8 Transforming the Maize Treadmill

Understanding Social, Economic, and Ecological Impacts

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Introduction

Maize was domesticated in Mexico around 9,000 years ago. Some 5,000 years later, maize spread from its center of origin in Mesoamerica to the rest of the American continent and subsequently to the rest of the world (Vigouroux *et al.*, 2011). In the early 1930s modern varieties began to be developed. These replaced almost all of the locally adapted traditional varieties, or landraces, of maize in the USA in little more than three decades (Duvick, 2001). In Europe, modern varieties were introduced at the end of World War II, completely modifying the traditional agricultural systems typified by high biodiversity and low external inputs (Duvick, 2001, 2005). This agricultural transformation, or “green revolution,” has had profound consequences for Earth’s biodiversity and ecosystem services (Bommarco *et al.*, 2013), agricultural systems (Garbach *et al.*, 2014; Power, 2010; Zhang *et al.*, 2007) and diets (Popkin, 1993; Baker, 2013).

Maize has been at the heart of socio-economic-ecological food systems transformations. Easily adapting to diverse climatic and agricultural conditions, as well as agro-industrial processes, maize is a central ingredient in high-fructose corn syrup (driving a transition to calorie-dense, nutrient-poor diets), animal feed (driving the meat industrial complex), biofuel, and plastics, among others. Monoculture corn production is the most widely planted crop in the world, driving land use change with significant climate impacts. At the same time, diverse smallholder maize systems continue to thrive in Mexico and beyond, demonstrating the resilience of these agricultural practices and their associated cultural and culinary traditions (Baker, 2013).

How do we understand, evaluate and account for the dynamics across diverse maize systems and their impacts over time? Recognizing the multiple costs and benefits provided by these systems is a first step in assessing their value and promoting strategies to mitigate negative externalities and strengthen positive benefits. This chapter highlights four TCA applications undertaken in very different

contexts in Mexico, the USA, Malawi, and Zambia.¹ These studies help us to understand the challenges and potential of using TCA to address food system externalities, both positive and negative. The approaches and methodologies vary significantly, but all shed light on the utility and limitations of TCA. Most importantly, they help us better to understand maize systems, their contributions, their histories, their impacts, and the ways that they are embedded in broader ecological, political, and economic systems. Key insights from these kinds of assessments can inform the policies, programs, and practices that shape agricultural systems worldwide. The authors of this chapter provide case studies summarizing their research results and then offer some high-level reflections about what was learned across the different cases. The first case study—an assessment of maize by colleagues at the National Commission for the Knowledge and Use of Biodiversity in Mexico—reveals the importance of smallholder agricultural systems for agricultural biodiversity. Through the cultivation of native varieties, traditional smallholders in Mexico and other parts of the world provide important evolutionary services to maize production worldwide. These smallholder systems promote genetic diversity by cultivating maize under a wide range of environmental, socio-cultural and economic conditions and by selecting certain traits to adapt maize to these different conditions or to satisfy cultural preferences. This study provides insights into how these evolutionary services can be further enhanced by supporting traditional agricultural practices and maintaining heterogeneous landscapes linked to cultural and ecological resources.

No country has benefited more from the industrialization of maize production than the USA, where corn is a crop of significant economic importance, adding \$48.5 billion annually to the US economy. To understand the US maize system, Harpinder Sandhu and team visited Minnesota where genetically modified (GM) and conventionally grown (hybrid) corn dominate the landscape, and organic corn is grown on only a fraction of the land. The second case study presented in this chapter compares the “true cost” of conventional GM corn and organic corn production in Minnesota, revealing how agricultural policy and programs “lock in” certain production practices, despite the clear benefits of organic corn systems.

The third case study is based on maize in Malawi. The notion that maize is central to food security in Malawi is a widely held view. To date, however, “maize-led development” has produced disappointing outcomes. Stephanie White provides an overview of the historical, political, and environmental context of the maize agri-food system in Malawi and uses the TEEBAgriFood framework to analyze maize in relation to three distinct parameters: input stocks and flows, fertility stocks and flows, and maize stocks and flows. This case study reveals the costs of remaining beholden to a maize-centric agri-food system, as well as the factors that keep this system in place, despite calls for agricultural diversification.

Finally, we draw on a study of three maize cropping systems in Zambia. These three systems have different characteristics—monocropping, smallholder

mixed, and larger-scale rotation. Each of these systems is carefully documented and analyzed to understand the implications of specific practices and provide guidance to farmers, businesses, and policymakers. This analysis helps us to understand the experience of farmers and how their farming systems can be improved to enhance soil health, livelihoods, and mitigate environmental impacts.

To conclude, we offer six reflections and challenges that emerge from a collective analysis of these four very different TCA studies. The case studies strive to describe the broader political, ecological, social, and cultural systems in which they are embedded, illustrating the challenge of systemic framing. Because the studies are so different, there is a challenge related to finding a common vocabulary for TCA. The studies balance an imperative to address the historical forces that shape food systems while focusing on direct and indirect costs. All the studies, in one way or another, illustrate the potential benefits provided by agrobiodiversity managed by smallholders, and how these benefits are narrowed in monocropped maize systems. The authors of this chapter noted the challenge of making meaningful comparisons across systems and studies, owing to the different approaches and methodologies used. All studies highlight the challenge of engaging decision-makers—farmers, business leaders, and policymakers—to reflect on research findings and adapt policies and practices accordingly. Finally, the authors note the importance of providing appropriate guidance for TCA studies to ensure their relevance and applicability to decision-making.

