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Rethinking Food Security in Mexico: Discussing the Need for Sustainable Transversal Policies Linking Food Production and Food Consumption

Repensar la seguridad alimentaria en México:discutir la necesidad de políticas sustentables transversales vinculadas con la producción y el consumo de alimentos

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Abstract. Two of the biggest challenges of humanity are to achieve global food security by reducing environmental impacts, and provide healthy diets for all people. In this paper, we discuss the complexity involved in designing solutions on food security. We focus on Mexico due to the heterogeneity of the country in relation to socioeconomic, cultural and ecological factors. First, we discuss the need to analyze food security by integrating the sustainability of both food production and food consumption. Then we describe the Mexican situation by analyzing five food production-consumption systems that illustrate the diversity of agricultural systems and dietary patterns. This analysis reveals that the pathway to achieve food security in Mexico should include sustainable food production systems and dietary patterns. The solution should be site-specific considering the ecological, socioeconomic and cultural situation, so an integrative geographical perspective is needed with a bottom-up approach; in this way, food security for future generation will not be compromised. To reach this, transversal policies involving the agricultural, health, environmental and federal agencies are required.

Keywords: Food Security; Mexico; Sustainability; Agriculture; Dietary patterns; Nutrition.

Resumen. Uno de los mayores desafíos de la humanidad es alcanzar la seguridad alimentaria global reduciendo los impactos ambientales y alcanzado dietas sanas para todas las personas. En este artículo, hacemos una reflexión sobre la complejidad de diseñar soluciones para la seguridad alimentaria. Nos enfocamos en México por su heterogeneidad en relación a factores socioeconómicos, culturales y ecológicos. Primero, discutimos la necesidad de analizar la seguridad alimentaria integrando la sustentabilidad de la producción y consume de alimento. Luego, describimos la situación de México al analizar cinco sistemas de producción-consumo de alimento que ilustran la diversidad de sistemas agrícolas y patrones alimenticios de México. Con este análisis demostramos que el camino para alcanzar la seguridad alimentaria debe incluir tanto un sistema productivo sustentable como una dieta sustentable. La solución debe ser sitio-específica considerando la situación socioeconómica, cultural y ecológica.; por lo que se necesita una perspectiva integral geográfica con un enfoque "bottom-up". De esta manera, no se comprometerá la seguridad alimentaria de futuras generaciones. Para esto, se necesitas políticas transversales entre las instancias/agencias gubernamentales agrícolas, salud y ambientales federales.

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Palabras clave: seguridad alimentaria, sustentabilidad, agricultura, patrones dietéticos, nutrición.

INTRODUCTION

Recent literature has shown the urgency to address global food security by reducing environmental impacts and achieving healthy diets for all people (Davids et al. 2016, Foley et al. 2011, Godfray et al. 2010a, Godfray et al. 2010b, Godfray et al. 2014). The current use of natural resources for human consumption is reaching the planetary limits, with global food production as a major driver (Rockström et al. 2009). In the coming decades, the global population will increase in both numbers and affluence. This means that there will be more people with a more luxurious food consumption, so more resources will be demanded. Rich diets have a higher environmental impact, as affluent diets that are rich in animal food products require more resources per person than basic diets (Kastner et al. 2012, Hoekstra et al. 2012, Leach et al. 2012, Ranganathan et al. 2016, Shibata et al. 2016). Diets are changing faster in developing countries due to the rapid urbanization, increased socioeconomic development, retail food services and fast food (Kearney 2010).

A large proportion of the global population does not have access to a healthy diet, even though global *per-capita* food consumption has increased in the past decades (FAO 2013). Malnutrition is still a current issue, and fighting hunger is FAO's main target since some 800 million people are currently undernourished worldwide (FAO et al. 2015). Today's rapid changes in the diet in developing countries are not improving nutrition. Obesity more than doubled at a global level since 1980, and nowadays almost 2 billion people are overweight (WHO 2016), resulting in serious chronic diseases (FAO, 2016). Obesity is a global epidemic and, in many countries, it is taking over malnutrition.

Thus, global food security involves two major complex issues: the large resource use and environmental impact related to food production, and the nutritional status of the global population. Several studies have shown that food security should be addressed from both the production and the consumption spheres; for example, changing production systems to a more sustainable production and shifting diets to lower meat consumption (Foley 2011, Ranganathan et al. 2016, Davids et al. 2016, Godfray etal 2010a/b, Godfray etal. 2014). These studies stress the need to implement integrated policies to solve the issue. However, global solutions should be tailored for each particular country, due to the marked differences between countries in terms of the socioeconomic, political, cultural and environmental circumstances.

