Assessing Sustainable Nutrition Security: The Role of Food Systems

Working Paper

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Acronyms Used in this Document

AgMIP: Agricultural Modeling Intercomparison and Improvement Project
AND: Academy of Nutrition and Dietetics
Bt: Bacillus thuringiensis
CGE: Computable General Equilibrium
CIMSANS: Center for Integrated Modeling of Sustainable Agriculture and Nutrition Security
DNA: Deoxyribonucleic acid
ESRI: Geographic Information Systems developer
FACE: Free-air CO2 enrichment experiment
FAO: Food and Agriculture Organization
FAOstat: Time-series and cross sectional data relating to food and agriculture for some 200 countries
FNS: Food and Nutrition Security
GAIN: Global Alliance for Improved Nutrition
GEOSHARE: Geospatial Data Hosting for Discovery and Decision Making
GHG: Greenhouse Gas
GTAP: Global Trade Analysis Project
HLPE: High Level Panel of Experts
IFPRI: International Food Policy Research Institute
ILRI: International Livestock Research Institute
ILSI: International Life Sciences Institute
IMPACT: International Model for Policy Analysis of Agricultural Commodities and Trade
INFOODS: International Network of Food Data Systems
IPCC: Intergovernmental Panel on Climate Change
IRRI: International Rice Research Institute
LMIC: Low- and Middle-Income Countries
M3 Crops Data: Harvested area yields of 175 crops from Navin Ramankutty
MAGNET: The Modular Applied General Equilibrium Tool
MIRCA: Global data set of Monthly Irrigated and Rainfed Crop Areas around the year
PE: computable Partial Equilibrium
SNS: Sustainable Nutrition Security
SPAM: Spatial Production Allocation Model
SSP: Shared Socioeconomic Pathways
UN: United Nations
UNICEF: United Nations International Children's Emergency Fund
USDA: United States Department of Agriculture
WHO: World Health Organization

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1. INTRODUCTION

1.1. Purpose of this Document

The Center for Integrated Modeling of Sustainable Agriculture and Nutrition Security (CIMSANS) was formed by the ILSI Research Foundation in 2012. CIMSANS has commissioned the preparation of this document in order to guide its program of work over the next few years.

To accomplish this goal, CIMSANS has adopted a "tri-partite" approach, bringing together scientists from academia, governmental entities, and the private sector. These public-private partnerships that can engage with local governments and international agencies in the areas of food, nutrition and health are a unique feature of the ILSI Research Foundation program. The CIMSANS vision is to produce a comprehensive, globally-integrated model-based assessment of how food (and especially its nutrient content) is produced, processed, wasted and consumed to determine the fundamental role food plays in sustainable nutrition security (SNS). While recognizing that SNS is ultimately dependent on a number of other factors such as sanitation and hygiene, access to health care and services, and good caring practices, CIMSANS concentrates on the essential roles that sustainable provision and consumption of nutritious food play in overall nutrition security, thereby making an important contribution to the broader food and nutrition security agenda.

To achieve its vision, CIMSANS aims to develop and test quantitative metrics and integrated models for assessing how the nutritional content of food consumed (as opposed to just the caloric content of food produced) contributes to the 'nutrient' security aspects of SNS. Work will include all of the world's most important staple and non-staple foods to ensure the proper macro- and micronutrient availability. However, before such models can be developed, the principal domains of SNS need to be defined and the appropriate metrics need to be identified and developed. Exploring the key domains of SNS is the primary purpose of this document.

In addition, CIMSANS intends to add to the existing body of knowledge by identifying and making use of new, untapped sources of food and nutrition data and by addressing additional factors that are increasingly important, such as increased ozone levels, urban food production, food losses and waste, and climate shocks (Pray and Pillsbury, 2012). These factors have not been included in previous assessments.

1.2. The Nutrition Security Challenge

The world faces an escalating challenge to meet accelerating demand (driven by both increasing population and per-capita income growth) for sustainable, nutritious food in the face of multiple constraints – climate change, human population pressure, local and global resource scarcity, and ecosystem preservation (Freibauer et al., 2011). About one billion people in the world live in conditions of poverty and lack sufficient food (FAO, 2013a). In addition, about two billion people already suffer from a number of micronutrient deficiencies (Myers et al*.,* 2014). These deficiencies may worsen due to increasing atmospheric CO_2, which not only drives climate change but also lowers crop concentrations of zinc and iron (Myers et al*.,* 2014). Inadequate intake or nutrient utilization may also result from situations of poor sanitation and hygiene.

Micronutrient deficiencies are caused by inadequate intake of essential vitamins and minerals in the everyday diet, which is common in populations who consume poor quality diets lacking diversity. This “hidden hunger” refers to the chronic lack of vitamins and minerals that are essential for human health, in daily food intake. Currently nearly 2 billion people worldwide are deficient in iron, vitamin A, iodine and folate (Black et al. 2008; Shetty, 2011), however zinc and vitamin D deficiency and insufficiency are increasing concerns. This number is likely to be higher when considering the totality of micro- and macro-nutrient inadequacies (WHO, 2009). Experts have long emphasized that a truly adequate diet provides the critical quantities of over 40 nutrients, although the diets of low-income populations are not always evaluated comprehensively. Micronutrient deficiencies can have dire long-term consequences for cognition, immunity and overall health (Tulchinsky, 2010). Of particular concern is stunting, which results from chronic under-nutrition and infectious disease, starting *in utero* and through the early stages of life, causing children to fail to grow to their full genetic potential, both cognitively and physically. While stunting prevalence has declined globally by 35% since 1990 (reduction of 2.1% per year), there are still an estimated 162 million children who remain moderately or severely stunted (Black et al., 2013; UNICEF, 2013). Wasting, which reflects acute malnutrition and is a strong predictor of mortality among children, impacts 52 million children under five years of age, with the highest prevalence in South Asia (Black et al., 2013).

On the other end of the malnutrition spectrum, about 1.4 billion adults aged 20 years and older are overweight (Keats and Wiggins, 2014). Of these, over 200 million men and nearly 300 million women are obese. Worldwide obesity has nearly doubled since 1980 (WHO, 2013). An estimated 43 million children under five years of age are overweight, and two-thirds of those children reside in low- and middle-income countries (Black et al., 2013; UNICEF, 2013). The problem is even more complicated: the triple burden of malnutrition (FAO, 2013b) is explained by the co-existence of hunger, micro-nutrient deficiencies and overweight / obesity in the same population across the life course, i.e. under-nutrition in early childhood increases the probability of over-nutrition in adulthood. Even more troubling, under-nutrition (including micro-nutrient deficiency) and overweight can exist in the same family (Kimani-Murage 2013; Oddo et al., 2012). These nutrition statistics are indicative of food system as well as health, care, knowledge and behavioral issues.

Malnutrition in all its forms is estimated to be either directly or indirectly responsible for approximately half of all child deaths worldwide, including both perinatal and infectious diseases as well as chronic diseases (WHO, 2013). Thus, a society with improved nutrition is a society with improved health status, which is an important aspect of societal sustainability.

1.2.1. Sustainable Production Challenges

Despite major advances in crop and animal productivity worldwide (Edgerton, 2009), global demand is now growing faster than supply (Diffenbaugh et al., 2012). This growth in demand is especially true of largely non-commodity staple food crops, such as cassava and rice, where recent yield gains are comparatively lower (Trostle, 2008). The decline in growth of global production relative to demand has led to concerns about global food supply (Cline, 2007). The impact of climate change and variability is of particular concern, especially when more food is required by a growing population in some areas and by growth in incomes and new sources of demand, such as bioenergy, in others (Dwivedi et al., 2013). Available evidence and predictions (e.g. Lobell et al., 2011; Thornton et al., 2010) suggest overall negative effects of climate change on agricultural production.

However, an even greater threat to both near- and long-term sustainability of food systems may be freshwater scarcity, which is already constraining agricultural productivity in many areas (Schewe et al., 2014). Approximately 70% of the world's freshwater withdrawals for human use are used in agriculture, and up to 90% in some low and middle income countries. However the share in actual global consumption (through evapotranspiration, etc.) is closer to 95% (Shiklomanov, 1999). By 2030, demand for water is forecast to be 50% higher than today, and withdrawals could exceed natural renewal by over 60%, resulting in water scarcity for a third of the world's population (WRG, 2009). Without adaptation, this obviously threatens to cause severe food shortages within the next 15–20 years. For example, it is anticipated that there could be up to 30% shortfalls in global cereal production by 2030 due to lack of water – this is equivalent to the entire grain crops of India and the United States (source: Frank Rijsberman 2003, then Director General of the UN's International Water Management Institute).