Case Study 1: Maize in Mexico: Ecosystem Services Provided by Agrobiodiversity and Traditional Small Holders

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Traditional smallholder agriculture has generally been considered a low-productivity system. Only recently has the role of traditional farmers as key contributors to local and regional food security been estimated and documented (Ricciardi *et al.*, 2019; Bellon *et al.*, 2018; Graeub *et al.*, 2016). A greater proportion of food and nutrients that feed people living in the most populated regions of the world is produced by small and medium-sized farms (Pengue and Gemmill-Herren, 2018). Small farms represent 93.3% of all farms in the Asia-Pacific region, 89.6% of those in Africa, 80.1% in Latin America and the Caribbean, 76.8% in North America, and 88.5% in Europe (Grain, 2014). Despite them representing 92.3% of all farms worldwide, they hold only 24.7% of agricultural land (Grain, 2014). The importance of smallholder agriculture, however, reaches far across time and space and, as discussed here using the case of Mexico, might also provide multiple benefits at the genetic, species, and landscape levels. The recognition of the multiple benefits

provided by agrobiodiversity managed by smallholders at these three levels is the first step in assessing the value of these systems and promoting strategies to scale up some of these principles among more intensive agricultural units.

The Genetic Level

Today, most maize grown worldwide is cultivated in intensive systems, destined for livestock, sweetener, and oil industries, as well as for the production of ethanol and other non-edible products (see review in Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, 2017). A great proportion of this production comes from modern varieties (2017), whose highly uniform genetic background makes them vulnerable to pests and pathogens causing severe crop losses (National Research Council, 1974, 1975). For instance, in the 1970s, the Southern Leaf Corn Blight (*Bipolaris maydis*; also known as *Helminthosporium maydis*) resulted in the loss of 15% of the maize crop in USA and generated economic losses of about \$1 billion dollars (Bruns, 2017). The fungus was able to spread rapidly and infect large areas because most hybrid maize at that time was uniform for a condition called cytoplasmic male sterility and happened to be susceptible to this fungus. Between 2012 and 2015 losses of maize yield owing to diverse root rots, seedling blights, and plant-parasitic nematodes in the USA and Ontario, Canada, were calculated at over \$27 billion (Mueller *et al.*, 2016). Genetic resources from landraces and wild relatives contributed to the recovery of pre-existing production levels in cases like these (Redden *et al.*, 2015; Maxted *et al.*, 1997). Currently, most of the genetic diversity of maize is harbored in Mesoamerica (Bedoya *et al.*, 2018), the center of origin and domestication of this crop (Pickersgill, 2007; Matsuoka *et al.*, 2002; Vavilov, 1926). Centers of domestication and diversity of crops represent key regions for the food security of present and future human societies (Brush, 1995) and are generally characterized by a long history of use of these species and a high varietal diversity that is fostered by traditional smallholders and co-occurrence with their ancestors and wild relatives (Vavilov, 1926, 1951; Vavilov *et al.*, 1992).

Traditional smallholders around the globe continue to grow maize, from sea level to 3,800 meters, including arid regions and regions with more than 11,000 mm of rainfall per year, and from 42° latitude South to 50° latitude North (Timothy *et al.*, 1988), using seed from the previous cycle, subjecting maize populations to a continuous evolution under domestication. The genetic base that confers maize its ability to prosper in such diverse environmental conditions is the result of its cultivation during millennia under this wide range of environmental conditions (Ruiz Corral *et al.*, 2008).

Considering the area cultivated with maize by traditional farmers in Mexico, it is estimated that about 1.38 trillion genetically different individual plants are subjected to both natural and artificial selection, under heterogeneous cultural, biological, and environmental conditions. From this, a breeding population of about 5.24 billion maize mother plants transmit their variation to the next

generation each cycle, which contributes to both preserving rare alleles and to generate new potentially adaptive variations (Bellon *et al.*, 2018). This “evolutionary service” constitutes a public good offered by traditional farmers in Mexico (Bellon *et al.*, 2018) and other regions of the world (Bedoya *et al.*, 2017; Bracco *et al.*, 2009; Carvalho *et al.*, 2004; Hartings *et al.*, 2008; Kumar *et al.*, 2015; Qi-Lun *et al.*, 2008) and to society in general. In Mexico, the genetic diversity of cultivated maize is also constantly broadening through the influx of genes from wild relatives like teosinte, which is tolerated or actively promoted by traditional farmers (Rojas-Barrera *et al.*, 2019; Hufford *et al.*, 2013; Matsuoka *et al.*, 2002; Wilkes, 1977).

Traditional farmers cultivating landraces in Mexico and other regions of the world do not only maintain their genetic diversity (i.e. evolutionary services), but also promote the identification and fixation of adaptive traits through the selection of the desired phenotypes. Local landraces are preferred by traditional smallholders in areas where they are traditionally grown, which tend to be areas with poorer soils or suboptimal climate conditions (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, 2017). Some maize landraces thrive in a wide range of environments, like the *Tuxpeño* which is to be found in 19 of the 28 climatic types present in Mexico. Others like the *Blando de Sonora* and *Azul* landraces were only found in three climatic types (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, 2011). In line with this, landraces have shown specific adaptations to nitrogen poor soils (e.g. *Rojo*, *Piedra Blanca*, *Llano*: Van Deynze *et al.*, 2018), resistance to drought (e.g. *Nantel*, *Conejo*, *Ratón*, *Cónico Norteño* (population Zac-58), *Chalqueño* (population MICH-21: Avendaño *et al.*, 2005; Muñoz, 2003; Wellhausen *et al.*, 1951) and to different pest and pathogens (e.g. *Zapalote chico*, *Tuxpeño*, *Olotón*: Bellon and Risopolous, 2001; Muñoz, 2003; Ramírez *et al.*, 2005; Widstrom *et al.*, 2003). Besides their adaptability (i.e. resistance to biotic and abiotic stresses), landraces are also appreciated for their precocity and their food/forage quality (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, 2011; González-Amaro, 2016; Muñoz, 2003; Perales, 1996; Rodríguez *et al.*, 2007; Sociedad Mexicana de Fitogenética 2007, 2009). Hence, maize landrace adaptations provide or complement ecosystem services of pest and disease control, weather and water regulation, soil fertility, and cultural services derived from their use.

