differently by different people. There are also ethical questions about valuing health capital – or the lack of it – as no third party can really determine what good health (or ill health) means to another individual in order to determine its value, even if the medical costs of treatment and restoring good health are calculable.

When it comes to valuing ***natural capital*** stocks, there are ethical, ontological and methodological challenges aplenty. Firstly, forecasting ecosystem services emanating from a particular natural asset is fraught with both scientific uncertainty (as we may not fully understand its underlying ecological processes, functions, and services) as well as risks (as there are many dynamic variables, and future ecosystem services may be quite different from present services due to numerous ecological and environmental changes). Secondly, most ecosystem services are in the nature of *public goods,* therefore appropriate discount rates are *social* discount rates and not *private* discount rates. Social discount rates imply ethical choices in determining them that depend on *who* decides, and on *what* inter-generational and intra-generational factors are being considered for such decisions. Furthermore, the nature of economic valuation can presume a Cartesian approach, and perhaps a Judeo-Christian mindset (i.e. viewing nature as distinct from and in the custody of mankind) and these approaches and mindsets many be ethically unacceptable for some societies. Notwithstanding these challenges, valuation of natural capital stocks impacted by or contributing to eco-agri-food system flows can oblige decision makers in most modern societies to better recognize and reflect these values in their decisions. Such choices need to be made appropriately and judiciously, reflecting societal contexts and mores.

Due to its "relationship" nature and the fact that it does not generate its own incomes, ***social capital*** has proved difficult to measure and value (Giordano *et al.* 2011). As aggregate indicators are not widely agreed upon, various proxies (e.g. indicators of the strength of social networks, measures of trust [Hamilton *et al.* 2017]) may give insights into its extent and condition. Some of these are indicators of collective action and cooperation, adherence to norms and regulations, and participation in local organizations and groups, social cohesion and inclusion (Grootaert and Van Bastelaer 2002). For example, recording information on farmer's cooperatives and understanding their functioning across agricultural production systems may provide valuable insights for decision-making. Similarly,

Figure 4.3 Stocks, Flows, Outcomes and Impacts in the TEEBAgriFood Evaluation Framework (Source: Obst and Sharma 2018)



understanding the participation and inclusion of women and other marginalized sections across agricultural systems is vital to informed policy-making.

4.9 VALUATION AND EVALUATION

Economic valuation methods can help quantify dependencies and impacts in monetary terms, thus making them more comparable to other things we value in society. They can be used to justify or change policies and business practices. However, economic valuation alone cannot provide a complete picture of eco-agri-food system scenarios and choices. For that we need additional *evaluation* techniques to understand the relative social, environmental and ecological merits of different actions, strategies, and policies. Different policies (e.g. which subsidies or taxes to choose, which agricultural policies?), resource allocation choices (e.g. how much water to use for irrigation?) and production decisions (e.g. what type of crop rotation to implement in a particular rural area?) made by different stakeholders (farmers, agri-businesses, policy makers) may involve considering trade-offs across different capital classes and ownership categories, across corporate shareholders versus stakeholders, between private and public interest. There may be ecological thresholds at hand that could be devastating if crossed, or there may be ethical issues associated with trading off the benefits of a few with the costs of the many, especially if they belong to different social strata.

Evaluation techniques beyond just "economic valuation" are required in such circumstances to understand whether the trade-off envisaged is ethical, equitable, ecologically safe or risky, and whether benefits are worth the costs and the risks not only on average to society as a whole but also to different groups of producers and consumers, while also assessing the wider social (particularly distributional) and environmental impacts of decisions.

Some of commonly used evaluation methodologies that help us understand how eco-agri-food systems function in light of these wider goals include

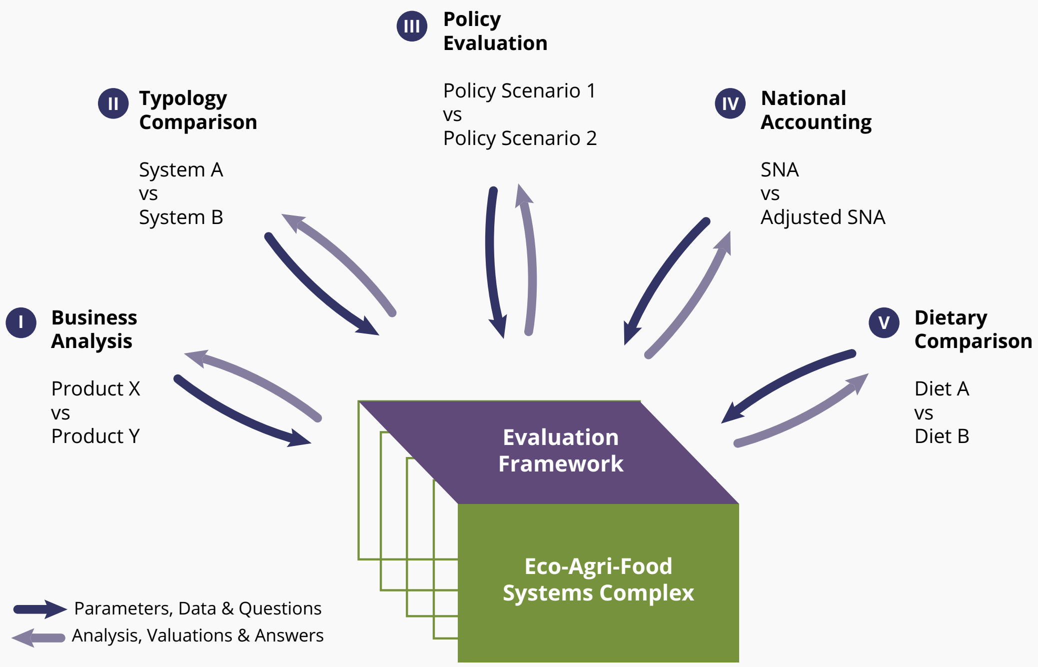
1. Cost Benefit Analyses (CBA) - to understand economic trade-offs between choices
2. Life Cycle Assessments (LCA)– to understand impacts and dependencies along business and other value chains
3. Multi-Criteria Analyses (MCA) – to look beyond cost-benefit or cost effectiveness results and allow the assessment of projects or choices against a variety of criteria, using different quantitative and qualitative indicators.