Another production challenge to achieving sustainable nutrition security is that of soil health. Soil mineral content can affect nutrient composition of crops (SARE, 2014). For example, soil fertilization with selenium (Se) has been shown to impact Se content of wheat (Broadley et al., 2010). Improved soil health also leads to better water quality outcomes in the adjoining water-bodies, by reducing nutrient, sediment, and pesticide losses via runoff and leaching (Schnepf and Cox, 2006). Healthy soils are essential for unimpeded crop growth, and therefore directly contribute to the potential for higher yields, sustainable intensification, and greater regional food security (FAO, 2014a). The increasing organic carbon content (both living and abiotic) of healthy soils represents a major global opportunity for climate mitigation, through the direct capture and retention of atmospheric carbon dioxide (Healthy Soils Australia, 2014). Healthy soils build greater resilience to the more intense and more frequent weather extremes that farmers face with the accelerating impacts of climate change (Stabinsky, 2012).

Urban and peri-urban agriculture (and especially horticulture) are increasingly important as these can make up a significant proportion of the nutrient supply of many cities (FAO, 2010, 2011a, 2011b). About 15% of the world's food is grown in urban areas, ranging from 0% to almost 100% in different cities (de Zeeuw and Dubbeling, 2009). Urban agriculture can take many forms (backyard, roof-top, balcony, community gardening in vacant lots and parks, urban fringe agriculture and livestock grazing in open spaces). However, its contributions are difficult to quantify and it has not been included in previous food or nutrition security assessments. From an SNS perspective, the urban production of fruits and vegetables can contribute greatly to dietary diversity among the urban poor, thereby representing an important source of micronutrients. However, quality aspects in production and marketing of urban agriculture products have to be closely watched, such as use of non-treated wastewater for irrigation, contaminated soils and polluted sites for production. The challenge is to combine productive spaces with other functions within the city and use synergies from a combination of various land uses: production of more healthful foods, recreation, economic benefit, etc. (Gerster-Bentaya, 2013).

1.3. What is "Sustainable Nutrition Security"?

As a background to discussing "*Sustainable Nutrition Security"* it is important to distinguish between *food* security and *nutrition* security. These are two quite different terms, but often used interchangeably in the literature. The "food security" element is derived from the widely-used definition of food security stemming from the 1996 FAO World Food Summit, where it is defined as the state or condition wherein:

> *All people, at all times, have physical, economic and social access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life* (FAO, 1996, 2013a).

The "nutrition security" element underscores the more general context needed, as reinforced by the recent Lancet Series (Horton and Lo, 2013). These two elements are brought together in the prevailing definition of food and nutrition security (FNS), which states that FNS exists when:

> *All people at all times have physical, social and economic access to food, which is safe and consumed in sufficient quantity and quality to meet their dietary needs and food preferences, and is supported by an environment of adequate sanitation, health services and care, allowing for a healthy and active life* (CFS, 2012).

In the context of this document, food security is seen as a crucial contributor to **nutrition** security (along with sanitation, health services, etc.); and **nutrients** are seen as a crucial contributor to food security (i.e. the FAO definition which includes the notion of "nutritious"). Recent conversations center on nutrition-sensitive agriculture or food-based approaches in agriculture (Thompson and Amoroso, 2011). As explained later in this document, the concept of FNS is extended to SNS by adding the dimensions of sustainability.

The FAO definition is valuable because it emphasizes the notion of access to food rather than food production; neither "agriculture" nor "food production" is included although they are implied as food must obviously be first produced in order for people to have access to it.

However, and even though the FAO definition includes the word "nutritious", food security is generally recognized to have multiple dimensions, but for lack of data is often measured in terms of access to sufficient food energy. This is certainly the case with approximately 1 billion hungry people who do not have access to sufficient calories. However, nutrient adequacy, embodied in the concept of safe and nutritious food, must also be taken into account. UNICEF was among the first to capture the nutrient component of food security (UNICEF, 1990). In **Figure 1**, this concept is adapted to illustrate the role of food as a part of nutrition security, including external factors that influence health and nutrient intake, which are also contributing factors in nutrition security.

The idea of "security" is usually taken to mean the state of being free from danger or threat. The concept is developed in relation to nutrition to mean free from threat of insufficiency of any essential nutrients, and comprehensive resilience in the face of any form of temporal variability – be it in production, distribution, prices, incomes, etc. The SNS assessment is also intended to be not just a global concept, but one that can be characterized across the full range of scales: national, local, households, subpopulations and individuals, while also considering notions of global justice, social equity and gender discrimination (Unterhalter, 2005).

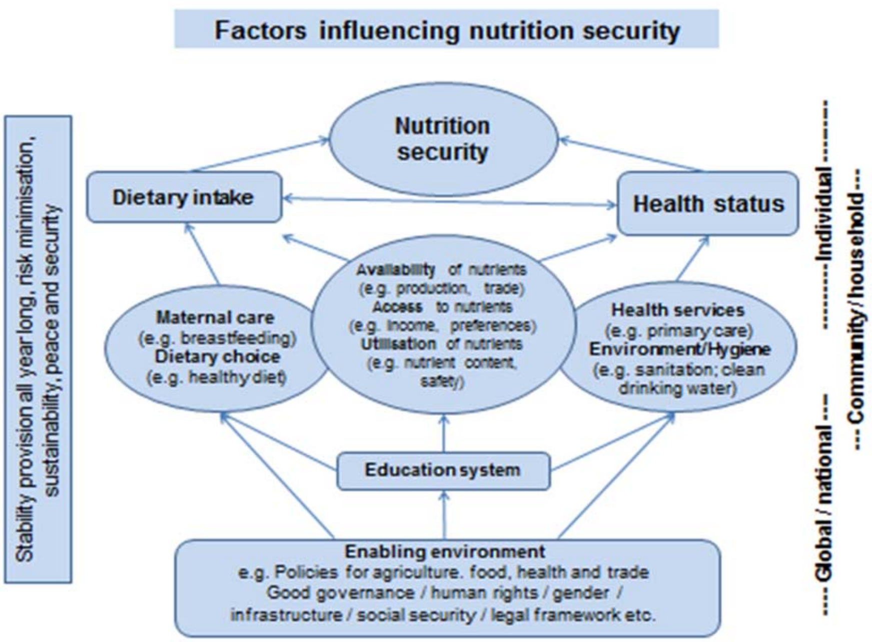

Figure 1. Factors influencing nutrition security. Adapted from (UNICEF, 1990).

Food systems involve a number of activities, including producing, processing, storing, distributing, retailing, preparing and consuming food. These give rise to a number of outcomes including the nutrient content of diets and other important elements of food security such as affordability and food safety and the impact of food waste (Ericksen, 2008; Ingram, 2011). International trade relationships are also crucial to nutrition security (Rosegrant et al., 2001) as are governance arrangements at local, regional and global levels. Taking a 'systems' approach, as opposed to just a production approach, is increasingly seen as a powerful way to analyze options for improving food security. While crop and animal productivity are fundamental to food and nutrient availability, the full set of food system activities must be considered, as they can all affect nutrient content. Improving nutrition security requires establishing science-based and decision-relevant metrics with which it is possible to categorize and compare different empirical scenarios and model outputs, with the ultimate goal of being able to measure and demonstrate local and global improvements in ways that generate effective responses (Fanzo et al., 2012).

1.3.1 Integrated Modeling of Sustainable Nutrition Security

Since the late nineties, several economic modeling teams have recognized the broader context of nutrition security and have attempted to incorporate nutrition information within computable general equilibrium (CGE) economic and partial equilibrium (PE) modeling efforts. Single country applications include Rwanda (Minot, 1998), Bangladesh (CIRDAP, 1998), Tanzania (Pauw and Thurlow, 2010), and India (Atkin, 2012). Global multi-country applications include the use of the Global Trade Analysis Project (GTAP) model (Hertel et al., 2007; Verma and Hertel, 2009) and the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) (e.g. Rosegrant et al., 2014). These studies all focus on macronutrient (i.e. calorie and sometimes protein) intake, which signals potential deficiencies (or affluence) in quantities consumed, but ignores micronutrient intake, i.e. the issue of diet quality.