The Species Level

In Mesoamerica, maize is cultivated along with beans (*Phaseolus vulgaris*) and squash (*Cururbita pepo*, *C. ficifolia*, *C. maxima*, *C. mixta* and *C. moschata*), also known as the “three sisters,” and a varying number of domesticated and semi-domesticated species in a system called *milpa* (Gómez-Pompa, 1987; Hernández-Xolocotzi *et al.*, 1995; Terán and Rasmussen, 2009). These species not only balance the nutritional quality/quantity of the *milpa*-derived diet, but also represent species that provide ecosystem services for the agricultural system itself (Amador and Gliessman, 1990; Table 1).

The review by Hajjar *et al.* (2008) indicated that ecosystem services (e.g. pollination, CO₂ sequestration, pest and disease control, improved soil fertility, and reduced soil erosion) provided by crop genetic diversity, are mediated by an increase in the number of functional traits and complex interactions occurring in diverse agroecosystems. In the case of the Mesoamerican *milpa*, the benefits provided by intercropping of the ‘three sisters’ are attributed to their distinct root architectures which allow them to use potentially complementary water and nutrient acquisition strategies (Postma and Lynch, 2012). The practice of intercropping maize with legumes (and often squash crops) has become a global heritage, implemented by traditional farmers in Mexico, but also by traditional smallholders as well as large-scale agricultural systems around the world (see review in Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, 2017).

Nutrient cycling services, which are facilitated by the intercropping of maize and beans, are enhanced owing to the fixation of aerial nitrogen by *Rhizobium* bacteria present in the roots of beans, increasing the availability of nitrogen for maize (Van Berkum *et al.*, 1996), and of phosphorus for both maize and bean (Latati *et al.*, 2013). Legumes are also used for weed (Caamal-Maldonado *et al.*, 2001) and pest (Altieri *et al.*, 1977) control in traditional agroecosystems. Squash has been found to suppress the growth of weeds and to avoid the loss of soil moisture (Chacon and Gliessman, 1982; Ghanbari *et al.*, 2010). Weeds, some of which are used and tolerated in the agricultural fields (Vibrans, 2016), may serve to reduce the presence of crop pests through different mechanisms: as alternative food sources for herbivorous arthropods or beneficial insects (predations, parasitoids, pollinators), and as a source of diseases for pests (see review in Capinera, 2005; Norris and Kogan, 2005; Wisler and Norris, 2005).

The Landscape Level

The size (e.g. small) and aims (e.g. semi-subsistence) of traditional agricultural systems tend to promote more diverse landscapes through the maintenance of surrounding native vegetation, the presence of home gardens, and the use of multiple species as a life strategy (Bellon *et al.*, 2020; Neulinger *et al.*, 2013; Palacios *et al.*, 2013). The heterogeneous landscapes that these rural strategies promote, not only favor the provision of ecosystem services at the local scale such as pollination, regulation of pests and diseases, and water provision, but could potentially do so at a larger scale (Landis, 2017) (Table 8.1).

The exploratory maize study sought to identify and value both the dependencies and impacts of two contrasting maize systems, from and on, various ecosystem services in Mexico, Ecuador, and the USA (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, 2017). Here, we decided to highlight the contribution of traditional smallholder farming systems to agrobiodiversity at the genetic, species, and landscape level. Understanding and recognizing these multiple benefits is the first step in assessing their value and

Table 8.1 Ecosystem services provided by intercropping of associated crops and semi-domesticated species in maize-centered agroecosystems and landscapes

<i>Crop/Landscape element</i>	<i>Mechanism</i>	<i>Ecosystem service</i>	<i>Source</i>
Bean	Fix atmospheric nitrogen through its association with bacteria from the <i>Rhizobium</i> genus	Nutrient cycling	Caamal-Maldonado <i>et al.</i> , 2001; Bilalis <i>et al.</i> , 2010; Van Berkum <i>et al.</i> , 1996
	Reduces weed density	Provision	
	Increases maize yield		Ebel <i>et al.</i> , 2017; Tsubo <i>et al.</i> , 2003
Squash	Prevents soil erosion, and increases carbon capture and storage	Nutrient cycling	Caldeira <i>et al.</i> , 2004
	Inhibits the growth of weeds through photosynthetically active radiation interception	Provision	Fujiyoshi <i>et al.</i> , 2007; Ghanbari <i>et al.</i> , 2010
Beans and Squash	Increase of expected yield of maize, bean and squash in monoculture	Provision	Ebel <i>et al.</i> , 2017; Postma and Lynch, 2012; Zhang <i>et al.</i> , 2014
Weeds	Interfere with the ability of insects to locate crop plants, provide alternative food sources for pests, harbor insect diseases, and attract beneficial insects	Pest control	Altieri <i>et al.</i> , 1977; Penagos <i>et al.</i> , 2003
Intercropping	Decrease in water loss and increase in water use efficiency due to early high leaf area index	Water provision	Ogindo and Walker, 2005
Landscape complexity, diversified agricultural systems and polycultures	Associated with a lower density of pests, increase of natural enemies, higher mortality of herbivore insects and less damage to crops	Pest and disease control	Kremen and Miles, 2012; Letourneau <i>et al.</i> 2011; Tonhasca and Byrne, 1994
Maintenance of natural habitats around agricultural fields	Provide food and refuge for natural enemies of agricultural pests	Pest and disease control	Landis <i>et al.</i> , 2000; Power, 2010; Tillman <i>et al.</i> , 2012; Tscharntke <i>et al.</i> 2005;
Use of native vegetation as hedgerows and maintenance of natural habitats	Provide food, refuge and reproduction sites for pollinator species	Pollination	Garbach <i>et al.</i> 2014; Power, 2010; review in Potts <i>et al.</i> , 2010 and Garibaldi <i>et al.</i> , 2011
Maintenance of riparian vegetation	Reduces water runoff and soil erosion	Regulation	Swinton <i>et al.</i> , 2007
	Removes nutrients and sediments before they leach into superficial water bodies		