Gundimeda *et al.* (2018) explain and provide examples of all the above methodologies, as well as guidance on the appropriateness and use of various specialized tools for land use planning, estimating water requirements and watershed impacts of agriculture, and estimating and valuing ecosystem services.

Furthermore, to evaluate agri-food typology choices in terms of their expected impacts on entire economic systems, or to help decide between two agri-food policy options in the same economic system, one can use a "general equilibrium" approach and model of supply and demand across all sectors in an economy. Such analysis is typically conducted using what is known as a 'computable general equilibrium' (CGE) model (see for instance Lofgren and Diaz-Bonilla 2010). CGE models are a standard tool of analysis and are widely used to analyze aggregate welfare and distributional impacts of policies whose effects may be transmitted through multiple markets, or may contain menus of different taxes, subsidies and quotas (Wing 2004). However, CGE models do not value or account for changes in the state of *natural capital* stocks other than incorporating land covered by agriculture, and neither do they account for *social capital*, a critical component of success in many farming communities. To be able to incorporate and measure such components of our Framework, it would be necessary to work with additional and complementary models, such as System Dynamic (SD) models. These models map out impacts and dependencies in great detail using Causal Loop Diagrams, which include positive and negative feedback loops. These models then iterate historic data to work out the best-fit equations for each impact and dependency, thereby creating a robust model that can be applied to evaluate in a practical way policy scenarios and choices. Most importantly, SD allows to forecast policy outcomes across sectors and economic actors for all dimensions of development (social, economic and environmental), over time and, when coupled with GIS models, in space.

The pillars of SD models are that they explicitly account for feedbacks, delays and non-linearity. SD models allow a modeler to integrate social, economic and environmental indicators in a single framework of analysis. By running "what if" scenarios, SD can inform policy measures that may improve several indicators at once (e.g. providing affordable food supply while generating employment and reducing forest loss),

Figure 4.4 Applications of a universal evaluation Framework (Source: Sandhu et al. 2018)



rather than estimating the optimal policy package for a narrower set of indicators. Turner et al. (2016) concluded that SD provides a useful framework for assessing and designing sustainable strategies for agricultural production systems, and Gundimeda *et al.* (2018) provide a detailed example (SAGCOT, Tanzania) of how such a model may be used.

4.10 USING THE FRAMEWORK: APPLICATIONS

One of the guiding principles in designing the Framework was "universality", which is key to its usefulness. As illustrated in **Figure 4.4,** it is designed to be used as a common 'wide-angle' lens for applications as diverse as dietary comparisons, policy scenario analyses, comparisons of different agricultural management systems, comparisons of the true costs and benefits of alternative food products, or even to derive adjustments to the accounts of society in order to include major externalities. In each context, applying the Framework rigorously will highlight all major costs and benefits – whether visible or invisible, private or public.

To illustrate applications of the Framework, notwithstanding that it is a new Framework, Sandhu *et al.* (2018) have conducted testing as to how it might shed light across ten existing, very diverse, case studies. These case studies had investigated different dimensions of agricultural management systems, including: business analysis, dietary comparison, policy evaluation and national accounts for the agriculture and food sector. From amongst these ten examples, let us look at two applications of the Framework, one each in evaluating agricultural management systems and in policy scenario analysis.

The first example compares conventional agriculture and organic agriculture in New Zealand. It considers the values of twelve ecosystem services from a sample of 29 fields (15 conventional and 14 organic), including "provisioning ecosystem services" (food, raw materials, etc.) as well as economically invisible "regulating and supporting services" (pollination, biological pest control, nutrient cycling, etc.). Composting and natural regeneration practices typically found in organic farming lead to higher below-ground (due to high organic matter and carbon) and above-ground (due to continuous ground cover) biomass and biodiversity thus these valuable but non-marketed ecosystem services are much higher in an organic agriculture context. Conversely, conventional agriculture suppresses these ecosystem services resulting in negative impacts on natural capital such as soil health, farm biodiversity, water quality and air quality. Thus, the economic value of ecosystem services from the organic system far exceeds that from conventional systems. As a result, in this study, the total economic value of ecosystem services in organic fields ranged from US $1,610 to US $19,420 $ha^{-1}yr^{-1}$ whereas that of conventional fields was lower, ranging from US $1,270 to US $14,570 ha^{-1} yr^{-1} (Sandhu *et al*. 2008). All ecosystem services including food production values were higher in organic fields compared to the conventional ones. This was due to higher market prices for organic produce, with comparable yields from both systems. The TEEBAgriFood Framework allowed comparison of trade-offs between these two alternative production systems. We see this however as a "partial" application of the Framework because it only covers the ecosystem service externalities of farming, and more research would be needed to compare aspects such as nutrition impacts, human health impacts and social equity across these two alternative systems. Secondly, it only covers the 'production' part of the eco-agri-food value chain, and not the entire value chain, which might reveal further interesting value-chain linkages, impacts, externalities, and trade-offs.