The emerging science of integrated modeling is used increasingly to assess how crop production, nutrient content, farm income, food prices, food security and the environment may be impacted by climate change, management strategies, and policy changes (Goulding et al., 2008; Parry et al., 2004). However, the underlying models being used in these assessments are often based on insufficient data and model assumptions that have not been fully tested across the systems critical to nutritional security. This limitation applies particularly when different models are integrated to address the complexity of different aspects of the food nutrition system (Ingram, 2011). To investigate a problem as complex and multi-dimensional as SNS, different disciplines of science need to be combined by an integrative and future-oriented method.

These ideas are summarized schematically in **Figure 2** and discussed in **Box 1** (see next pages). CIMSANS intends to partner with several other organizations in order to characterize SNS. One especially important partner is the Agricultural Model Intercomparison and Improvement Project (AgMIP). CIMSANS will specifically partner with AgMIP on the development of new tools to quantify basic nutrient availability, price, and the sustainability metrics (GHG[1] emissions, water, energy, waste, etc.) associated with the production of these basic agricultural commodities. However, additional partners, particularly private sector players in the food value chain, have critical information that must be combined with this basic nutrient availability and sustainability information in order to provide the final nutrient availability, price, and sustainability metrics of the foods available to individual consumers (**Figure 2**). The actual consumption and overall sustainability of the various food types containing these nutrients are then complicated functions of consumer preferences (taste, education, culture, food preparation, waste), and access (disposable income, allocation and prices). For instance, fruits and vegetables contain certain components (such as phytonutrients and other bioactives) critical for good health, which may not be accounted for in nutrient composition data bases. This limitation suggests the importance of defining dietary quality in terms of dietary patterns, in addition to

[1] Greenhouse Gases, typically expressed as g CO_2 eq per unit of food

nutrient intake. Later in this document (**Section 3.1**), **Figure 2** is referenced as the basis for scoping a "conceptual framework" for characterizing SNS.

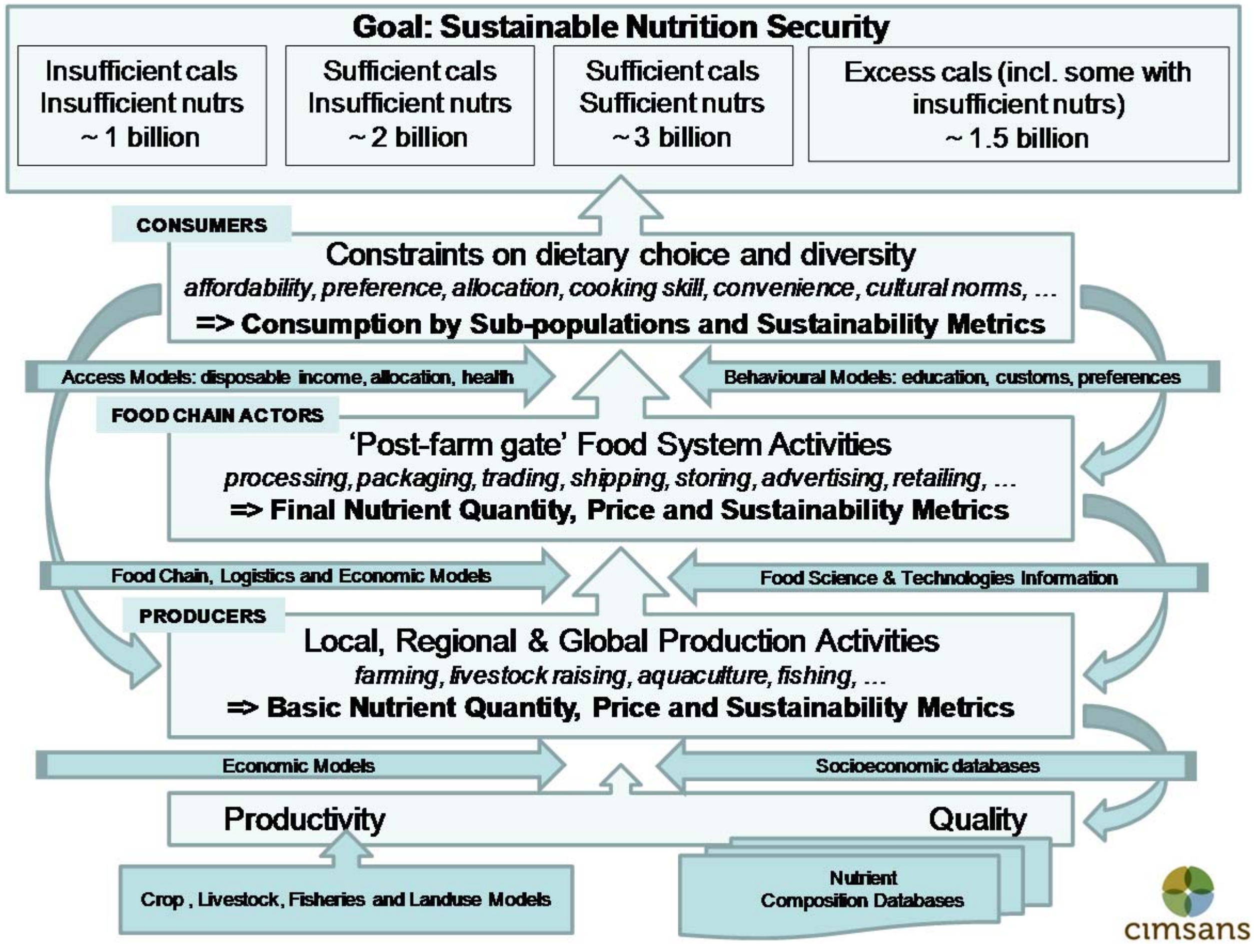

Figure 2. Schematic demonstrating the multiple types of information that must be assembled by CIMSANS and partners in order to characterize sustainable nutrition security.

Box 1: What determines sustainable nutrition security?

About 1 billion people are hungry and also lack sufficient nutrients; a further 2 billion lack sufficient nutrients; and a further 1.5 billion are overweight or obese. Of the current more than 7 billion people, therefore, over half are not achieving a healthy diet and hence are food insecure: they have either too little or too many calories, and/or too few nutrients. This proportion is likely to increase as both population and wealth (for many, but not all) rises over coming decades. The key issue for those who do not get enough calorie/nutrient is generally lack of access to appropriate food often due to poverty, but also for cultural and/or infrastructural reasons. Overconsumption of food can lead to obesity, which may occur in the presence of nutrient deficiencies due to excessive intake of low-cost, high-calorie food that is low in nutrient density. Food and nutrition insecurity is already a serious concern today (as represented by the food security 'categories' at the top of **Figure 2**), and there is a real risk of this increasing as population and wealth continue to rise. CIMSANS is helping to address this concern by promoting research based on a developing conceptual framework. This is summarized in the **Figure 2**, which aims to show schematically how better understanding can be obtained of the factors that determine into which nutrition security category an individual will likely fall.

Fundamentally, an individual's food and nutrition security is determined by a wide range of factors that constrain that individual's dietary intake and diversity. These include, for instance, affordability, preference, cooking skill, convenience and cultural norms. Estimating these requires an integrated assessment of access to food (based on knowledge of disposable income and temporal variation in access), and an individual's genetic makeup-up and health (both of which may determine the bioavailability of certain nutrients). But it is also strongly determined by behavior, level of education, customs and cultural norms, all of which contribute to choice decisions. These factors are summarized in the top section of **Figure 2**.

Linking food production with food consumption

While access and behavior affect choice, they are in turn determined by what is actually available to the consumer, in what form and at what price, and this is largely determined by the activities in the 'food chain' (or 'value chain'). Food chain, logistics and economics models combined with knowledge on food science and technologies can help estimate the *final nutrient quantity and price*, as available to the consumer. These factors are summarized in the middle section of **Figure 2**.