can support the development of strategies to enhance biodiversity and ecosystem services not only in smallholder systems, but also in more intensive agricultural systems.

Case Study 2: Corn in Minnesota: Comparing Conventional GM and Organic Systems

Harpinder Sandhu³

In Minnesota, corn adds \$4.5 billion annually to the local economy. Genetically modified (GM) corn dominates the landscape, with organic corn grown in a fraction of the area. GM corn is grown primarily for ethanol production and a by-product from the ethanol processing process is used for animal feed. It is typically grown in rotation with soybean as a monoculture. Organic corn is primarily used directly as animal feed and is grown in mixed farming systems. To provide some context related to the scale of GM and organic production, in the USA, approximately 88% of the corn grown is GM, whereas certified organic corn represents only 0.02%.

In order to examine corn-based farming systems in the US context, two contrasting management systems—GM corn and organic corn—were selected for a study in Minnesota. The TEEBAgriFood food systems evaluation framework (described in Chapter 4) was applied to these two corn production systems in Minnesota to reveal impacts and dependencies on produced, social, human (including health), and natural capital and evaluate the hidden costs and benefits of corn production (Sandhu *et al.*, 2020).

Corn production in the US intersects with a number of critical environmental issues. Corn-based ethanol production has increased the demand for corn and hence increased associated environmental impacts without a clear reduction in the carbon intensity of fuel. Moreover, corn produced for animal feed is much less efficient in terms of producing human food calories per unit area than corn produced for direct human consumption. Large amounts of fertilizers and herbicides are used in GM production systems. This increases the cost of production and reduces net returns. In addition, there is continuous exportation of nitrate, phosphorus, and sediments from farmland to watersheds and ravines in the Mississippi River basin, which leads to the hypoxic zone in the Gulf of Mexico.

A number of policy and program drivers have resulted in the expansion of corn systems in the state of Minnesota and across the USA. These include the Renewable Fuel Standard, which created favorable market prices for corn. However, these farming systems are being modified to include sustainable practices or Best Management Practices, such as inclusion of cover crops, minimum, or strip tillage to minimize soil degradation and prevent loss of nutrients from the system. Some of the practices are promoted by the Environmental Quality Incentive Program and Conservation Stewardship Programs.

The study revealed that corn production is driven by economic factors—produced capital—and is supported by extensive social networks in Minnesota. Regarding human capital, there are significant health costs associated with GM corn production. The health costs are based on the production side of the corn value chain. These do not include capital costs incurred in the public health system, loss of economic productivity, and loss of taxes and Gross Domestic Product. They might, to a certain extent, include the individual medical expenditures associated with the health impacts of living near corn farms (Sandhu *et al.*, 2020). Natural capital—externalities related to climate change, water quality, air quality, and soil quality—is impacted negatively by GM corn production in Minnesota. At a macro level, the study revealed that each bushel of GM corn (at a market price of \$3.05 per bushel) generates negative environmental externalities of \$0.37 (+\$0.02) and \$0.88 in health costs (see Table 8.2).

Corn is a dominant crop in Minnesota and is vital for the agricultural economy. About 24,000 corn farmers generate more than \$4.5 billion for the state economy. Net returns for farmers are higher in organic corn systems. GM corn yield is higher than organic corn systems, but net returns are lower owing to high variable costs of agrochemicals and lower market price. The total environmental costs (including impacts on climate change, water quality owing to nitrate and phosphorus load, air quality, and soil quality) associated with GM corn production are \$71.60 per acre or \$557.65 million annually in Minnesota, and this does not include environmental costs associated with the transport, processing, and consumption. Uncertainty and spatial heterogeneity cause this estimate to vary greatly. There are high health costs associated with

Table 8.2 Summary of Health and Environmental Cost \$/bushel of Corn Under Two Production Systems

	<i>GM corn</i>	<i>Organic corn</i>
Market price (\$/bushel)	3.05	7.46
Environmental costs associated with fertilizer use (\$/bushel)	0.37	Not quantified owing to lack of data on organic farms
Environmental costs associated with energy use (\$/bushel)	0.02	0.03
Health cost (\$/bushel)	0.88	0.00 Although there is some suggested evidence for reduced adverse association of organic corn production with general health, quantifying the health costs requires data on exact location and planted area of organic corn farms. This was not available.