The Mexican Context as Study Case

Mexico is a novel country to look at when addressing food security. It is one of the transition countries where the diet of its inhabitants is evolving at a fast pace due to urbanization and the increase in income (Rivera et al. 2004). Furthermore, the current status of the food system shows complex and diverse issues in both agricultural production and food consumption. As regards agricultural production, there is a large diversity in agricultural practices that translates into an heterogeneous productivity and the various environmental issues related to it. The reasons are complex and involve socioeconomic, agro-climatic and cultural conditions. Mexico is a megadiverse country that offers optimal conditions for a number of crop types (Sarukhan et al. 2010). The socioeconomic situation of farmers ranges from low-income small producers with small-scale farms and low use of agricultural inputs, to high-income producers with large-scale farms and a substantial use of inputs. For instance, according to the 2007 National Census of Agriculture, 50% of farmers engaged in maize corn production had less than 1.5 hectares per farmer (INEGI, 2007). These farmers produced less than 10% of the total maize production in Mexico, with very low crop yields. In contrast, large-scale maize producers (which own more than 10 ha per farmer) represent a mere 4% of all farmers engaged in maize production. These large-scale farmers produced 50% of the total maize production in Mexico, with very high crop yields (INEGI, 2007). The technologies used by each farmer are also widely diverse, resulting in contrasting productivities and environmental problems. For instance, in relation with irrigation, in a national average in 2014, maize production using irrigation reached crop yields of 8 tonnes per hectare in contrast with 2.3 tonnes per hectares with rain-fed maize production (SIAP, 2016). Consequently, irrigated systems involve a considerable consumption of water and a low use of land per kilogram of crop produced, relative to rain-fed agriculture. This illustrates the important trade-offs between the different production systems in terms of use of agricultural inputs.

On the other hand, there are marked differences in food consumption patterns throughout the Mexican population leading to diverse nutritional issues. Only 14% of the Mexican population have no nutritional health issues; the rest suffers malnutrition, overweight or other nutritional disorders (Castillo Negrete, 2013). Malnutrition has improved in the last decades; however, it is still a serious problem in many sectors of the population. Child malnutrition reaches 7% in urban areas and 14% in the rural population (UNICEF, 2016). In addition, obesity and overweight are becoming a threat to the Health System (Secretaría de Salud, 2013). In 2012, almost two thirds of the Mexican population older than 20 years and one third of school children (5-11 years) were either overweight or obese (ENSANUT, 2012). The root causes of the nutritional issues are complex given the socioeconomic, demographic and cultural situation of the population. In the late twentieth century, the opening of trade borders between Mexico and the USA led to a rapid shift in the national food supply, introducing processed food that boosted the diabetes epidemic (Castillo Negrete, 2013). Furthermore, the rapid urbanization has contributed to the increased overweight issues in the Mexican population, since it is linked to a sedentary life and an increased consumption of fast food and processed food products (Kearney, 2010). Navarro-Meza et al. (2014) show the difference in food consumption between the rural and urban population in the state of Jalisco, Mexico, where the urban population has a larger consumption of fat-rich food. Additionally, the socioeconomic status has a large impact on the dietary pattern. The poor sector of the population shows a low intake of animal food products, vegetable oils, sugar and fruits (Martínez Jasso et al., 2003).

This complex situation in both agricultural production and nutrition throughout the country points to the urgency to solve the food-security issue for the Mexican population within an integrated geographic framework. Society demands natural resources (land, water, nutrients) to produce food in agricultural systems. On the one hand, the type of food demand leads to nutritional issues related to socioeconomic and cultural factors. On the other, the type of production entails environmental and social costs. Usually, the demand for food (urban areas) is spatially away from food-production sites (agricultural systems). Geography is the ideal approach to understand the interrelationships among these social, economic and environmental factors at different spatial and temporal scales.

The aim of this paper is to illustrate that the analysis of food security in Mexico requires, first, understanding the specific cultural, socioeconomic and environmental context, and, second, the integration of food production and consumption. In this paper, i) the concept of food security is discussed in the context of Mexico, ii) food production-food consumption scenarios are laid out, which illustrate the diversity of food production and consumption schemes in Mexico. Then, the sustainability of each scenario (environmental, economic and social costs of production and consumption) is analyzed, and iii) alternative scenarios to achieve food security in Mexico are discussed.

MEXICAN FOOD SECURITY FRAMEWORK

Food Security

The United Nations Food and Agricultural Organizations (FAO) defines Food Security as follows *"Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (World Food Summit 1996)* (FAO 2008). This definition focuses on increasing food production and/or food availability to achieve food security.