A second example of a Framework application is for policy evaluation of a pesticide tax in Thailand. Thailand started subsidizing credit to farmers to promote the use of pesticides in order to increase agricultural production in the late 1980s (Praneetvatakul *et al*. 2013). However, the gains from pesticide use started falling from 2010 onwards. Moreover, policy makers started seeing the negative effects of pesticides on the environment, on farmers' health, and on risks to consumers. This study estimated external costs of pesticide from farm workers' exposure to these chemical agents. It also examined the costs associated with the enforcement of food safety standards. This resulted in two options: increasing taxes on pesticide, making them more expensive, and promoting non-chemical pest management methods through farmer training and education. The TEEBAgriFood Framework is useful in identifying those areas where policies and institutions can address the areas of greatest costs and benefits along eco-agri-food system value chains. It can help analyse costs at a national level to support national policy reforms. In this case, the majority of external costs of pesticide use were to farmworkers, and not consumers. Therefore, an environmental tax which would raise pesticide prices could act as a barrier, and with appropriate policy support, could steer farming practices towards alternative and biological forms of pest control. This illustrates how the Framework can help differentiate and nuance policy responses and target the most relevant parts of food value chains.

However, we found that there was no single example amongst the ten showcased studies where impacts along the *entire* value chain had been measured. In part, this may reflect data limitations with a set of old studies, but in larger part, it reflects not imposing a sufficiently broad and systemic perspective on eco-agri-food systems.

Using information from evaluating each of these studies, various issues within the Framework were explored, including the need for future modifications and adaptations. We concluded that the availability of the TEEBAgriFood Framework will encourage more ambitious assessments using the full gamut of economic analysis tools. There is evidently a compelling case to develop and apply the analytical discipline of this Framework to a range of Framework-testing studies which are more complete in perspective, better served with researched data, and will help us understand *all* positive and negative externalities in diverse eco-agri-food systems for a wide range of applications.

4.11 THE FRAMEWORK AS A LIVING DOCUMENT

We believe that the evolutionary nature of the Framework will allow it to be modified to be used in an increasing number of circumstances and applications across many countries. We expect that analysts will test it in different ecological, farming and business value chain contexts, through a series of "Framework-testing studies" from which the Framework will draw lessons and evolve over time to become a new orthodoxy, replacing simplistic older yardsticks such as "per hectare productivity". Our vision is that agri-food policy makers, agri-businesses, farmers and civil society organizations will be able to make use of the Framework to better manage the risks associated with degradation of natural, social, human and produced capitals along eco-agri-food systems, thereby creating better opportunities to provide nutritious food for all citizens without dangerously degrading ecosystems which are vital for the success and sustainability of food and agriculture.

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"THE PHILOSOPHERS HAVE ONLY INTERPRETED THE WORLD IN VARIOUS WAYS; THE POINT, HOWEVER, IS TO CHANGE IT."

-KARL MARX

CHAPTER 5

What Next?

Chapter 5 draws upon key findings and the TEEBAgriFood “theory of change” to set out a way toward a more sustainable and equitable food system. In particular, it proposes next steps for the TEEBAgriFood Evaluation Framework as a wide-angle lens enabling holistic analysis to better inform diverse decision-makers including policy-makers, agri-businesses, farmers, civil society, and citizens. It outlines the importance of ongoing and varied ‘pilot studies’ of the Framework to evolve and establish a new mainstream approach for food system evaluation. It underlines the importance of implementing this approach in-country, with government involvement and support. It outlines why agriculture and food systems are crucial for implementing both Agenda 2030 and the Paris Agreement, 2015, and how the TEEB approach and Framework might help as a review mechanism. It also provides glimpses of success and visions of what eco-agri-food systems might be if we replicate and scale successes. A deep and wide-ranging transformation in food systems will require appropriate and holistic metrics, such as the Framework.

5.1 INTRODUCTION

The scale and intensity of externalities brought about by today's eco-agri-food systems have grown considerably in recent years, yet accounting for such externalities or mitigating actions to counter their negative effects has not kept pace. Despite increased public scrutiny of the health and environmental effects of food and agricultural practices over the half-century since the publication of *Silent Spring (Carson 1962)*, there remains considerable denial and pushback from the agribusiness and food supply industries as they influence consumer perceptions and deny the veracity of evidence supporting the need for change. Evidently, holistic information and an informed public is a liability to some, but it also provides opportunity to introduce new and different types of business. This leads us to the question of whether good information is in fact a significant driver of change, and if so, under what conditions and in what contexts? Addressing this question raises another vital question: what is *TEEBAgriFood's* theory of change?

5.2 WHAT IS TEEBAGRIFOOD'S 'THEORY OF CHANGE'?

A sound 'theory of change' identifies actors, processes and preconditions for interventions to best attain their intended consequences. May *et al.* (2018) present a theory of change (ToC), which posits that better knowledge of and quantified measurements of major externalities of the food system enabled by the TEEBAgriFood Evaluation Framework can be used to influence decision makers in particular contexts. This ToC suggests that if the targeted change in policy, farming model, agri-business practice, or citizen behaviour *already* has a community of support, some credible champions and perhaps some traction, then the comprehensive evaluations that result from applying TEEBAgriFood's Framework can provide a case for further pressure and opportunities for such a change. In consonance with existing initiatives and actors already advancing such changes, applying TEEBAgriFood can help strengthen a case to redirect resources or change products or practices, helping targeted decision makers escape from the trap of many "lock-ins" and achieve more sustainable food systems.