GM corn production. Total annual health costs associated with corn production in Minnesota are \$1.3 billion (\$233 per capita) or \$171 per acre (for 7.6 million acres of harvested corn in Minnesota in 2017). GM and hybrid corn production systems notably use large amounts of ammonium and nitrate fertilizers and herbicides. Fertilizers, herbicides, and dust from corn systems have been associated with different types of cancer (affecting digestive and reproductive organs and blood) and respiratory diseases. Considering that organic corn production refrains from chemical usage, it is assumed that these systems' agri-environment has a neutral impact on health. The study demonstrated that general health of individuals decreases by 0.67% with GM corn production, totaling annual non-financial health costs of corn in Minnesota at some \$1.3 billion.

Outcomes from this study can be used to make decisions about production systems and practices that can improve all four capitals, and policymakers can use this information to incentivize systems and practices that enhance social, environmental, and economic well-being of farmers and society at large. This would require a major shift in US agricultural and energy policies that currently favor GM corn systems.

This multidimensional assessment has helped understanding of key impacts and dependencies and the true costs and benefits of two corn production systems in Minnesota. In order to apply this understanding to effect change there is a need to understand how farmers and policymakers adopt new information and a need to work in consultation with these decision-makers to develop pathways for change. True Cost Accounting (TCA) needs to become a relevant decision-making tool at the farm level and needs to be integrated into policymaking.

Case Study 3: Maize-led Development in Malawi

Stephanie White⁴

Efforts to transform the farm sector in low-income countries (LICs) have persisted in one form or another since the inception of the "Green Revolution" in the 1950s, an approach to farming, food security, and economic progress that rested on the assumption that the basic problem in agri-food systems development was low agricultural productivity. Agriculture, so the argument goes, can serve as an "engine of modernization and growth," provided that yields can be raised, economies of scale achieved, and global markets accessed. At the farm level, the planned transformation of agriculture in LICs was carried out through increased use of modern inputs, which includes hybrid "improved" seeds, chemical pesticides, fertilizers, and insecticides; irrigation and mechanization; land consolidation; and integration of farmers into global markets, which has implications for what crops should be grown. Seventy years after its inception, this basic approach to agricultural development and food security continues to dominate policy interventions and recommendations.

The technologies, policies, and other investments associated with the Green Revolution dramatically boosted aggregate output per person, while income and population growth, policy liberalization, foreign direct investment, and other globalization processes drove exponential growth and consolidation of the retail food sector (Hawkes, 2006, 2018; Reardon *et al.*, 2009, 2018; Thompson and Scoones, 2009). Particularly over the past three decades, financial and trade liberalization encouraged transnational food and beverage corporations to colonize local value chains in many low- and medium-income countries, replacing them with food exchange processes that are spatially long and vertically integrated, that is, supermarkets (Anand *et al.*, 2015; Hawkes, 2006; Reardon *et al.*, 2018; Stuckler *et al.*, 2012). This structural transformation is indicative of economic globalization and therefore reads as economic development and progress towards an “advanced” food system (Reardon *et al.*, 2018). However, the link between agricultural productivity, commercialization, and improvements in well-being are widely assumed, although common development indicators tell a mixed story. They also tell an incomplete story as many outcomes, such as soil degradation, pest build-up, price volatility, or other contextual factors, such as climate change, are left out of analyses and/or treated as separate, unrelated problems.

Transitioning away from agriculture that is preoccupied with yields and governed by the notion of competitive markets, towards one that aims towards sustainable food security requires different frames. Most TEEBAgriFood work has focused on environmental sustainability, but in order for agriculture to be sustainable and *just*, frames must also acknowledge historical injustice and power relationships that are at the foundation of development food policy and practice.

In Malawi, for example, maize is the preferred staple and foundation of the agri-food system. It occupies at least 60% of cultivated land and is farmed by 97% of farming households on very small tracts of land, ranging in size from 0.5 hectares to 1.5 hectares. It makes up 60–70% of total food intake and 48% of protein consumption. Average yields are around 1.2 MT/ha, which is lower than the average for Africa (1.8 MT/ha), also considered far below the average potential. Western economists have referred to maize as “a ray of hope” for Africa’s food security crisis, while policymakers and donors assert that raising maize productivity and improving the performance of maize input and output markets is an essential condition for achieving food security. Consequently, huge investments have gone towards raising maize yields. At an international level, public and private agricultural research organizations devote millions of dollars every year to developing improved varieties and cropping techniques.

The association of maize security with food security has its roots in colonialism (Kampanje-Phiri, 2016; McCann, 2001). From about 1912 onwards, the British promoted maize as a foundation for food security and used it as a vehicle to exert control over agricultural production and distribution. Kampanje-Phiri (2016) explains how legislation introduced during the colonial period asserted control over what smallholder farmers grew, rationalized by the British as a necessary measure “because of African improvidence” (Ng’ong’ola, 1986, pp. 244).

Following independence in 1964, Kamuzu Banda, who presided over Malawi from 1964–1994, continued to use maize-based food security as a means of exerting control, but in ways linked more tightly to Malawian culture. Beginning in the 1980s, Banda's government began to promote hybrid maize and fertilizer use among smallholders. The parastatal marketing board Agricultural Development and Marketing Corporation turned its attention to the smallholder sector, distributing subsidized fertilizers, marketing farmers' grain, and transporting grain to food-deficit areas during the hungry season. It was this combination of practices that marked the onset of continuous maize monocropping and land tilling. Since 2004, the Malawian government's central policy to bring about maize self-sufficiency is the Farm Input Subsidy Programme (FISP), which seeks to provide around half of farm households with fertilizer and improved seeds at varying subsidized costs. At one point, FISP was celebrated as the Malawi Miracle, but in recent years it is frequently maligned as expensive and inefficient, though many still credit it with creating macro-level food security.