There are two concerns about this definition. First, even though FAO acknowledges the need for sustainable food production (FAO, 1996), the definition of food security fails to address both sustainable food production and consumption, and consequently, food availability for the next generation. As Loos *et al.* (2014) state, "the food system should be resilient to assure food production for future generations." Second, we believe that in some cases food preferences should not be included in the definition of food security, especially if these preferences include food items not required for a healthy diet and involve the use of large amounts of natural resources and external inputs (such as land, pesticides, irrigation and fertilizers). An example is the recent shift of affluent consumption toward a "western diet" in many developing countries. There is a controversy between food preferences for cultural reasons (which should be included in food security) and food preferences due to globalization. This topic should be discussed in detail in further research. For this paper, we assume that the rapid evolution to an affluent consumption due to urbanization and globalization should not be considered as a cultural food preference.

For these two concerns, we define food security as follows: "*Access (physical and economic) to sufficient and nutritious food for all people at all times for present and future generations*". Similar to the FAO definition, ours would imply that the four dimensions of food security have to be fulfilled: food availability in the country (food production and food stocks), access to food (both physical and economic) at the household level, nutritional level (diversity of food, good care and preparation of food, and intra-household distribution), and stability (food availability for all periods of time) (FAO 2008). In addition to the FAO definition, we add *"for this and next generation"*, which would imply that the food system should be stable and resilient -- not only food production, but also consumption. Therefore, we emphasise the indirect link |among production (agriculture) and consumption (diets). We define the production-consumption system of food which should be analysed together to assess food security (Figure1).

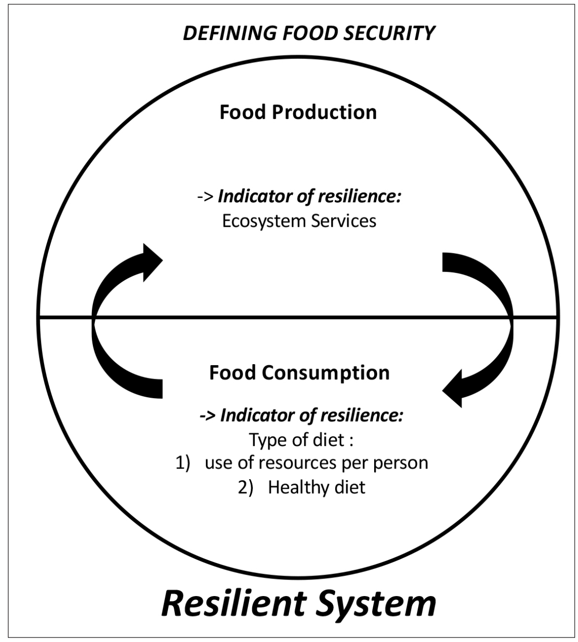

Figure 1. Definition of food security used in this paper. Food Security has to include both food production and food consumption, and by definition both of these have to be resilient not to compromise food production and availability for future generations. See text for details.

Figure 2 shows the factors crop production, food chain and food consumption that involve food security (in green), as well as the factors that do not lead to food security, such as consumption of non-essential food items (sodas, etc.), biofuels, and animal food products that are not needed for a nutritious diet, and food losses which could be avoided.

Although agricultural ecosystems can provide a wide set of benefits to man, the management of agricultural production systems is governed primarily by food production. Agricultural systems are a source of provisioning, regulation and cultural services the so-called ecosystem services (ES), while at the same time depend highly on them in order to function (Power, 2010). Furthermore, certain agricultural management practices greatly impact service-producing ecosystems, as is the case of intensive farming or intensified food production (Power, 2010). Therefore, the production system should be stable and resilient, especially given the