TEEBAgriFood's ToC addresses the roles of *information and denial in the politics of evidence*. Calculating and successfully sharing *"the true cost of cheap food"* is part of that broader challenge. Identifying the most important and useful *drivers of change* leads us to identify the mainactors as points of entry forthe strategies of TEEBAgriFood. *Leveraging enabling institutions and governance systems*is also essential, and this in turn requires drawing on diverse narratives for change, including *food security and food sovereignty narratives.*

Last but not least, it is important to recognize *the two sides of path dependency-* and target positive path dependencies. *TEEBAgriFood can support the implementation of the SDGs and the Paris Agreement* in many ways, and recognizing their interlinkages can help sustainability advocates and food system decision-makers to best support systemic transformations towards sustainability. Application of the TEEBAgriFood Framework can provide deeper insights in the complex nature of eco-agro-food systems and guide implementation at national and international level. We discuss below each of these themes, and their role in the theory of change of TEEBAgriFood.

5.3 INFORMATION, DENIAL AND THE POLITICS OF EVIDENCE

The link between better information and system change is tenuous for at least three reasons. Firstly, better information or better access to it does not necessarily translate into decision-making. This has been widely shown in psychology with respect to risk (e.g., health risks of smoking tobacco) and with respect to environmental costs and risks (Weber and Johnson 2009). Worldviews, political ideologies and economic interests are factors that strongly influence change. Therefore, information such as evaluation of sustainability benefits and costs may have a positive effect only if it coincides with efforts to progressively shape visions and raise awareness that will trigger changes in value systems and in collective deliberation.

Secondly, much information is simply lost, even to scientists and specialists in a given field. Doemeland and Trevino (2014) have shown, for example, that approximately one-third of the documentation made available by the World Bank is never downloaded. Making large amounts of data available speaks well for transparency, but the usefulness of so much information can be called into question.

Third, deliberate strategies and "strategic unknowns" (McGoey 2012; Rayner 2012) are very often designed to cause confusion, defuse knowledge and generate ignorance in the fields of agriculture and the environment. This applies to cases as diverse as that of honeybee decline (Kleinman and Suryanarayanan 2012) or the strategy behind under-reporting farm-workers' pesticide poisoning in California and France (Dedieu et al. 2015). Agricultural research is sometimes oriented so as to select or block topics and sources such as non-industry-funded works on GMOs (Elliott 2015).

Notwithstanding these hurdles, there are ways forward. Recent surveys (Nielsen 2016) by a leading consumer research firm show a significant change in consumer attitudes toward the health characteristics of foods, which will undoubtedly shape the direction of things to come. For example,

- 36 per cent of 30,000 global online survey respondents in 66 countries said they have an allergy or intolerance to one or more foods;
- 64 per cent of respondents said they followed diets that limit or prohibit consumption of some foods or ingredients (particularly in Africa/Middle East and Asia) – and nearly half of these did not feel they were being adequately served by food available to them;
- More than half of consumers said they were avoiding artificial ingredients, hormones or antibiotics, genetically modified organisms (GMOs) and bisphenol A (BPA).

Consumer decision-making is largely influenced by the level and quality of information obtained from markets. Though manipulation of information to provide a healthy image to consumers is commonplace, an antidote is consumer awareness of the characteristics and quality of foods that promote positive changes in eco-agri-food systems. Communication strategies that engage a wide audience on food and health and reveal underlying linkages to social and environmental problems are useful in informing and influencing consumer behaviour. Inter alia, Weigelt *et al.* (2018) recommend a "Food Atlas" that would lay out the impacts of food and agriculture on the four different capitals that are part of eco-agri-food systems in easily comprehensible terms. Citizens can use the TEEBAgriFood Framework to better understand the constitution of sustainable diets, the health implications of their food consumption patterns, and the size of their food footprints.

From a behavioural psychology perspective, at an individual or collective level, worldviews and political alignments are often more important in determining willingness to change than whether the information received is adequately convincing (Weber and Johnson 2009). However, if information obtained through TEEBAgriFood analyses can be provided to interest groups, communities, or CSOs working on food system reform, there is much greater potential for success. None of this is easy, especially as the most precarious dietary conditions are found among poor people, who – even in the richest countries – are more susceptible to diet-related illnesses such as obesity and diabetes.

There is also an ethical case to proceed: in the absence of any counter-balancing factual information (such as that emerging from applying TEEBAgriFood's holistic Framework and methodologies) the public arena is simply ceded to public relations campaigns led by major food and agri-input companies, including policy dialogues, major media coverage of food issues and intensive lobbying of international aid organizations. The aim is often to position large-scale agroindustry's high-external input systems as the "only" way to reliably produce "enough to feed ten billion people", and to position these businesses as champions of social sustainability using yields per hectare as a simple benchmark. Such campaigns are very often misleading, serve certain self-interests, and are difficult to combat. Nevertheless, there is no question that the food industry has undergone significant transformation over the past decade, mainly due to consumers' concern over their health and that of the environment. The food localization movement has combined with concern for excessive reliance on long distance transport and trade for foodstuffs, whose freshness is questioned. Buying organic produce or fresh food locally becomes a way for individuals to make a positive statement to their peers regarding their contribution to mitigating climate change, supporting family farmers in their neighbourhood, and protecting agricultural lands near major urban centres.