A closer examination guided by the TEEBAgriFood framework reveals that maize-led development has produced disappointing outcomes. Despite notable (reported) increases in average national maize yields, human development indicators have scarcely budged and, in some cases, are deteriorating. High volatility continues to characterize maize markets, diets are poorly diversified, malnutrition among children remains high, and poverty levels have increased in recent years (International Monetary Fund, 2017; Mazunda, 2013; Mockshell and Zeller, 2016; Schiesarie,). In addition, environmental resource stocks such as agrobiodiversity and soil fertility, which are particularly critical to smallholder farmers who are not able to easily access purchased inputs, are deteriorating due to the continuous cropping of hybrid maize (Bezner Kerr and Patel, 2014). Climate change is expected to have widely variable impacts that exacerbate uncertainty and extremes. Changes to rainfall distribution are uncertain, but no models project increased precipitation. In the short term, climate change could benefit maize production, but increased maize production could worsen soil degradation and deforestation.

At the heart of maize-centricity is the persistent narrative that maize security and food security are the same thing. In addition to technical interventions and programmatic investments, there is a basic and fundamental need for a national conversation to challenge that narrative and to engage the population to identify alternatives. In addition to the core "maize security equals food security" narrative, multiple dependencies keep the maize agri-food system locked in. An alternative path forward will include investments and other forms of support to the public extension system and local food exchange practices, institutions, and processes; use of decision-making frames governed less by imperatives to "modernize" and participate in a global food system, and more by socio-ecological well-being and agri-food system resilience in the face of climate change; and immediate transition to regenerative agriculture practices that reduce reliance on imported nutrients. The application of the TEEBAgriFood

framework to research protocols could help to develop alternative strategies in collaboration with farmers and other food system actors in Malawi. Among the various geographies and ecologies in Malawi, what alternative food crops could help to transition away from maize? What is their cost of production? How do food security calculations change? What existing food practices could be supported to improve income-earning opportunities to diversify not only the maize production system, but other areas of food exchange, processing, and retailing? What are the hidden costs of other potential staples in relation to the daily realities of average Malawians?

Knowledge creation is a political and ecological process. Any metric system comes with embedded values about what matters, and like any metric system, TEEBAgriFood may be used to further particular interests. Moreover, the TEEBAgriFood evaluation framework is not immune from being used in overly technocentric ways and excluding non-experts from decision-making. To bring about more sustainable and *just* agri-food systems, engagement of marginalized and poor communities should be integral and profound.

Case Study 4: True Cost Assessment of Different Maize Cropping Systems in Zambia

Rainer Nerger and Gyde Wollesen⁵

This assessment was carried out by Hivos Zambia and involved the analysis of three farming systems and ten representative farms.

- Cropping System 1: Small-scale farms producing only maize (monocrop system)
- Cropping System 2: Small-scale farms applying a mixed farm system (small-scale rotation)
- Cropping System 3: Larger-scale farms with a mixed cropping system (large-scale rotation)

The three systems were different in a number of ways. The farms in Cropping System 1 did not have irrigation and were left fallow about half of the year. Comparatively small quantities of fertilizer (synthetic and manure) were applied in these systems, resulting in comparably low yields. Some of the crop residues were left in the field. The farms in Cropping System 2 cultivated maize in rotation with vegetables such as cabbage and onions. Irrigation was used, and slightly higher amounts of synthetic fertilizers were applied, and yield levels were significantly higher compared with Cropping System 1. Some of the farmers in this system applied small amounts of compost and manure, some planted cover crops, and in other cases crop residues were either left on the field or were burnt. In Cropping System 3, the larger-scale farms cultivated maize in rotation with leguminous crops such as field beans or soybeans. Various irrigation systems were used, and comparably high amounts of synthetic fertilizers were applied, resulting in comparably good

yields. Some of the assessed farms applied small quantities of compost and manure, but only one farm used cover crops and left crop residues in the field.

To provide a more qualitative description of the farms, two farmers are described below. Mrs Chingambu's farm was part of cropping system one. Over the past 20 years, her best harvest decreased from 2.2 tonnes per hectare to 1.0 tonne per hectare. The seeds that she used were not high quality and not selling at the best possible price. Mrs Chingambu's maize was recently affected by diseases and infections and her plants appeared unhealthy at various stages. Mrs Chingambu has been losing revenue and intends to shift her farming to exclusively livestock. This is a result of the debt that she has accumulated buying fertilizers and chemicals, which she is unable to pay for because of a lack of profit. In contrast is Mr and Mrs Moyo's farm. This farm was part of Cropping System 2 and rotated maize with legume cover crops. Frequent weeding, the addition of animal and green manures, and intercropping with beans resulted in high soil fertility and good yields. Mr and Mrs Moyo planted natural hedges around their maize to discourage pests. They regularly slashed the green manure crop and pruned the legume shrubs, leaving the residues to cover the soil. The family is harvesting about 2.1 tonnes per hectare.

TCA examined the environmental implications and externalities of farming practices across the three cropping systems. Findings illustrate that the real cost of maize production systems is on average 2 to 2.5 times higher than what is actually being paid for in the marketplace. In other words, maize is produced at the expense of future production potential. More sustainable farming practices, as demonstrated by Cropping System 2, can have an almost neutral environmental cost that becomes a net benefit after 5–7 years of using better practices. The major limitation of the TCA calculations in this study is the small number of farms studied.

Table 8.1 shows the environmental costs if maize is more sustainably grown. This includes the following sustainable farming practices: 1) using the crop residues for composting or mulch instead of spreading or burning them; 2) reduce tillage; and 3) systematically use cover crops to loosen the soil, suppress weeds, keep the soil moist and cool, and fix atmospheric nitrogen into a form in the soil that is usable by crops. If these practices are applied, then the environmental costs can be reduced significantly per hectare and year.