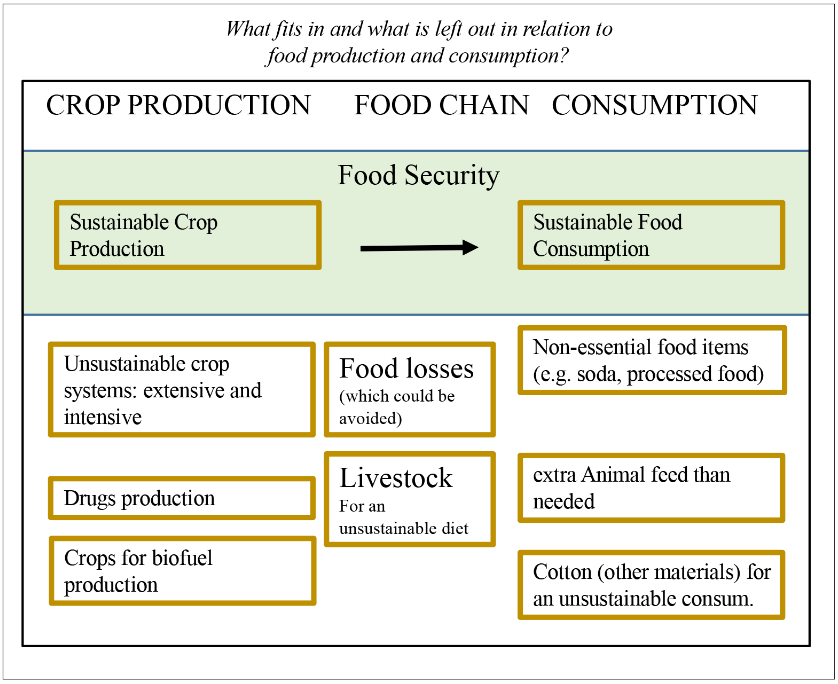

Figure 2. Definition of Food security for the context of Mexico

global and local changes in climate, socioeconomic changes and globalization. A stable, resilient and sustainable food production system should provide the greatest variety of ecosystem services (Power 2010): production, cultural, regulation and support services. Due to the marked differences in agro-climatic conditions in Mexico, production systems will highly divert throughout the country. Each site should identify which management system and crops are the best suited to the local agroclimatic, socioeconomic and cultural conditions.

Not only sustainable food production is needed; sustainable food consumption is also essential. We define sustainable food consumption as a healthy and nutritious diet requiring the least resources possible to produce food. This type of consumption would eliminate malnutrition and obesity issues across the country. Therefore, sufficient macro- and micronutrients for a healthy life should be included in the diet, and, in contrast, non-essential food items -- salty snacks, sodas, meat that is not necessary for a healthy diet -- should not be included in the diet. Furthermore, agricultural resource requirements should be at the lowest possible; therefore, footprint analysis is needed to calculate the requirements of land (Kastner et al. 2012), water (Hoeskstra et al. 2012) and other agricultural inputs such as nitrogen (Leach et al. 2012; Shibata et al. 2016). Agricultural resources (land, water, nutrients, energy) used for the production of non-essential food items should be avoided. In this way, the use of resources under a sustainable food consumption scenario will reduce the total use of resources by the Mexican population, hence increasing the resilience of the national food system.

Figure 2 shows several aspects of the agricultural system which are outside the definition of food production, i.e. the production of non-food items such as biofuels and drugs, which competes with the production of food crops. Whether the production of biofuels should be considered as a sustainable fuel is controversial, given the strong competition with food (Rathmann et al. 2010, Tilman et al. 2009). In Mexico, biofuel production has been subsidised by the government through several programs. For instance, the 2009-2012 National Program for the Production of Sustainable Fuel (SAGARPA 2009) promoted the production of five main crops: jatropha, "higuerilla", sugar cane, sugar beet and sweet sorghum. Furthermore, the amount of arable land in Mexico used for illegal drug production is unknown, yet it is clearly competing with food production. This is a sensitive issue due to the legality and (political) power of drug producers. Nonetheless, any discussion on food security and the need of arable land requires to consider drug production.

Thus, this framework shows that food security, by definition, is sustainable for including both sustainable food production and sustainable food consumption. A sustainable production for an unsustainable and unsustainable production diet does not lead to food security.

As regards government food security programs, policies and strategies in Mexico, the Secretariat of Agriculture, Livestock, Rural Development, Fisheries and Food (SAGARPA) developed, in collaboration with the FAO, the Strategic Project for Food Security (PESA) (SAGARPA 2015). This project focuses on improving sustainable food security in extremely poor rural areas by providing goods and services. However, PESA does not address food security in urban areas or for the rest of the Mexican population. Another program is the "Sustainable Modernization of Traditional Agriculture program" (MasAgro: masagro.mx), developed by SAGARPA in collaboration with the International Maize and Wheat Improvement Centre (CIMMYT). This program focuses on improving stability and profitability of maize and wheat crop yields.

In relation with other instances, the Development Plan of the current government (Peña Nieto 2013) points to the need to have an indicator of "food insecurity" measuring access to quantity and quality food. This indicator addresses the extremely poor population, focusing on solving malnutrition only, but neglecting other nutritional issues such as overweight and obesity, which are currently more prevailing nutritional health problems. As regards obesity, in 2013 the federal government, in collaboration with the Secretariat of Health and other Secretariats and Commissions, developed the National Strategy for the Prevention of Obesity, overweight and Diabetes (Secretaria de Salud 2013). This strategy focuses on food consumption to raise awareness and promote changes in eating habits, as well as on the health system to improve medical care. In this strategy, SAGARPA is one of the collaborators, though its task is neither strong nor a pillar for the strategy. SAGARPA's role is to support self-sufficient farmers (*campesinos*), increase subsidies to poor producers, and promote urban gardens.

This review shows that food security is one of the priority topics in the agenda of the Mexican government. Several governmental agencies (Agriculture, Health, Federal) are managing this topic, but they do it separately, with no coordination between them, which results in not linking issues and solutions that are indirectly connected.