This is, in turn, determined by the *basic nutrient quantity and price* from the food producers. Clearly this depends in part on yield of crop, livestock unit or fisheries catch, but estimates of the actual amount produced is needed, which in turn depends on area harvested, number of livestock units included, etc. Economic models combined with socioeconomic data can help determine these parameters. It is not, however, currently possible to model the quality of this yield in terms of nutrient content (except, for example, protein based on nitrogen content), but this information exists in diverse databases that can be combined with model output to derive basic nutrient quantity and price. These factors are summarized in the bottom section of **Figure 2**.

In summary, the schematic indicates how *basic nutrient quantity and price* can be assessed; what factors determine *final nutrient quantity and price*, and how this can be assessed; what factors determine *consumption by individuals* (and sub-populations), and how this can be assessed. It is the latter which substantially determines into which *nutrition security category* an individual will fall.

Box 1 (continued):

The curved arrows, however, indicate it is not a simple linear system; feedbacks occur between each section, sending signals back “down” the chain. Consumers may favor a particular production method, whether this be at a local level on that person’s own farm (e.g. a traditional crop and livestock system), or via social lobby (e.g. for more sustainable industrial fishing). Or actors and other stakeholders in the food processing, retailing, etc., activities may signal the producers about quantity and quality of product needed from their activity. Or consumers may signal processors or retailers about price, quality, appearance, etc.

Sustainability Metrics

The activities of each set of food system actors (*producers, food chain, consumers*) all have sustainability implications: economic, environmental, and social. As indicated in **Figure 2**, these may be characterized by *sustainability metrics*, which must be quantified in order for the assessment to include a holistic characterization of the performance of the food systems from an overall societal perspective. Hypothetically, appropriate levels of nutritious food could be consumed, but at unacceptable economic, environmental, and social costs. The inclusion of well-constructed sustainability metrics (e.g. BASF, 2014), will ensure that a balance is struck (see **Section 2.7**).

2. METRICS FOR CHARACTERIZING SUSTAINABLE NUTRITION SECURITY

The vision for CIMSANS is to conduct an assessment of SNS using quantitative measures to characterize nutrition security as an augmentation to current modeling approaches; however, these quantitative measures must be identified and/or developed, and then added to available integrated modeling tools. Six such metrics have been identified and are discussed in this section of the document. Development of each of these metrics has been incorporated into the proposed Work-Plan (see **Appendix 1**). In every case, it is critical to develop recommendations regarding the spatial and temporal scales over which these metrics will be most relevant and usable. It is anticipated that these metrics will be used to improve current food system modeling approaches to incorporate nutrition sufficiency and quality and can be used in conjunction with existing measures of public health status of populations[2].

2.1 Caloric and Nutrient Adequacy

Work on caloric adequacy is already widely available and quantifies the extent to which a diet provides adequate energy (kcal) for a member of a particular population, given the person’s age, gender, health status, activity level, and other relevant factors. The measurement of nutrient adequacy includes both indicators of chronic and acute under-nutrition as well as indicators of excess macronutrient intake with and without adequate micronutrient intake. Inadequate nutrient intake is associated with anthropometric changes indicative of stunting and wasting as well as diseases and sub-optimal health caused by micronutrient deficiencies (e.g. anemia, mental disabilities, rickets, blindness, lethargy). Excess energy (macronutrient) intake is

[2] A population can refer to the population of a region or sub-populations, such as adults, pregnant women, children, vegetarians, etc.

associated with overweight and obesity as well as increased risk of non-communicable diseases (e.g. cardiovascular diseases, diabetes, certain cancers) and other concerns such as dental caries. Thus identifying appropriate measures of nutritional outcomes as a part of the assessment is necessary to address these public health concerns.

Measuring nutritional outcomes requires metrics that examine signs of nutrient inadequacy in a population as well as measurements of food intake and dietary patterns. Anthropometric indicators of nutritional status such as body weight, lean body mass, body mass index and waist circumference are useful for indicating stunting, wasting or overweight, but do not necessarily point to the underlying nutritional cause. For instance, those who suffer from stunting and wasting due to inadequate energy or protein intake are very likely to suffer from concomitant micronutrient deficiencies. Additional data obtained from laboratory-based measures (e.g. blood tests) will provide more specific information as will food intake data to determine dietary inadequacies, nutrient content of the diet and dietary patterns. While these tools are useful, the degree to which data are available from various populations, including vulnerable sub-populations and those from low and middle income countries (LMICs), is variable.

2.2 Dietary Quality

Among the key challenges are how to quantify nutritional quality of diets and the availability of the required data, as well as how to incorporate such data into an SNS assessment. Relevant data on the impact of crop diversity and growing conditions on the nutrient content of specific crops/foods as well as on the impact of post-harvest handling and processing on nutrient stability will enable an assessment of how agriculture and post-harvest processing can improve nutrition security. Processing, particularly cooking, can change the nutritional value of food between harvest and consumption (FAO, 1990; Floros et al*.,* 2010; Kapica and Weiss, 2012; Weaver et al., 2014). Post-harvest handling and food processing are important in minimizing food waste and ensuring the year-round availability of wholesome food in sufficient quantity (Floros et al*.,* 2010). While some consideration is needed to evaluate the stability of nutrients under various processing conditions, equal consideration must be given to the value of food processing and packaging in preserving foods and reducing waste (FAO, 2011c) so that they can be transported to markets where needed, and prevent further nutrient degradation during storage.

Agro-processing can contribute to improved nutrition indirectly through generating income for smallholders with which to purchase a more varied and nutritious diet and directly through availability of food products in which the nutrient and other bioactive components can be preserved or increased. Agro-processing involves turning primary agricultural products into other forms for market. Drying, fortification, and other processes can improve the nutritional status and income of households. Processing can also preserve foods to extend their shelf life and thus increase opportunities for access and decrease losses due to spoilage. Often, in low-income settings, diets based largely on plant sources do not meet nutrient requirements and may need to be improved by processing (e.g., dehulling, germinating, fermenting), fortification, or adding animal-source foods, e.g. milk (De Pee and Bloem, 2009). Processing can also remove anti-nutrients, such as phytates that inhibit absorption of key nutrients, such as iron and zinc.

Countries have employed nutrient fortification programs to address public health concerns within a population (e.g. fortified flours, vitamin A in margarine and dairy products, iodine in salt, iron in fish sauce) as well as supplementation programs (e.g. vitamin A supplements for children under five and iron and folic acid for pregnant women) (Tanumihardjo, 2008). Countries have also made efforts to reduce some ingredients that have been shown to be public health threats (trans fats, sodium etc). Newer strategies include the development of biofortification approaches, which may enable an improved profile of some nutrients within certain crops (including fruits and vegetables), either through breeding technology or agricultural practices. Data on fortification polices and availability of fortified foods and crops with improved nutrient profile are needed for accurate SNS assessments.

2.3 Dietary Diversity

Dietary diversity is critical to nutrition security. Existing dietary diversity metrics will be evaluated and adapted as necessary (e.g. FAO Household Food Security, World Food Programme Committee on World Food Security). Such tools might consider the balance of staple and non-staple crops that are affordable, accessible and convenient for use as well as the relevant sources of nutrients for a population.

A diverse food supply is needed to meet nutrient needs and dietary patterns associated with health and well-being. Households and individuals must have access to the diverse dietary mix of nutritious foods meeting both macro- and micronutrient requirements of the population, and respecting cultural and social norms.

Many of the foods that diversify dietary patterns to better meet nutrient needs are highly perishable in their raw state (e.g. animal foods, dairy products, fruits, and vegetables). Post-harvest handling, processing and packaging can be used effectively to reduce waste and improve access to these foods as well as the availability of nutrients from foods, especially plant foods.

Existing dietary diversity metrics can capture information about both macro- and micronutrients, and about a balanced diet in general (e.g. Individual Dietary Diversity score (FANTA, 2006a); and Household Dietary Diversity scores (FANTA, 2006b)). While such tools are becoming more available, it is not clear that a widely acceptable, validated assessment tool for measuring dietary diversity as a component of assessing nutrition security is currently available. For example, locally produced and consumed leafy green vegetables are often not captured in studies such as the FAO market balance sheet (FAO, 2014b). As another example, what percentage of energy should come from animal source foods? Determining the best way to assess dietary quality and diversity at the household level, as well as the population level, is essential to understand micronutrient intake or maintain adequate nutritional status.