5.4 CALCULATING AND MESSAGING "THE TRUE COST OF CHEAP FOOD"

It is often asked if appealing to peoples' growing concern with the origin and quality of the food they eat is a sufficient or at least a significant driver of change towards sustainable food systems. This awareness is juxtaposed with the idea that 'we need cheap food to feed the world'. Such narratives are based on cultural framing that emphasize "cheapness, convenience… and rendering invisible the origins of food products" (Campbell 2009, p.313). These conceptions contribute not just to perpetuating unsustainable food systems, but also to increasing nutritional gaps between rich and poor, with health diets catered to the affluent and highly processed food to poorer populations, leading to both malnutrition and obesity (Dixon 2009). To counter such narratives, it is necessary to expose the true cost of food, supported by more complex scientific evidence and feedback mechanisms, which will strengthen arguments with incumbent vested interests (Young and Esau 2016). TEEBAgriFood provides new evidence on costs and benefits that contributes to counter-narratives that take ecological values into account, exposing the true cost of food.

5.5 PRIORITIZING ACTORS AS POINTS OF ENTRY FOR CHANGE

To strategically apply TEEBAgriFood, its users need to identify *which* potential influencers in *which* typical contexts it wishes to equip in order to activate *which* levers on *which* actor groups. Outreach strategies must be geared towards potential users, or even directly communicated towards certain actor levers.

The two main groups of actors include first of all key players in a given food system whose actions are driving – or constraining – the system. These actors' behaviours and choices need to change if the food system is to evolve in sustainable ways. The second group is actors desiring to bring a change in food systems by making use of TEEBAgriFood resources, thus collabourating with actors of type 1 to disseminate knowledge of the true costs inherent in the food system. Since it was shown above that information in itself may be insufficient to provoke a change, it will need to be mobilized by such actors (Majone 1989; Fisher and Forester 1993; Laurans *et al.* 2013; Mermet *et al.* 2014; Feger and Mermet 2017).

To respond to these challenges, a three-tier approach to study design and strategy is proposed, based on the TEEBAgriFood Framework. These three elements concern different (though linked) stages in production and overlap in time.

- ***Phase 1. Design a study and plan for intervention: context assessment and strategic framing.*** As for any assessment and evaluation study that aims to deliver a message and eventually produce a change in society, TEEBAgriFood authors should understand the strategic context in which their study will intervene (Mermet 2011; Coreau 2017). What efforts have already been made to put key questions on the food system reform agenda and tackle them (e.g., environmentally harmful subsidies), by whom, with what effect? Did opposing actors react to newly provided information, and with what effects? How were coalitions on each side structured? Do they still exist today? These types of questions should enable author teams to identify the users and targets discussed above. Then, author teams should engage with different users to better integrate their own experience of the issues at stake (Turnhout *et al.* 2012) and co-construct parts of the study with them, to maximize the chances that the study has impact once released.

- ***Phase 2. Conduct strategic outreach and intervention.*** Once the study is produced, or even better, while it is being produced, an intervention strategy should be designed. For the global scope results, for instance, the intervention strategy could be adapted to different national contexts. Indeed, at a given point in time, national and regional arenas are agitated by different debates, and these debates frame how governments, media and the general opinion view different types of information. If controversy is roaring in a given country on, for instance, pesticides, agricultural reform, or deforestation, the use of new results and messages will resonate stronger if some parts of the messages are highlighted to specifically contribute to these debates. This "strategic packaging" (Waite *et al.* 2015) of results consists of choosing which messages to highlight, in national press releases for instance, to better serve potential TEEB users in their quest for change. Beyond the media, specific discussions could be organized with potential users to help identify the elements that could be of most efficient use in their own advocacy strategies. The discussions held in Phase 1 obviously constitute preparatory work for Phase 2.

- ***Phase 3. Monitor and respond.*** After results and messages are conveyed, monitoring activity will be useful: any given study must be acted upon to have impact (Latour 2005). In the case of TEEB, this monitoring could focus on identifying: i) the positive impacts of the TEEB study, to foster reflexive learning for TEEB, and ii) how different biodiversity-agriculture debates evolve and how the study could be mobilized, even some years after publication. This could also include a monitoring of evidence for strategic ignorance of TEEB and TEEB-like results (see section 2.1). This monitoring could then help build a response to this evolving context: issue a new press release targeted towards an emerging debate and to which previous TEEB results could contribute, or work with TEEB users to see how different actors could be mobilized.

In summary, TEEBAgriFood's theory of change recommends developing strategies to design and disseminate actor-relevant information as the way forward.

5.6 DRIVERS OF CHANGE

A key concept in a Theory of Change is the notion of a 'drivers of change', which is usually specified behaviours, outputs, activities and processes of a group of actors (e.g.: governments, farmers, agri-businesses, consumers, civil society organizations (CSOs), etc.) which result in the *outcomes* and *impacts*[14] that are contributing to 'business as usual' in eco-agri-food systems. For each actor group, there is a set of *levers* that determine the actor's behaviour and on which agents of change can exert influence. Governments, or more specifically ministries, can make use of TEEBAgriFood results to frame negotiations with agribusiness regarding agri-food policies. But there are also cases where a government (sometimes the very same government) will be a key actor that CSOs will pressure, based on TEEBAgriFood results, to induce changes in legislation. All of these pressure points will in turn be driven by good research arising from applying the Framework in a variety of contexts.

TEEBAgriFood will need to evolve with the active engagement of three sets of actors. The first is the community of academicians and experts who will be engaged to explore the Framework and its applications in diverse socio-economic and agronomic contexts, and over diverse ecologies and geographies. This process of engagement will result in studies that can serve as examples of holistic evaluations that are *comprehensive* by design, in that they address whole value chains and capture all major externalities, *universal* in that they apply the *same* Framework in different contexts, and *inclusive* in that they are conducted by groups of experts from diverse disciplines and ideologies. Gradually, the information assembled through these studies (the so-called "Framework-testing studies") will counterbalance (though not ignore) information provided through the narrow lens of 'per hectare productivity'.