Compared with the business-as-usual (baseline) scenario, the significant difference of the sustainable alternative model is that carbon is sequestered, and soil was not eroded but built up. These impacts lead to an increasingly resilient farming system, making better use of nutrients and water, reducing the risk of increasing production costs and crop failures. Ultimately, this moves farmers from a vicious to a virtuous production cycle.

The assessment results showed that the true cost of maize production is 2 to 2.5 times higher than the current market price. However, if sustainable production practices are promoted and incentivized the farmer's risk is reduced and the resilience of the maize-based farming system increases. The currently

Table 8.3 Results of True Cost Accounting of Different Maize Production Systems⁶

	Cropping System 3			Cropping System 1			Cropping System 2		
	Large-scale mixed system			Small-scale single maize system			Small-scale mixed system		
	Baseline: large-scale maize rotation	Scenario: large-scale maize rotation		Baseline: maize monocrop system	Scenario: maize monocrop system		Baseline: small-scale maize rotation	Scenario 1: small-scale maize rotation	Scenario 2: small-scale maize rotation (+7 years)
<i>n</i>	2	2	3	3	3	5	5	5	5
GHG emissions	€-329.99	€-109.90	€-122.12	€-83.88	€-313.80	€-139.26	€-146.48		
C-Sequestration	€10.66	€48.83	€13.08	€14.34	€26.69	€207.40	€400.60		
Water pollution	€-109.58	€-14.58	€-109.58	€-14.58	€-109.58	€-14.58	€-14.58		
Water use	€-264.38	€-237.94			€-264.38	€-237.94	€-237.94		
Erosion	€-323.06	€-49.04	€-323.06	€-49.04	€-323.06	€-49.04	€-49.04		
Soil build-up	€1.91	€87.43	€2.34	€2.57	€4.78	€37.14	€71.74		
Biodiversity	€-12.89		€-12.89		€-12.89				
Total/ha	€-1,027.33	€-275.20	€-552.23	€-130.59	€-992.24	€-196.27	€24.31		
Total/kg	€-0.40	€-0.14	€-0.71	€-0.24	€-0.17	€-0.03	€0.03		
Add. scenario cost/ha: cover crops & compost		€100.00		€100.00		€100.00	€100.00		
Current cost of production/ha	€670.00	€670.00	€480.00	€480.00	€575.00	€575.00	€575.00		
True cost of production/ha	€1,697.33	€1,045.20	€1,032.23	€710.59	€1,567.24	€871.27	€650.69		
% true/current cost/ha	253%	156%	215%	148%	273%	152%	113%		
Real cost: How many times higher?	2.5	1.6	2.2	1.5	2.7	1.5	1.1		

hidden costs will be lower. In turn, the volatility of food prices could be reduced. Otherwise, the steeply rising cost of living could cause increased poverty and with it social unrest.

To achieve resilience, Zambian maize farmers should be incentivized by policymakers to adopt a balanced crop rotation and to reduce fallow fields through the cultivation of cover crops. These practices are unevenly used by farmers and should be implemented systematically. Cover crops fix nitrogen, keep the soil moist and cool, suppress weeds, build-up root biomass, and increase soil organic matter and microbial life. If appropriate deep rooting cover crop varieties are selected, tillage could be further reduced as the cover crop roots will loosen the soil. Composting crop residues transforms the decomposing plant material into humus, which provides growing plants with the required nutrients. If these practices are promoted and incentivized through the right enabling policy environment and via agricultural extension services, Zambian maize producers will be able to disrupt the vicious cycle of more and more fertilizer requirements per year at increasing fertilizer prices.

Over the past 50 years Zambia's agricultural system has turned into a maize-based monoculture system which is not resilient to climate change. Maize productivity and suitability in Zambia is estimated to decrease between now and 2050 (Ramirez-Cabral *et al.*, 2017; International Center for Tropical Agriculture and World Bank, 2017). Agriculture is the main driver of deforestation (International Center for Tropical Agriculture and World Bank, 2017), and these pressures will increase deforestation and thus foster climate change. This study shows that a resilient maize production is possible using the described farming practices, minimizing environmental externalities and improving the livelihoods of Zambian smallholder farmers. The results of this study are being used to support farmers to adopt new practices and to advocate for policy change.

Cross Cutting Reflections and Challenges

The four case studies above applied TCA to better understand the dynamics of the systems they were assessing, to measure and value dependencies and impacts, and to inform decision-making. In the case of Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO), the assessment led to further work supporting smallholder farmers and the local value networks that enhance and strengthen agricultural biodiversity. In the case of corn in Minnesota and maize in Malawi, the study results were shared with local farmers and/or stakeholders through discussions about using TCA as a tool for more holistic agricultural and food systems assessments. In the case of Zambia, the study was used to advocate for policy changes and provide a rationale for sustainable production practices. In all cases, these “proof of concept” TCA applications revealed important lessons for strengthening and mainstreaming TCA in food systems. Collective analysis of these TCA studies has surfaced the following reflections and challenges.