2.4 Dietary Sustainability

The commitment to sustainable development and the elimination of poverty and food insecurity requires metrics and tools to better understand what is meant by sustainable diets for different populations and contexts, how these diets can be assessed within our global food system, and how environmental sustainability can be achieved within our consumption patterns and dietary goals (Fanzo et al., 2012). It is essential that the developed metric explicitly includes both pre-harvest food production activities, including waste, as well as the impacts of any local and regional post-harvest processing technologies that are in use or might be regionally appropriate. The metric must also encompass all three pillars of sustainability: economic, environmental, and social.

The agricultural sector needs to play a central role in reaching population goals for nutritional quality of the diet both in terms of foods produced as well as production practices. In order to realize that role, nutrition and dietary recommendations need to be considered in the development of agricultural policies and practices. As part of the assessment described in this document, CIMSANS intends to develop a methodology that will make it possible to test the overall effectiveness of various agricultural adaptation options (agronomic and economic).

Producing enough *available* food to meet consumer demand is necessary but not sufficient to ensuring people achieve the level of nutrients needed for full health benefits. Food security at the household and individual level depends on *access* to food and the use of that food. Socioeconomic factors will impact not only the adequacy and availability of the diet and nutrition but access to clean water, sanitation, and health care, all of which influence health and well-being.

Finally, the role of women in assuring and improving sustainable nutrition security already is, and will become increasingly significant; their involvement in production of ‘minor crops’ and husbandry of animals contributes to a varied diet, which improves the nutritional quality of the food supply. Also their work on farms, in gardens, and in microenterprises generates food and cash and thus increases potential household food availability and contributes to a positive net effect of women's work on child nutrition, especially in low income households (Holmboe-Ottesen et al., 1989; Unterhalter, 2005). Women’s social status plays an essential role in determining nutrition for their children. Improving women’s own nutritional status would also improve that of their young children, especially during pregnancy and lactation. Therefore, raising women’s status in the agricultural regions of LMICs is a powerful force for improving health, longevity, mental and physical capacity, and productivity of the next generation of young adults (IFPRI, 2005; Smith et al., 2001).

The SNS assessment requires reliable data on where specific food crops (staples and non-staples) can be grown optimally for the best yields and nutritional quality. Data are also needed on agricultural practices that can maintain or improve nutrient quality (Foley et al., 2011). In addition, such an assessment needs to consider the relevance of livestock production as a contributor to nutritional status in the context of its impact on environmental and social sustainability.

2.5 Consumer Choice

Taste, cost, convenience, and cultural norms are primary factors in consumer choice of foods and combine in a complex way with economic factors to determine the quantity of particular foods (and their nutrients) that are actually consumed and the amounts that are not eaten (a major component of food waste in the high-income countries). These choices directly impact nutrition and sustainability outcomes, and the degree to which the capacity for consumers to make such choices is directly related to such factors as disposable income and food availability. It is this capacity for making such consumer choice that is quantified by this proposed metric. The metric should focus on the affordability and accessibility of choices that meet nutritional guidelines and recommendations.

Socio-cultural influences and norms impact food availability, access and preferences. These norms or rules affect behavior and are often shared across communities and generations. Every cultural setting maintains multiple concepts about how decisions are made regarding food selection, preparation, serving and consumption, often through proscriptions and prescriptions; in other words, foods that are to be avoided or preferentially consumed by all or by segments of a cultural group (Gittelsohn and Vastine, 2003). Sociocultural patterns of food procurement and rules of food distribution within households and communities can interact with other biological factors, such as illness (Messer, 1984).

2.6 Resiliency of the Food System

The concept of resiliency of the food system in meeting nutrient needs in the face of climate or other changes is one that needs to be studied (Fanzo, 2011). Quantitative measures of such resiliency are needed. Regional food systems with high resiliency would have alternative sources of nutrients as well as alternative routes for obtaining foods. This resiliency can be achieved either through the production of alternate crops potentially at different times of the year or foods within the region or via trade or post-harvest processing activities that result in robust access to recommended food sources and nutrients for all members of a household or population.

2.7 Metrics for Characterizing Social, Environmental and Economic Sustainability

In addition to broadening the analysis to include nutritional metrics, sustainability metrics will become an integrated component of the assessment. In doing so, and as is traditionally conceived, CIMSANS will adopt the standard three pillars of sustainability: economic, environmental, and social. With the increasing concerns about climate change, biodiversity loss and other aspects of environmental degradation, the environmental pillar is often assumed to be the predominant issue – indeed it is often used synonymously with overall sustainability. However, in the SNS context, “social” and “economic” pillars are of equal importance, even more so if they are thought of broadly: “Social” should include nutrition/health outcomes, but also include cultural diversity; the social, cultural and religious functions of food; and social capital. “Economic” should explicitly include the notion of the business sustainability of the enterprise, given the importance of the many enterprises in the food system. These could be that of an individual farmer/fisherman or a multinational corporation: they are all enterprises and are also key actors in the food system; they all have to be sustainable from a business viewpoint for the food system to function. “Economic” could also encompass public health economics and the overall costs of environmental externalities.

All three pillars apply across all the sets of food system activities related to food production (farming, fishing, etc.) through the food chain (processing, packaging, storing, transporting, retailing) to consuming (cooking, eating) – all three sections in **Figure 2**. It is however hypothesized that the relative degree to which each sustainability pillar is seen to underpin/contribute to overall sustainability varies across the three main sets of actors in **Figure 2**. Gaining a better understanding of this potential variation will be part of the CIMSANS research agenda.

3. ASSESSMENT METHODOLOGY

3.1. Conceptual Framework

The conceptual framework for what is required in order to characterize SNS was presented schematically in **Figure 2**. Current integrated models primarily describe the production processes associated with the lower box in this figure, albeit normally without the nutrition and sustainability metrics that must be included. One unique aspect of this new conceptual framework is the presence of the processes captured in the boxes that appear higher within the figure: (1) all of the processes that convert raw agricultural commodities into the types of foods available in the marketplace; and (2) the complex set of factors that combine to determine which of the available foods are actually consumed by individuals in particular sub-populations.

Nothing in **Figure 2** is “place-based,” but the intention is to develop a modeling framework which represents the entire global food system at a level of geographic detail sufficiently precise to inform the actions of decision-makers, whether they be local or regional governmental officials considering the impacts of various policy options, or private-sector players considering investments to improve regional or global SNS.

3.2. Required Integrated Modeling Improvements

A number of improvements and enhancements must be made to the existing suite of integrated models in order to quantify SNS as it has been defined here. A key task in the overall Work-Plan (see **Appendix 1**.) will be to prioritize which improvements must be implemented as part of the initial assessment and those which ideally should follow. Some of the proposed developments include:

i. Link outputs from (multiple) climate, crop, economic, food chain and behavioral models within an overall modeling framework models (as in **Figure 2**)
ii. Extend the number of scenarios analyzed, e.g. specifically linking to Shared Socioeconomic Pathways (SSPs) 1, 2 and 3 (representing low, medium and high challenges in terms of climate change, respectively) under plausible ranges of productivity growth, greenhouse gas concentrations, etc.

iii. Improve models' ability to handle comprehensive nutritional dimensions
iv. Consider non-agricultural incomes as a key determinant of access to nutritious food and nutritious diets for most of the world's people and many of the world's poor
v. Link metrics of sustainability to the existing crop models and the SNS assessment model proposed here
vi. Account for the impacts of post-harvest processing
vii. Develop concepts to include year-to-year variability (due to climate or other drivers) in economic models
viii. Improve coverage of changing consumer preferences in economic models
ix. Develop an approach which models the whole system as depicted in **Figure 2** (as distinct to linking sub-models as proposed in (i) above). This would involve:
    a. Defining the 'system' boundaries, the spatial and temporal levels of interest
    b. Agreeing a set of variables to include and the relationship between them
    c. Developing a 'simple' model drawing on systems approaches such as fuzzy cognitive mapping and/or agent-based modeling
x. Develop capabilities in existing models or add model modules to account for some additional potential aspects of this SNS assessment, as discussed further in **Section 3.6**. These include, for example:
    a. The effects on crop and animal production resulting from expected increases in climatic variability from year-to-year or season-to-season
    b. Adding Impacts of biotic or ozone induced stress on crop or animal production
    c. Improving ability of models to account for effects on crop production associated with degraded soils characterized by poor soil health, low soil carbon, soil nutrient deficiencies, and decreased water availability.
    d. Nutritional changes in crop and animal raw food materials as a consequence of environmental change
    e. Explicit consideration of waste and other post-harvest losses