The second set of actors – including some already engaged through the UN – are the governments of countries facing significant challenges in agriculture: livelihoods losses, human health impacts, freshwater scarcity, yield and productivity issues, and the accentuation of these by climate change. Policy makers in developing countries could be encouraged to use TEEBAgriFood's Framework-testing studies to help them design better policies and incentives to address their specific problems and challenges in the arena of eco-agri-food systems.

A third and equally significant group is civil society, many of which have already developed significant inroads with policymakers and the general public through their positions and supporting narratives. These narratives could benefit from and be reinforced by the kind of research that is provided by TEEBAgriFood's Framework-testing studies.

5.7 LEVERAGING ENABLING INSTITUTIONS AND GOVERNANCE SYSTEMS

The success of engagement of each of these three groups of actors, especially governments, will depend on the quality of institutions and governance systems in the country. The TEEBAgriFood ToC relies on supportive governance systems and enabling institutions (including rules and regulations) as building blocks and addresses societal mind-sets (both world views and values). In combination with countervailing public pressures

14 See Chapter 4 for definitions

and alliances, and instruments such as certification, incentives or sanctions, systems and institutions can be mobilized to address externalities in food chains.
TEEBAgriFood's Evaluation Framework provides systematic linkages to a range of related global processes, and supports (i) a more encompassing understanding of the eco-agri-food system, (ii) outreach to a broad range of constituencies, and (iii) a more holistic analysis to identify strategic interventions and setting of priorities. Chapter 10 of the TEEBAgriFood Foundations Report spells out its relevance for today's global sustainability governance.

For example, the Implications of the Aïchi targets is of high relevance for eco-agri-food systems and the TEEBAgriFood Framework can contribute to the achievement of this international agreement. The Aïchi Targets have been adopted in 2010, together with a more general Strategic Plan for Biodiversity 2011-2020. This strategic plan relates in many ways to the functioning of eco-agri-food systems.

Another example - the role of TEEBAgriFood in the progressive realization of the Right to Food - is on the one hand about the enhanced understanding of externalities and how they are undermining the achievement of a world free of hunger, and on the other hand about the application of the Framework to support States in uncovering the structural causes of food insecurity in some communities.

5.8 FROM FOOD SECURITY TO FOOD SOVEREIGNTY NARRATIVES

Counter-narratives to the prevailing "feed the world" narrative can challenge social norms and achieve both local and global impact (Fairbairn 2012, Lang 2010, Martinez-Alier 2011, Phalan et al. 2016, Wittman 2009). For example, the Food Sovereignty Movement, which emerged in the 1980s, challenges the definition of food security grounded in increasing individual purchasing power (Edelman 2014) by means of large-scale mechanization and globalized food systems (Jarosz 2014). Instead, the food sovereignty movement aims at "transforming the current food system to ensure…equitable access, control over land, water, seed, fisheries and agricultural biodiversity" (International Planning Committee of the People's Food Sovereignty Forum 2009, quoted in Jarosz 2014, p.169). The movement adopts a rights-based approach that emphasizes sustainable, family-farm based agricultural production, and diversification and localization of food systems.

5.9 THE TWO SIDES OF PATH DEPENDENCY

A recent report (IPES-Food 2016) describes *eight* key lock-ins that represent or reinforce inertia against proposed changes in today's food systems, including "feed the world" narratives of industrial farming; expectations of cheap food; trade and export orientation; compartmentalized and short-term thinking; inappropriate measures of success; and path dependency. Path dependence (Nelson and Winter 1985), a term from evolutionary economics, is a key reason the current system has persisted, deepened and expanded over the years despite increasing knowledge of its negative externalities. Pressures to shift the *status quo* are impeded by those who have interests in maintaining the current system.

Furthermore, "history matters" and *inertia* is a powerful: the trajectory of technology, economy and society is largely predetermined by what came before. We use a "QWERTY" keyboard, made popular by a design from 1878 that helped avoid typewriter keys from jamming when common keys were hit in quick succession. That problem is obsolete, but we still use "QWERTY" keyboards. In the world of food systems, as pointed out earlier, some of the greatest health challenges and social costs today relate to the *undernutrition* of over two billion people, and yet, agricultural subsidies (e.g. for wheat, rice, maize and sugarcane subsidies) are still mainly instead targeting *caloric intake* based on earlier recognitions of the huge problem of solving hunger. Furthermore, it is our view that this path dependency is creating *further* health problems, as cheaper calories contribute towards growth in the number of people overweight or obese.

Path dependence can also be harnessed for positive change. For instance, consumer concern about the health effects of saturated oils or of corn-based sweeteners has begun to push its own positive path-dependence. Avoidance of such ingredients may become a new industry norm. Indeed, building positive path dependency can be a recipe for success. For example, the electric car industry has reached such a critical mass that is has spurred research and technological advances in battery efficiency. These advances further "lock in" the electric car industry in a positive sense.

Although path dependency makes it difficult to escape a particular technological or organizational paradigm, positive change is still possible. Consistent with the TEEBAgriFood ToC, to effectively intervene agents of change must work at the systems level and be aware of social, spatial, temporal and symbolic dimensions of change (Sydow *et al.* 2009).

5.10 TEEBAGRIFOOD, THE SDGS AND THE PARIS AGREEMENT ON CLIMATE CHANGE

TEEBAgriFood emphasizes the importance of "systems thinking" as the only appropriate approach to the complex reality of food systems; hence the term 'eco-agri-food systems'. However, the reality remains that some of the most important decision-makers around food systems today *do not* adopt systems thinking.