Crop Production Systems and Ecosystem Services

We have identified four types of production systems that illustrate the spectrum of crop production systems throughout the country. For each system we have identified their main ecosystem services, described below. Ecosystem services are classified based on their type, as follows: production, support, regulation and cultural services (Power 2010). Production services refer to the productivity of the agroecosystem based on the crop yield obtained. Support services refer to soil retention, carbon storage, humidification and nutrient supply. Regulation services refer to air, water and soil quality, pest control, biodiversity and pollinators. Cultural services refer to recreation, education, wellbeing, cultural heritage, native crops conservation, job sources.

A) **Extensive Traditional Systems**: small produces, low/no external inputs, low crop yields, mismanagement practices: soil depletion, erosion, deforestation. López-Ridaura et al. (2002) have shown that this type of system is characterized by higher soil erosion, higher risks, and lower crop yields than an innovative system such as the *milpa* system discussed below.

B) **Agroecological Systems: the *milpa* system:** small producers, low-input systems, traditional management practices to avoid soil depletion and erosion, local inputs (Bermeo et al. 2014, López-Ridaura 2002). It combines several crops to increase resilience and food diversity for self-sufficiency of producers (Aguilar et al. 2003).

C) **Intensive/Industrial Systems**: large producers (agribusiness) monocultures, high-input systems, large use of energy, local pollution (eutrophication, air, soil), GHG emissions. Pimentel (2009) has shown the differences in the use of inputs and productivity between extensive and intensive production systems in developed and developing countries. Similar to these examples, intensive systems do exist in Mexico, which involve a large use of external agricultural inputs.

D) **Organic Agriculture**: small producers, ecolabelling needed, local organic inputs, low crop yields, good management practices (Gómez Cruz 2007). Nowadays, only 5% of the organic agriculture produced in Mexico is consumed within the country, the rest is exported. The main products grown under organic agriculture are (CNPO, 2017) coffee (48%), avocado (15%), green vegetables (9%) and herbs (8%); maize only represents 3000 ha.

Dietary Patterns and Nutrition

We have identified five dietary patterns that illustrate the Mexican spectrum of food consumption patterns. Several drivers determine the type of consumption, such as demographic situation (urban-rural), socioeconomic condition (mean *per-capita* income) and cultural context. The type of consumption and the main drivers are described below.

A. **Poor Rural Diet**: The population lives in conditions of extreme poverty conditions in rural areas, and malnutrition is prevalent (Pelcastre-Villafuerte et al. 2006). The main food items are tortilla, beans and chili, and occasionally eggs, meat and seasonal fruit. The head of the family either works in agriculture or migrates to urban areas to get temporary jobs to earn some money.

B. **Traditional Mexican *Milpa* Diet**: Nutritious healthy diet based on food crops produced in the *milpa* system: maize, beans, courgette and chili, with occasional consumption of other food items such as animal food products (Almaguer González et al. 2016). It is common in rural areas where families have their own *milpa* to produce their food. Persons consuming this diet are frequently poor, but not under extreme poverty. They do not usually suffer nutritional disorders.

C. **Transition urban diet**: The population is commonly low/middle-income class. The diet consists mainly in the consumption of high-energy food products, sugar-rich food (sodas), salty and fat-rich products and abundant animal fats, and a low consumption of fruits and vegetables. This type of food consumption coupled with the sedentary life of the urban population results in nutritional disorders such as obesity and overweight. To define this food pattern, we used the study of Navarro-Meza et al. (2014), who compared the food consumption of rural vs urban population (belonging to a low socioeconomic level, since the population only had primary education). Navarro-Meza et al. (2014) reported that this sector of the urban population showed a higher consumption of fats and sugars.

D. **Rich urban diet**: The population is commonly middle-high income class. In contrast with the transition urban diet, this portion of the population consumes high-quality animal food products (e.g. beef meat) combined with a higher amount of vegetables and fruits, and does not have nutritional health issues. (Martinez-Jasso 2003).

E. **Organic diet**: This is a new trend in the consumption pattern of the urban middle-high income class. It is based on organic food products to achieve a healthy diet in response to the nutritional issues associated to the urban lifestyle worldwide. It is a

Table 1. Ecosystem services provided by the four agricultural production systems selected

	Production	Support	Regulation	Cultural
Extensive System	Low crop yield	Low	Low	Moderate
Milpa System	Low crop yield	High	High	High
Industrial System	High crop yield	low	Low	Low
Organic Agriculture	Low crop yield	high	High	High

nutritious consumption based on a high amount of cereals, legumes, nuts, vegetables and fruits, and a low consumption of animal food products. Organic food products should have an eco-label to target this market. Some of the food products in this category are imported. This food pattern is new in Mexico, being stronger in other countries, the consumption of organic food in Mexico is on the rise as a result of the international influence.