3.3. Data Needs Relevant to the Assessment

In addition to the modeling improvements needed, it is widely recognized that "Open Data" are essential to ensure the credibility and acceptance of integrated modeling, as well as any assessments of food or nutrition security produced using such tools. Accordingly, in September 2013, the CIMSANS Open Ag Data Working Group launched a one-year pilot project supporting the development of GEOSHARE (Geospatial Open Source Hosting of Agriculture, Resource & Environmental Data for Discovery and Decision Making). The mission of GEOSHARE is to develop and maintain a freely available, global, spatially explicit database on agriculture, resources, and the environment accompanied by analysis tools and training programs for new scientists, decision makers, and development practitioners. The specific goal of the 12-month GEOSHARE pilot project sponsored by CIMSANS is to focus on two countries (India and Ghana), as a way to better assess the challenges involved for a global implementation. Pending the successful outcome of this pilot project, it is our current intention to utilize GEOSHARE as a preferred location for the storage of data required for the SNS assessment. This will necessarily imply that all data will be freely available in a spatially explicit format. The intent is to allow for continuous addition of new metrics to under the GEOSHARE platform.

Another key task will be to identify particular data sets (e.g. agricultural land-use, crop and livestock yields, food processing activities, local food availability, etc.) that are needed to support the assessment, identify the best sources of all such data, and – most importantly – identify where critical data gaps exist. Where essential data are missing and resources for collecting the needed data cannot be secured, estimation methods may be required. Similarly where data, if available at all, are only presently found for large geographic areas (e.g. behavioral and health related metrics) aggregation /disaggregation spatial tools will be needed to make extrapolations/ inter-conversions in order to make the data available for models operating at different spatial scales. Approaches similar to the Spatial Production Allocation Model (SPAM) (HarvestChoice, 2014; You et al., 2006) for converting data between spatial frameworks and documenting the associated assumptions are being investigated as a part of the GEOSHARE pilot program mentioned above.

Table 1 (see pages 28–29) contains an initial listing of some of the types of data that have already been identified by this white paper as being necessary to support the SNS assessment. This table is envisaged as a living document that will identify key data sets needed to conduct SNS assessments as well as list the current best available sources of such data and the spatial scales at which they are available. It is expected that the list will develop with time and provide a valuable reference to those designing data generation programs. This is a working document of CIMSANS and will continue to be the source of additional focus as the Work-Plan is implemented.

3.4. Temporal Scale and Resolution of the Assessment

The initial assessment will cover the time period 2000 through 2050. The underlying economic models will have a monthly time step in order to explicitly account for the impact of variability and seasonality in a number of domains (climate, weather, economic, livelihood, etc.) but results will generally be presented at five year intervals. The retrospective period (2000 through 2015) is being included in order to demonstrate how well the integrated models represent observed patterns of SNS, during the recent period of rapidly increasing demand, extreme weather, and other disruptive factors. The monthly time step of the assessment will make it possible to understand whether seasonal vulnerabilities exist – enabling issues around resiliency to be addressed.

The long-term scenarios will be based on those used in the IPCC Fifth Assessment Report (and adapted by AgMIP) (IPCC, 2014). Any additional information specific to the food and agricultural sector will be developed via a multi-stakeholder consultative process involving scientific experts in the public- and private-sector.

3.5. Spatial Scale and Resolution of the Assessment

Results will be presented on a global basis as a series of gridded maps (see example in **Figure 3**), probably with a resolution of approximately 50 x 50 km (to be refined as one of the first activities). However, as discussed above, not all metrics and modeling inputs (for instance, consumer demand factors) are likely to be available with such fine geographic precision. Similarly, outputs of SNS assessments at this grid scale may have limited application for governments or regional policy/decision making. Hence the need for approaches both for upscaling gridded model outputs to jurisdictional unit scales (e.g. country and regional administrative boundaries) as well as for disaggregating data down to the grid cell scale as model inputs. Clearly, this output format will allow for convenient mapping of assessment outputs but for the present while SNS metrics are maturing, it is envisaged that the assessment outputs will be collections of maps, graphs and textual explanation.

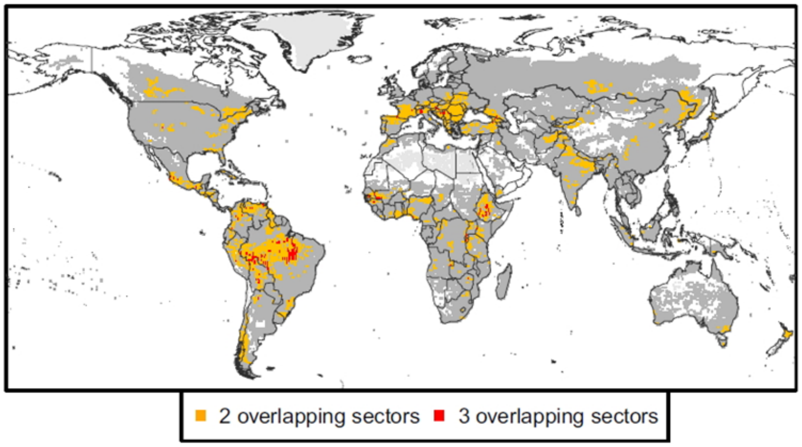

Figure 3. Example of a map-based assessment product, in this case a multi-sectoral climate impact hotspot analysis (from Piontek et al., 2014). The dark gray indicates regions where one of the considered sectors (hydrology, crop yields, ecosystems, or malaria) is severely impacted by climate change. Regions with multiple severe sectoral impacts are colored either in yellow (two sectors) or red (three sectors).

3.6. Additional Potential Aspects of the Assessment

There are a number of additional factors that should be considered for possible inclusion in the SNS assessment. Several of these are discussed briefly below. An early action item within the Work-Plan is for CIMSANS to convene a discussion with integrated modeling experts and others to determine which ones of these can be included, either in the initial assessment or as part of future work. Many of the factors listed below are primarily associated with agricultural production, rather than the other aspects of food systems (see **Figure 2**). However, it is certainly true that producing insufficient quantities of basic food nutrients inevitably constrains the ability of the food value chain to make nutritious food available to consumers at affordable prices and of the appropriate nutrient quality.

3.6.1. Climate Variability

Climate change is already widely recognized as a threat to agricultural production (IPCC, 2014), but the full range of impacts to food systems are not yet fully understood. While the current suite of crop models address rising temperature and carbon dioxide levels of future climate change, they ignore the effect of increasing weather variability extremes due to climate change, such as short-term (1–2 week) periods of heat or cold stresses on reproductive growth for example, or flood damage. Modeling these effects of increased variability will also require improvements in the economic models.

3.6.2. Ozone

In addition to being a GHG, tropospheric (near ground level) ozone is the atmospheric pollutant most destructive to plant and animal life. Ozone is created in a variety of chemical reactions involving both natural and manmade gasses. The extent of ozone creation also depends on temperature, ultraviolet radiation and the presence of nitrous oxides and the hydroxyl radical. Research has shown that both wheat and soybean are sensitive to ozone levels above approximately 40 ppb, which is well below the ambient levels already present in important agricultural regions, such as China (van Dingenen, 2009). There is likely to be local variability in ozone concentrations due to differences in elevation, temperature and ultraviolet radiation intensity. Accounting for ozone and its variability are both challenging, from a modeling perspective, but seem worthy of consideration for future assessments, given the large role that these productivity losses are possibly already having on overall food nutrient availability.

3.6.3. Biotic Stresses

Biotic stresses to plants (and animals) are those caused by biological threats to productivity. There are three categories of stressors - insects, mycorrizal pathogens, and viruses. As a general rule these stressors all respond positively to an increase in temperature and to a lesser extent humidity. They can affect the productivity of the plant directly (a reduction in yield) or indirectly by reducing the quality of the commercial component of the plant or animal (e.g. aflatoxin, see section 3.6.8). Accurately modeling the effects of increasing biotic stresses will require major improvements in current models, but seem worthy of further development as this would improve understanding of the resulting impacts on the consumption of nutritious foods.