Weigelt et al. (2018) analyse how to link the TEEBAgriFood Evaluation Framework with the SDGs, perhaps the single most important policy entry points for advocating and achieving change before 2030. A key challenge for the SDGs is that policy responses happen mainly in silos, within the respective mandates and administrative boundaries of government ministries--a familiar challenge for sustainable development.

Thus there is perhaps no better illustration of the need for systems thinking, which also helps to identify path dependencies and make the case for policy *coordination,* than the domain of eco-agri-food systems, whose drivers and outcomes not only determine success in **SDG 2** on sustainable agriculture, but impacts the achievement of **SDGs 1, 3, 5, 6, 10, 12, 13, 14 and 15**.

SDG 2 is about ending hunger, achieving food security and improved nutrition, and sustainable agriculture. However, as *fish* provide the main source of animal protein for over a billion people in the developing world, food security and better nutrition may not even be possible without achieving **SDG 14**, which entails conserving and sustainably using the oceans. At present, we seem to be intent on competitively mining the oceans' fish stocks to depletion, destroying life under the seas in defiance of both common sense and good economics. The relationship is similarly strained when it comes to life on land, the subject of **SDG 15.** We already use around 40 per cent of available land for growing our food, three-fourths of that being used for growing meat and feedstock for livestock, and this 40 per cent is projected to reach a staggering 70 per cent if we pursue "business as usual" (EAT 2016). That would ring the death-knell for many of the planet's terrestrial ecosystems, significantly threaten land-based biodiversity, and transfer pressures for protein demand to the seas, further risking the achievement of **SDG 14**. Our food systems also generate a significant part of the greenhouse gas emissions that are driving global climate change, the subject of **SDG 13.** This linkage works dangerously in the other direction too: some of the most important staples that we grow today are vulnerable to a changing climate.

These interlinkages do not stop with life on land, life under water and climate change – the 'ecological' and foundational layer amongst the SDGs – but continue through the 'social' layer of SDGs as well. We find that food systems are undermining human health, permitting and even promoting inappropriate diets and unsafe foods (Sukhdev *et al*. 2016). As the Global Nutrition Report states: "Diet is now the number-one risk factor for the global burden of disease" (IFPRI 2016). This defines perhaps the biggest health challenge of our times, and takes us to the heart of **SDG 3**, which aims to ensure healthy lives and promote well-being for all ages. Whilst an estimated 0.8 billion people remain hungry, another 1.9 billion people take in over 3,000 kcal/day (Alexandratos and Bruinesma 2012) - far above the World Food Program's recommended 2,100 kcal/day. Far from reducing inequalities as envisaged by **SDG 10,** today's food systems appear to be adding to it! Obesity is increasing, not just in developed but in developing nations, and especially amongst children because their diets are increasingly dominated by processed foods high in fats and carbohydrates, and sugar-laden sodas. Thus **SDG 12** on responsible consumption and production is challenged comprehensively by today's food system.

On the positive side, however, *system-wide solutions*cancome to light by tracing these SDG interlinkages through to their logical conclusions. For example, we know that agriculture is the world's largest employer, with over 1.5 billion jobs. An estimated billion of these are in small farms of under 2 hectares. If policy reforms could be focused on making small farms economically stronger – by lowering risks, increasing yields, achieving fairer prices – that would go a long way in achieving **SDGs 1, 2, 5, 10**. Furthermore, there is a strong case emerging that dietary shifts towards healthier diets with more plant-based foods and less meat could reduce food related greenhouse gas emissions (Springmann *et al.* 2016) by an estimated 29-70 per cent *as well as* reducing mortality by 6-10 per cent by 2050. If this change could be achieved, it would in turn go a long way in achieving several **SDGs** especially **3, 12, 13**.

The TEEBAgriFood Framework is a natural candidate for a toolkit to frame and address these complexities and implementation challenges of the 2030 Agenda. TEEBAgriFood can contribute to this agenda's integrated implementation by identifying and mapping the positive and negative externalities of specific measures with regard to achieving the different SDGs. In other words, implementing the SDGs will require drawing and navigating "SDG maps" that show how SDGs are interlinked across different economic sectors and policy domains, understanding how policy responses targeting one goal may impact progress towards others, and creating parliamentary and policy platforms and contexts in which different ministries can cooperate, co-design and coordinate policy responses in a holistic manner. In this regard, the follow up and review mechanisms of the 2030 Agenda offer a concrete entry point for TEEBAgriFood and are in the need of strengthening with the kind of insights offered by it.

Application of the TEEBAgriFood Framework supports the integrated implementation of the 2030 Agenda and the SDGs and thus provides a unique opportunity to identify and address both negative and positive externalities. Considering that the 2030 Agenda itself is also linked to and built on other global agendas such as health, biodiversity, climate and the right to food, TEEBAgriFood also contributes to informing these other processes.

TEEBAgriFood's Framework also provides the basis to move from financing agricultural investment to funding sustainable food systems. The Addis Ababa Action Agenda (AAAA) on financing for development needs to become another relevant entry point for TEEBAgriFood. Investments in sustainable food systems have to go far beyond increasing productivity only, they have to take the eco-agri-food system as a whole into account.

The private sector is a further important target of TEEBAgriFood. TEEBAgriFood showcases how sustainability, i.e. implementation of the SDGs and the Paris climate agreement can become a business. Therefore, using the Framework to create business platforms supporting knowledge exchange will create ownership of the approach and may help to change business strategies.

Finally, the universal and comprehensive approach of TEEBAgriFood leads to engagement with stakeholders from different constituencies and contributes to other initiatives beyond SDGs. The development of targeted communications strategies based on the application of the Evaluation Framework is a necessary next step. For example, it is imperative to interact with consumers and consumer organisations, for which the Framework becomes an important tool to present the findings of TEEBAgriFood. The implementation of the SDGs and the Paris Agreement will in the final analysis happen through markets, hence new and innovative business plans are needed in addition to enabling conditions such as better policies and regulations. Consumer choices and coordinated action of stakeholder groups canhelp drive this process.