Relevance of Production Systems and Diets in Mexico

The production systems and diets described above are not evenly distributed throughout the country (systems) and the population (diets). Table 3 gives an indication of the relevance of each system and diet in Mexico.

We combined the *milpa* and extensive systems because doing so facilitates the identification of the differences with local case studies of the resilience of the system and the non-production ecosystem services (support, regulation and cultural): the *milpa* system has higher ecosystem services relative to the extensive system.

We have used the size of the agricultural producer (cropland area) to identify extensive/*milpa* and intensive systems. We considered that extensive/*milpa* systems are small (i.e. less than 1.5 hectares) and, in contrast, intensive systems have more than 10 hectares. According to the 2007 National Agricultural-Livestock Census 2007 (INEGI, 2007), only 8% of the total cropland area in Mexico was managed by small producers (less than 1.5 hectares), and 58% of the cropland

Table 2. Main drivers/characteristics of the 5 diets selected

	Demographic	Socioeconomic Status	Nutrition
Poor rural diet	Rural	Poor	Malnutrition
Milpa diet	Rural	Poor	Healthy
Transition urban diet	Urban	Poor-middle	Obesity/Overweight
Rich urban diet	Urban	Middle-rich	Moderately healthy
Organic diet	Urban	Rich	Healthy

Table 3. Production system and diet in Mexico

Production systems

	Demographic	Socioeconomic Status	Nutrition
Harvested area	1.7 Mha	13 Mha	0.4 Mha
(ha of cropland and % of total Mexican cropland)	8%	58%	0.3%

Diets

	Poor rural diet[4]	Milpa diet[5]	Transition urban diet[6]	Rich urban diet[7]	Organic diet[8]
Population[9]	8.8 million	8 million	51 million	11.7 million	Less than 1 million
	7.4%	6.7%	43%	10%	>1%

Source of data: [1]Crop producers with less than 1.5 ha of cropland, INEGI (2007) [2]Crop producers with more than 10 ha of cropland, INEGI (2007) [3]CNPO (2017) [4]Rural population with "low access to food", CONEVAL (2012) [5] We assumed that the people consuming this diet are maize producers owning less than 1.5 hectares and includes 6 family members, data from INEGI (2007) [6]Urban population with overweight issues: 70% of people older than 20 years, and 35% of people younger than 20 years old, ENSANUT (2016) [8] Assumption by the authors [9] Total Mexican population in 2010: 117.9 million; urban: 91.71 million, rural: 26.19 million (CONEVAL, 2012).

area was managed by large producers (more than 10 hectares). However, the number of agricultural producers and the total production of each system does not follow the same trend. For instance, for maize production (the most important crop for agriculture and food security in Mexico), 50% of producers are small, suggesting a "campesino" lifestyle and *milpa* production system, but they grew only 8% of the total maize production in only 12% of the cropland. In contrast, large producers represent only 4% of all producers and contribute with 50% of total maize production in 40% of the total maize cropland area (own calculations from INEGI, 2007). Organic production systems in Mexico have been increasing vigorously in the last decades: the production area has undergone a 20% increase in the last decades (CNPO,2017). Today it represents a mere 0.3% of Mexico's total cropland area (CNPO, 2017).

In relation to diets, the most common diet in the Mexican population is the transition urban diet (43% of the population). The inhabitants consuming this diet are persons who have overweight disorders in urban areas, and account for 70% of the urban population older than 20 years and 35% of the urban population younger than 20 years. The rich urban diet is difficult to identify because there is no clear indicator associated with it, in contrast with the other diets (malnutrition, overweight or lifestyle) (peasants with milpa systems). We assumed that the 10% richest sector of the population shows this food pattern, and lives mostly in urban areas. In the case of the poor rural diet, we assumed that people consuming it have "low access to food" in rural areas (CONEVAL, 2012), and includes 8.8 million people. For the *milpa* diet, we assumed that maize producers with less than 1.5 hectares of crop land show this food pattern, and that each producer has 6 family members (8 million people). In relation to the organic diet, no data are available on the relevance of this dietary pattern in Mexico, as it is a new trend; we assumed that less than 1 million people consume this diet. Note that the percentage of each diet type does not add to 100% because some production systems and diets in between them are not considered (e.g., agricultural producers with cropland area between 1.5-10 hectares and population with poor urban diets).

Linking food production and consumption: 5 scenarios and their sustainability

The five types of dietary patterns described above (section 2.3) are commonly associated with certain types of production systems as described above (section 2.2). We have related these dietary patterns to the production systems to describe 5 scenarios for the food systems currently in Mexico. This makes possible to evaluate the sustainability of these five scenarios to discuss potential strategies to achieve food security in Mexico. The analysis is discussed in the text below and illustrated in Figure 3. Each sustainability pillar (economical, environmental and social) of both food production and consumption is analysed. We discuss below whether the combination of these 3 characteristics lead to resilient production and consumption systems for future generations.