3.6.4. Soil Degradation and Soil Health

Another production challenge to achieving sustainable nutrition security is that of soil health. Healthy soils are essential for unimpeded crop growth, and therefore directly contribute to the potential for higher yields, sustainable intensification, and greater regional food security (FAO, 2014a). The concept of soil health is one that treats soil as an ecosystem, which when healthy is able to provide diverse services with little intervention. One such aspect is a soil mineral content, which can affect nutrient composition of crops (SARE, 2014). For example, soil fertilization with selenium (Se) has been shown to increase Se content of wheat (Broadley et al., 2010). Improved soil health also leads to better water quality outcomes in the adjoining water-bodies, by reducing nutrient, sediment, and pesticide losses via runoff and leaching (Schnepf and Cox, 2006).

Two crucial characteristics of a healthy soil are its biodiversity and its soil organic matter. Loss of biodiversity ultimately affects ecosystem functioning. Subsistence farmers in the tropics are more likely to be adversely affected than farmers in other regions, because they rely to a larger extent on these natural processes to sustain soil fertility (FAO, 2014a). If the organic matter is maintained at a satisfactory level for productive crop growth without fertilization much beyond the replacement needs in the crop harvest, it can be reasonably assumed that a soil is healthy. The increasing organic carbon content (both living and abiotic) of healthy soils represents a major global opportunity for climate mitigation, through the direct capture and retention of atmospheric carbon dioxide (Healthy Soils Australia, 2014). Healthy soils build greater resilience to the more intense and more frequent weather extremes that farmers face with the accelerating impacts of climate change (Stabinsky, 2012). The primary mechanism for this increased resilience is the greater moisture holding capacity of such soils and better water penetration.

3.6.5. Changes in Nutrient Composition

In addition to the productivity effects of climate change, there is also mounting evidence that climate change alters nutrient contents of plants, which ultimately could impact the nutritional content of foods as consumed. This was highlighted, for instance, by the recent High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security (HLPE), which stated:

> *Grains have received the most attention – with both higher CO_2 levels and temperature affecting grain quality. For example, Hatfield et al. (2011) summarize research showing that protein content in wheat is reduced by high CO_2 levels. FACE experiments in the US reported by Ainsworth & McGrath (2010) and in China by Erda et al. (2005) show substantially reduced protein content and minerals such as iron and zinc in non-leguminous grain crops for CO_2 concentrations that are likely to occur by mid-century. Wrigley (2006) reported that yield increase in wheat due to doubling of CO_2 comes from more grains rather than larger grains and produces lower protein content and higher starch content. The International Rice Research Institute (IRRI, 2007) reported that higher temperatures will affect rice quality traits such as chalk, amylase content, and gelatinization temperature (HLPE, 2012).*

At the present time, it does not appear that research into the effects of climate change on the nutritional composition of animal products has yet been undertaken.

3.6.6. Genetic Improvements

Current integrated models generally do not account for genetic improvement, although this was described in a recent report from IFPRI (Rosegrant et al., 2014). Crop cultivars can be improved via application of both traditional breeding and other methods of genetic modification (e.g., recombinant DNA biotechnology). Agronomic or nutritional traits added to crops through agricultural biotechnology often result in the reduced use of herbicide, fungicide, insecticide, labor, and energy (Newell-McGloughlin, 2013), and can have important beneficial nutrition and other consequences. Examples include Golden Rice (vitamin A nutrition), submergence-tolerant rice (flood-tolerance), insect-resistant *Bt*-maize (reduces pesticide use and potential for mycotoxin formation), *Bt*-cotton, virus-resistant papaya, and herbicide-tolerant crops (that conserve soil, and reduce time and labor in production).

3.6.7. Urban and Peri-Urban Food Production

As noted previously, high intensity urban production is rapidly becoming more popular in certain parts of the world, such as in the Middle East. Some of these systems represent extreme instances of intensification, such as highly managed multi-level greenhouses – so-called “vertical farming” (Porritt, 2013). At the opposite end of the economic spectrum, within certain low-income countries, fresh fruit and vegetables are simply picked along urban streets. The FAO has considered the contribution of urban and peri-urban agriculture in several small-scale nutrition security assessments (FAO, 2014c). It will be critical to account for these production systems in order to present a comprehensive assessment of SNS.

3.6.8. Consideration of naturally occurring toxins

Various naturally occurring toxins are known to contaminate certain food crops and thereby have health consequences if consumed at levels above a particular threshold. Aflatoxins, for example, are produced by fungi on maize grain or peanuts damaged by poor growing conditions or post-harvest handling and have been associated with stunting in children of LMICs (Leroy, 2013). Food-borne aflatoxin exposure in maize and groundnuts is common in Africa and Asia (Khalngwiset et al., 2011). More evidence is needed on how the selection of resistant crop varieties, post-harvest storage, and food handing can help control for aflatoxins, which could indirectly have an impact on the nutritional status and growth of young children (Leroy, 2013; Wild, 2007).

3.6.9. Food Loss and Waste

The issue of losses and waste in the food value chain has reemerged after a 20 year hiatus as a major contributing factor in SNS (Barilla Center for Food & Nutrition, 2012; FAO, 2013b). In addition to the food lost for consumption, food waste throughout the global food system also results in tremendously negative environmental impacts (Dobbs et al., 2011) in terms of land, water, energy and chemical resources invested in growing crops as well as substantial greenhouse gas emissions (from methane production) when wasted organic materials degrade. In LMICs, the greatest driver of food waste is upstream, starting with agricultural production. Lack of infrastructure for post-harvest handling and storage contribute to spoilage, spillage and pest infestation; very little waste occurs downstream at the point of consumption. In high income countries, some losses occur at the agricultural level, but more sophisticated infrastructure exists to minimize losses in processing, storage, handling and transportation; but the greatest sources of losses are predominantly downstream at the point of consumption, largely driven by cultural norms, personal taste, and consumer factors (FAO, 2011d; Gunders, 2012). Regardless of the root causes for waste, the order of magnitude is similar in both LMICs and high income nations and is estimated to be as much as 40% (FAO, 2013c). Fruits, vegetables and root crops, as well as some animal source foods, can easily spoil if care is not taken during harvest, handling, processing, packaging and transport, and if not properly addressed in the waste stream, may increase the potential for pathogen transmission. Protecting perishable fruits vegetables, and dairy, fish, and meat products requires adequate product handling, packaging, cold storage facilities, transportation, and distribution (Nugent et al., 2011).

4. NEXT STEPS

The creation of the SNS Assessment will require, at the outset, a prioritized list of the desired integrated modeling improvements, data, and data processing tools – as well as the resources to do the work. CIMSANS will secure funding for this estimated three-year initiative (see

Appendix 1 for the work-plan timeline), and will reach out to the partner organizations that have the scientists with the required expertise. A budget will be developed, with resources allocated to the various partners in an appropriate manner.

Once the initial SNS assessment is completed, the findings will be published and case study validations of the SNS assessment will be carried out in selected countries in order to identify future research needs. This will help to determine what can and cannot currently be done in terms of characterizing SNS. The particular activities already agreed upon are described below, and illustrated in the flow-diagram in **Appendix 1**.

4.1. Identify, Assemble and Curate Data

CIMSANS will collect the data sets that are needed to support the SNS assessment. Discussions on this topic will begin during a joint GEOSHARE-CIMSANS Workshop, to be held at Purdue University on September 10–11, 2014. This will require the identification, assembly and curating of data, and the establishment of the best sources of all such data. As discussed earlier, CIMSANS envisages using a data matrix stemming from **Table 1** as a living repository of best available data sources and a record of associated assumptions and caveats. Where critical data gaps exist, CIMSANS will seek resources to collect missing data. This is a particular instance where cooperation among and between the three parts of the tri-partite relationship (i.e. academia, governments and the private sector) will be essential to access the best available data to meet the SNS goals. If no suitable data can be found for certain topics, then estimation methods may be required.