1) The Challenges of Systemic Framing and a Common TCA Language

While TCA and the TEEBAgriFood Evaluation Framework allows for scaling (up and down), it is challenging to determine the Framework's boundaries across scales. The exercise of providing a description of a system—a key element of the process—is often confused as the application itself. Several questions emerge: How can a whole system be captured? The Framework provides a checklist for assessing the system, but how detailed does this need to be? What is the best way to describe and represent nested systems? A common approach to describing food systems would support greater cross-disciplinary understanding of each application from the outset, as well as providing suitable and stable entry points for systems analysis and discussion, whatever the focus of the specific application. Integrated systemic thinking is the underlying driver for the Framework yet poses significant conceptual and practical challenges. The examples from Mexico, Minnesota, Malawi, and Zambia illustrate these challenges well, as they were only able to capture some systems dynamics due to the scope of work.

The very different approaches taken by the study teams reveals the challenge of finding a common TCA vocabulary. All studies outline the impacts, costs, and benefits of different systems, but because of the different scales examined, and the different methodologies used, these studies lack coherence as a set. This kind of cross application coherence might not be necessary, but a common vocabulary or TCA language would enhance the legitimacy and utility of the approach.

2) Balancing the Imperative to Address History and Power that Shape Food Systems While Focusing on Direct and Indirect Costs

The studies cited in this chapter recognize the importance of context and history and how food systems are shaped by these dynamics. For example, the maize in Malawi study describes contemporary maize production as an outcome of colonial policies and programs. The Zambia assessment focused only on production practices, but acknowledges the broader system dynamics that influence these practices. Indeed, it is difficult to approach any moment in time without describing the broader context and history. In thinking about capitals and flows, and trying to quantify these, entrenchment and the dependencies that keep the system in place loom large. Coursing through these systems are power relations that also need to be acknowledged. Where do TCA assessments allow for this analysis?

3) The Multiple Benefits Provided by Agrobiodiversity Managed by Smallholders

CONABIO's study illustrates the important and often invisible contribution smallholder farmers make to agricultural biodiversity. If these contributions were more widely recognized and upheld, farmers could be better recognized

as stewards of biocultural landscapes and, in particular, the dynamic agricultural biodiversity that the global food system depends upon. The concept of evolutionary services amplified by CONABIO could be translated into other contexts to support smallholders to stay on the land, to thrive in rural areas, and to contribute important ecological and cultural services essential to global biodiversity and climate priorities. CONABIO's findings seem particularly relevant to the Malawi and Zambia research, and this kind of cross study analysis and reflection can bring different perspectives together, creating new opportunities to promote food systems transformation.

4) The Challenge of Making Meaningful Comparisons Across Systems

The corn in Minnesota and Zambia studies reflect the difficulty of comparing two different systems at vastly different scales, with different data available. How do we make meaningful comparisons? How do we build alignment across the issues of each study or across a series of studies? Study leads and reviewers noted both a lack of data and too much data. Where do we find the right data? What original research needs to be undertaken to support the studies? How do we distil data into key metrics? How do we determine what metrics are meaningful to stakeholders? What is the difference between true cost and true value? These are socially situated questions, and clearly depend on the goals of the comparison or assessment. We use the language of accounting but often the results do not reflect costing and accounting and the answers sought are far broader.

5) The Challenge of Engaging Farmers and Decision-Makers

The intention of these studies is to influence both policy and practice. Results need to be presented in a way that is useful both for policymakers and practitioners, especially farmers. Stakeholder engagement is a central part of TCA's theory of change, but this has not been reflected in all of the early "proof of concept" studies. What does long-term stakeholder engagement around TCA for food systems look like? In the Malawi, Zambia, and Minnesota studies there was a modest attempt to engage local stakeholders and decision-makers. As White (2019) concludes "Knowledge creation is a political and ecological process...To bring about more sustainable and *just* agri-food systems, engagement of marginalized and poor communities should be integral and profound."

6) The Importance of Providing Appropriate Guidance for TCA Studies

What guidance resources can be developed to support study leads? These guidance resources need to reflect the multidimensional aspects of the applications—from study definition and boundaries, to stakeholder engagement, to methodological approaches. How can the community of actors interested in TCA and TEEB AgriFood work together to develop and refine these guidance documents and suite of tools?

As a central actor in food and agriculture systems, maize/corn is worthy of deeper study and consideration. Indeed, the societal, economic, and ecological transformations of food systems will depend on the deep transformation of key commodity value chains. These studies illustrate the value of understanding food system impacts holistically and point to the importance of political economy—or political *ecology*—to understand key systems dynamics and linkages. TCA is both an approach and a tool that supports more holistic understanding of food and agriculture systems and should be mobilized to inform decision-making from the farm level onward.

Notes

- 1 The case studies are drawn from the following publications:
 - 1) Comisión Nacional para el Conocimiento y Uso de la Biodiversidad. (2017). *Ecosystems and agro-biodiversity across small and large-scale maize production systems*. TEEB Agriculture & Food, UNEP, Geneva.
 - 2) Sandhu, H., Scialabba, N.E., Warner, C. et al. (2020). Evaluating the holistic costs and benefits of corn production systems in Minnesota, *US Scientific Reports*, 10(3922).
 - 3) White, S. (2019). *A TEEBAgriFood Analysis of the Malawi Maize Agri-food System*. Global Alliance for the Future of Food.
 - 4) Bandel, T. & Nerger, R. (2018). *The True Cost of Maize Production in Zambia's Central Province*. Hivos, Soil and More, 2nd ed.
- 2 Comisión Nacional para el Conocimiento y Uso de la Biodiversidad.
- 3 University of South Australia.
- 4 Michigan Department of Health and Human Services, formerly at MSU's Global Center for Food System Innovation.
- 5 Soil & More Impacts GmbH.
- 6 This assessment is based on the guidelines of the Natural Capital Protocol (Natural Capital Coalition, 2016) using the monetization factors suggested by the Food and Agricultural Organization of the United Nations (2014).

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