The discussion of each sustainability pillar is based on the following characteristics (Table 4). The environmental factors associated with crop production would imply local environmental issues derived from the production system: pollution, erosion, and soil degradation. The indicators of this impact are the support, regulation and production ecosystem services. The economic factors of crop production refer to the production costs for producers: access to inputs, subsidies and labels to target a certain market niche (e.g. eco-label). The social factors of crop production refer to the cultural importance of production to the farmer OR the health implications for the producer when using certain inputs such as herbicides.

The environmental factor of food consumption refers to the *per-capita* use of resources according to the type of diet. Several studies have shown that affluent diets with large consumption of animal food products consume more resources than staple diets (Hoekstra et al. 2012, Kastner et al 2012, Leach et al 2012, Shibata et al 2016). We discuss this factor based on the consumption of animal food products in the diet. The economic factor of food consumption refers to the economic access to food products: the costs for the consumer. The

Table 4. Defining the 3 sustainability pillars for crop production and food consumption

	Environmental	Economic	Social
Crop Production	Local impact of the production systems: use of resources per kilogram produced, pollution (Support, regulation and production Ecosystem Services)	Cost for the producer, access to inputs and subsidies, access to eco-labels (cost for the producer)	Cultural importance for the producer (cultural heritage and traditional knowledge)
Food consumption	Use of resources per person: the type of diet determines que requirements of resources (footprint studies)	Economic access to food products: costs for the consumer	Health: nutrition of the consumer (malnutrition, obesity)

indicator is food price. The social factor of food consumption is related to the nutrition status of the consumer, i.e. whether or not the food pattern is leading to nutritional issues such as malnutrition, obesity or overweight.

The first scenario represents the typical situation of extremely poor rural population. It is a local system where production and consumption occur in the same place. Local families may or may not own agricultural land, which they use for self-sufficiency and sometimes yield a surplus to generate income. The costs of crop production are low since no external inputs are used. However, due to mismanagement practices, severe land degradation occurs compromising production for future generations. Therefore, this production system is not resilient. From the consumption side, the food pattern seems resilient in economic and environ-

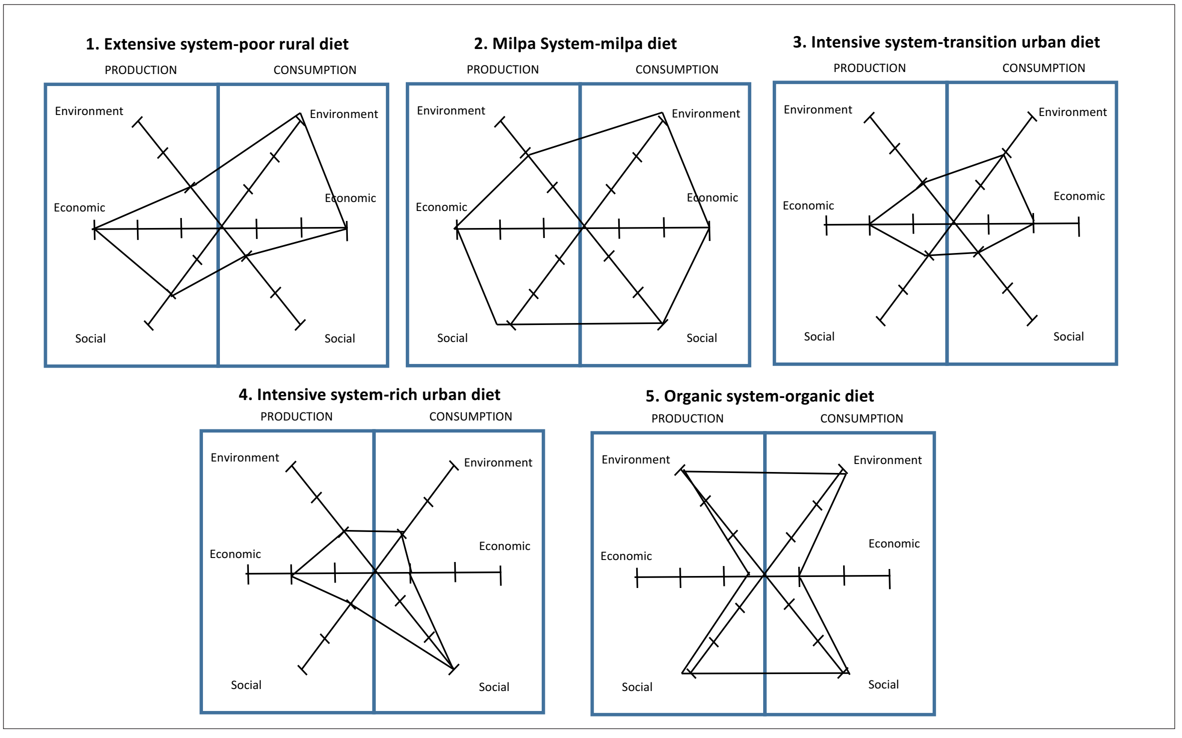

Figure 3. Five scenarios of the current Mexican food system. Each graph illustrates the sustainability of both production and consumption based on the definitions in Table 4.