4.2. Improve Component Models and Whole System Modeling

In collaboration with its various partners, CIMSANS will add SNS metrics to available integrated models – e.g. IMPACT, MAGNET (including Household layer), etc. (see Nelson et al., 2014 for a more complete list). In order to begin this task, CIMSANS will host an “Improved Modeling Summit” at Purdue University on September 11–12, 2014, immediately after the workshop mentioned above. In this meeting, the particular component models/modules that require improvement or *de nouveau* development to address the SNS scope will be prioritized. All components that require improvement/development and are to become part of the first assessment must be available by the end of Year 2, as part of the three-year Work-Plan (see **Appendix 1**). CIMSANS will also review and develop approaches to model the food system “as a whole” (i.e. **Figure 2**).

4.3. Conduct Case Study Validations

The models mentioned above (IMPACT and MAGNET) are global models, and therefore are not applicable to individual countries. However, the types of improvements described in this paper are ambitious and will not be possible to fully test at the global scale within the three year period. Accordingly, CIMSANS will conduct case study validations with the tool in all or selected regions of the following three countries: Ghana, India, and the Netherlands. Ghana and India are logical choices for this effort, as they are the two countries that are the subject of the ongoing GEOSHARE pilot project. The Netherlands is an excellent example of a higher income country with plentiful data and a number of researchers interested in collaborating on the topic of SNS. These case studies will be useful for identifying parts of the assessment methodology that require further refinement in order to reliably and credibly characterize SNS at the global scale.

5. CONCLUSIONS

Multiple lines of evidence confirm that expected changes in climate and water availability represent major challenges for food systems to successfully meet accelerating global demand. However, available assessments have not included the many sustainability and nutrition aspects described within this document. The new assessment described in this paper will allow decision-makers to more appropriately evaluate the implications of the various interventions and investments in food systems that could be taken to improve overall societal outcomes.

The ultimate product of this CIMSANS endeavor will be an assessment in the form of a gridded global map depicting the status of SNS under a variety of assumptions. The integrated modeling framework used to produce this assessment can be deployed to identify the key factors limiting SNS, and to test the impact of various public and private sector food system interventions.

Researchers, food and agricultural companies, development agencies, public health organizations and local and national governments would benefit from applying the SNS tool to help guide interventions in the food sector aimed at improving SNS. Stakeholders interested in becoming involved or supporting the initiative should contact CIMSANS@ilsi.org.

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Table 1. Preliminary Assessment of the Data Needs for Characterizing Sustainable Nutrition Security

Desired Quantifications	Activities Addressed	Models	Input Data	Desired Model Output Data	Relevant questions	Available Data sources
Farm-gate Nutrient production from basic food types at local & regional scales *Farm-gate Nutrient price per unit* *Farm-gate Nutrient - sustainability metrics per unit*	**Farming, livestock raising, aquaculture, fishing**	Crop	Soils, environmental, crop-specific parameters, agro-ecozones, agronomics, pests, disease, etc.	Crop production for estimating nutrient production and regional availability	Current and future production predictions	Regional institutes, standard AgMIP data sets; ESRI data
		Livestock	Feed, infrastructure, confined vs. pasture, etc.	Livestock meat and dairy production and regional availability	Current and future production predictions	Regional institute, ILRI
		Fisheries	Catch data?	Fish and Fish product production and regional availability	Current and future production predictions	WorldFish
		Economic	Socioeconomic databases, elasticities, accessibility estimates?	To be determined	To be determined	Local household surveys via regional institutes, IFPRI
		Land use and allocation	Land use, local drivers of crop selection, cropping capability data, outputs from above models	Overall national mosaics of total food production based on allocations between competing crops to modify estimates from above models	Current and future effective regional production given physical and economic constraints	SPAM, MIRCA, FAOstat, M3 Crops Data

Table 1. Preliminary Assessment of the Data Needs for Characterizing Sustainable Nutrition Security

Desired Quantifications	Activities Addressed	Models	Input Data	Desired Model Output Data	Relevant questions	Available Data sources
		Nutrient content estimator via a calculator which is effectively a simple nutrient estimator per Kg of crop production (i.e. not modeling nutrient production per se)	Pre-processed nutrient content as % of biomass by crop	To translate regional crop production estimates to nutrient farm gate estimates	National, regional, environmental, stress and climatic impacts on Nutrient levels in each crop	USDA national nutrient database, ILSI nutrient databases, private industry data, FAO's INFOODS
		Sustainability metrics	Accepted global or regional crop, livestock, fishery sustainability values (i.e. not novel predictions?)	Environmental, biodiversity, carbon, etc.	What are the current overall sustainability implications arising from efforts to adapt nutrient provision?	To be determined
		Future casting	Climate/resource scenarios	Predicted change in production under various climate change scenarios	What is longer term sensitivity of nutrient predictions to price or climate change scenarios?	To be determined

Table 1. Preliminary Assessment of the Data Needs for Characterizing Sustainable Nutrition Security

<table>
<tr><th>Desired Quantifications</th><th>Activities Addressed</th><th>Models</th><th>Input Data</th><th>Desired Model Output Data</th><th>Relevant questions</th><th>Available Data sources</th></tr>
<tr><td rowspan="4">Post-farm-gate nutrient quantity for sum of regional staples and primary processed foods (plus imported materials)

Post-farm-gate nutrient Price per unit based upon output above

Post-farm-gate nutrient Sustainability Metrics per unit to include processed plus staples</td><td rowspan="4">Processing, packaging, shipping, storing, advertising, retailing</td><td>Food Chain</td><td>Food Science & technologies Information</td><td>Nutrient composition of fresh and processed retail foods & sustainability impacts</td><td>National and regional variation in nutrient content due to processing differences</td><td>GAIN</td></tr>
<tr><td>Logistics</td><td>To be determined</td><td>To be determined</td><td>To be determined</td><td>To be determined</td></tr>
<tr><td>Economic models</td><td>To be determined</td><td>To be determined</td><td>To be determined</td><td>To be determined</td></tr>
<tr><td>Sustainability metrics</td><td>Accepted global or regional post farm-gate commodity-to-food management sustainability values (i.e. not novel predictions)</td><td>Environmental, biodiversity, carbon, etc.</td><td>To be determined</td><td>Bioversity</td></tr>
</table>

Table 1. Preliminary Assessment of the Data Needs for Characterizing Sustainable Nutrition Security

Desired Quantifications	Activities Addressed	Models	Input Data	Desired Model Output Data	Relevant questions	Available Data sources
Nutrient Consumption by Sub-populations	**Food acquisition, food preparation, eating and drinking, waste**	Access	Income, allocation, health	To be determined	To be determined	To be determined
Calorie consumption by subpopulations		Behavioral	Education, customs, preferences, affordability, preference, allocation, cooking skill, convenience, cultural norms	Nutrient composition of consumed diet & sustainability impacts	To be determined	To be determined
Nutrient and calorie consumption rated by Sustainability Metrics		Uptake and effect	To be determined	To be determined	To be determined	To be determined
		Sustainability metrics	To be determined	Environmental, biodiversity, carbon, etc.	To be determined	To be determined

Abbreviations: AgMIP: the Agricultural Modeling Intercomparison and Improvement Program; ESRI: Geographic Information Systems developer; FAOstat: Time-series and cross sectional data relating to food and agriculture for some 200 countries; GAIN: Global Alliance for Improved Nutrition; IFPRI: International Food Policy Research Institute; INFOODS: International Network of Food Data Systems; ILRI: International Livestock Research Institute; M3 Crops Data: Harvested area yields of 175 crops from Navin Ramankutty; MIRCA: Global data set of Monthly Irrigated and Rainfed Crop Areas around the year; SPAM: Spatial Production Allocation Model; USDA: United States Department of Agriculture

Appendix 1. Work-Plan, Timeline and Next Steps Schematic

YEAR ONE:

- Prioritize list of desired integrated modeling improvements
- Existing tools for quantifying nutrition security will be evaluated for possible use in the SNS assessment.
- Identify means to add all SNS metrics to available integrated models.

YEAR TWO:

- Implement improvements to integrated models, including the addition of SNS metrics
- Complete assembly of all necessary data, models, and methods for conducting the SNS assessment

YEAR THREE:

- Conduct SNS assessment and publish findings
- Implement case study validations of the SNS assessment in selected countries or parts of countries, to help identify future research needs and other actions – show what can and cannot yet be done in terms of characterizing SNS

Appendix 1. Work-Plan, Timeline and Next Steps Schematic

Next Steps: Development and Execution of a Sustainable Nutrition Security Assessment