At the Rio+20 Conference in 2012, member states of the UN agreed to set up an intergovernmental High-level Political Forum (HLPF) to oversee and coordinate the desired transformation towards sustainability. The HLPF is providing political leadership, guidance and recommendations for the implementation, follow-up and review processes of the Agenda 2030. One of its main responsibilities is to strengthen the integration of the three dimensions of sustainable development (economic, social and ecologic) in a holistic and cross-sectoral manner thereby upholding the essential value of the 2030 Agenda, i.e. to leave no one behind. Therefore, the 2030 Agenda offers a strategic entry point for TEEBAgriFood to address integrated implementation. The TEEBAgriFood Framework can identify and map the positive and negative externalities resulting from the implementation of different SDGs, thus informing the agreed follow up and review mechanisms of the 2030 Agenda.

As mentioned earlier, the climate impacts of eco-agri-food systems are extensive. Considering this and other factors, the role of policy changes addressing agriculture and food systems is of paramount importance, and the discipline of our recommended comprehensive Framework – which includes value-chain accounting for GHG impacts – can help achieve Paris targets, the 'Nationally Determined Contributions' of various countries.

5.11 OUR VISION

We envision and aspire towards *a world where informed decision-making upholds the public good and ensures suitable nutrition and good health for all humans so they* *can live in harmony with nature*. We believe that the true *value* of our food far exceeds the true *cost* if we make the right choices: the challenge is to have good and complete information and a transparent and fair way of evaluating that information before making those choices. We recommend the Evaluation Framework of TEEBAgriFood as an appropriate, purpose-built, universal, comprehensive, and inclusive lens that truly enables holistic and transparent analysis for decision-makers.

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ANNEX 1: LEXICON

agri-food (as in system): a subset of *eco-agri-food* in which ecological considerations (e.g. impacts and dependencies upon *natural capital*) are often left out

capital: the economic framing of the various stocks in which each type of capital embodies future streams of benefits that contribute to human well-being (see also '*stock*' as well as '*human capital*', '*natural capital*', '*produced capital*' and '*social capital*')

consumption: the final of four stages in the value chain, including purchases of food for consumption within the household, purchases of food supplied by restaurants and the hospitality industry more generally, and consumption of food grown at home

distribution, marketing and retail: the third of four stages in the value chain, including the activities associated with the transport and sale of goods, for example to retailers or consumers

driver: a *flow* which arises from the activities of agents (i.e. governments, corporations, individuals) in eco-agri-food value chains, resulting in significant *outcomes* and leading to material *impacts*

eco-agri-food (as in system): a descriptive term for the vast and interacting complex of ecosystems, agricultural lands, pastures, inland fisheries, labor, infrastructure, technology, policies, culture, traditions, and institutions (including markets) that are variously involved in growing, processing, distributing and consuming food

ecosystem service: the contributions that ecosystems make to human well-being (e.g. classified by CICES into provisioning, regulation & maintenance and cultural)

externality: a positive or negative consequence of an economic activity or transaction that affects other parties without this being reflected in the ~~cost~~ price of the goods or services transacted

feedback (loop): a process whereby an initial cause ripples through a chain of causation, ultimately to re-affect itself

flow: a cost or benefit derived from the use of various capital stocks (categorized into agricultural and food outputs, purchased inputs, ecosystem services and residuals)

Framework, TEEBAgriFood Evaluation: an approach for describing and classifying the range of outcomes/impacts for a given scope and value chain boundary, and caused by specified drivers, that answers the question "what should be evaluated?"

human capital: the knowledge, skills, competencies and attributes embodied in individuals that facilitate the creation of personal, social and economic well-being

impact: a positive or negative contribution to one or more dimensions (environmental, economic, health or social) of human well-being

manufacturing and processing: the second of four stages in the value chain, including the operations involved in converting raw materials into finished products

marketing: (see '*distribution, marketing and retail*')

natural capital: the limited stocks of physical and biological resources found on earth, and of the limited capacity of ecosystems to provide ecosystem services.

outcome: a change in the extent or condition of the stocks of capital (natural, produced, social and human) due to value-chain activities

processing: (see '*manufacturing and processing*')

produced capital: all manufactured capital, such as buildings, factories, machinery, physical infrastructure (roads, water systems), as well as all financial capital and intellectual capital (technology, software, patents, brands, etc.)

production: the first of four stages in the value chain, including activities and processes occurring within farm gate boundaries (including the supply of ecosystem services, the supply of goods and services, and connections between producers)

retail: (see '*distribution, marketing and retail*')

social capital: encompasses networks, including institutions, together with shared norms, values and understandings that facilitate cooperation within or among groups

stock: the physical or observable quantities and qualities that underpin various flows within the system, classified as being produced, natural, human or social (see also '*capital*')

system: a set of elements or components that work together and interact as a whole

systems thinking: an approach that focuses on the identification of interrelationships between components of a system

theory of change: a basis for planning intervention in a given policy or project arena that helps to identify processes and preconditions whereby actions can best attain their intended consequences

value: the worth of a good or service as determined by people's preferences and the tradeoffs they choose to make given their scarce resources, or the value the market places on an item

value chain: the full range of processes and activities that characterize the lifecycle of a product from *production*, to *manufacturing and processing*, to *distribution, marketing and retail*, and finally to *consumption* (including waste and disposal across all stages)

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