mental terms, given the low cost for consumers due to the self-sufficiency of the system and the low use of resources per person. However, malnutrition is common in this consumption system; therefore, the whole consumption system is not resilient due to health issues.

The second rural scenario is similar to the one just described, but it does not involve extreme poverty. Two major differences exist between them. First, there are no issues derived from management practices, leading to a low incidence of environmental problems and high support, regulating and cultural ecosystem services, all of which are important for producers. Second, the consumption pattern is more diversified, resulting in a healthy diet with no malnutrition. All these characteristics result in a resilient system.

The third and fourth scenarios represent typical situations of food production for urban populations. Production takes place in highly intensive systems with high input costs, resulting in high crop yields. However, this system involves high environmental impacts such as pollution, GHG emissions, and health issues for producers due to use of herbicides and insecticides. The amount of food produced is high; however, the system is not resilient given the high environmental issues which compromise production for future generations (high risks of harvest failure). The production-consumption system is not local, and a large amount of energy is used for transportation, storage, food processing and cooling. Consumption under the third scenario is unsustainable due to the health issues (obesity) and middle amount of resource use (due to large/middle consumption of animal food products). Consumption under the fourth scenario involves a higher diversity of food items (vegetables and fruits) and a lower consumption of fats, which altogether results in a healthy diet. However, due to the large *per-capita* use of resources (high amounts of affluent food items: animal food products, vegetable oils), consumption is not resilient for future generations because it compromises resource availability for food production due to the large *per-capita* requirements.

Finally, the fifth scenario represents a new urban trend in food consumption, with food produced under organic agriculture. The system resembles scenario two in environmental and social terms in that the system is extensive and involves good management practices, while the diet is healthy and requires low amount of resources due to the low consumption of animal food products. However, reaching the market requires production to be certified (eco-label). This involves high costs for the producer. Therefore, although some producers included in scenarios 1 and 2 actually produce organic items, they cannot enter this urban market niche without a label. In addition, costs for consumers are high due to the label and because some food products are imported. So, this system is not resilient either due to the high economic costs. Furthermore, the system may involve high energy costs if food products are imported. This will depend on the source of food products and on how they were produced. Further analysis is needed to identify energy costs.

To conclude, Figure 3 shows that the most resilient production-consumption system is scenario 2 due to the low risks associated with agricultural production (resulting in a resilient production system), low costs for both consumers and producers, low *per-capita* resources (diet), healthy diet and cultural importance of the production system. However, to discuss whether this scenario can provide effective food security, it should be assessed this system could be extrapolated to the urban population. This gives rise to the following questions that should be addressed in detail in further research: Is there enough land to produce food for the whole Mexican population under a *milpa* system? Would this system preserve its resilience if expanded to produce the food required to meet the needs of the whole Mexican population? What are the barriers (social, economic) to modify the dietary patterns to adopt the *milpa* diet?

DISCUSSION

Pathways to Achieve Food Security

A review of the government programs and strategies reveals that food security is an urgent topic in Mexico (section 2.1).However, the government is not taking immediate measures to link solutions to the nutritional issues (malnutrition and obesity) to solutions associated with food production, both in a sustainable way to ensure food security for the future. The recent report of the Commission on Sustainable Agriculture and Climate Change (Beddington et al. 2012) states that to achieve long-term national food security, it is essential to incorporate food security and sustainable agriculture into national policies, reshape diets into healthy and sustainable food patterns, and reduce environmental issues. We propose that the pathway to integrate the food production and consumption sustainability is through transversal public policies which integrate decision-making forums and associated agricultural resources; this would ensure that agriculture, food security and nutrition programs and policies involve all the Mexican population (Figure 4).

A transversal policy should be coordinated by an agency working along with different "action fields" agencies. Diet is a key driver to health, use of agricultural resources, and local environmental and social impacts. Strategic links should be established between the different policy stakeholders (Olivier et al., 2010). For example, food (diets and nutrition) should be the cornerstone of public policy(e.g. the Mexican Secretariat of Health), focused on i) achieving good nutrition levels for all Mexicans, ii) improving food availability and affordability (quantity and quality) for all Mexicans at all times; iii) protecting vulnerable populations from poverty-related food insecurity and malnutrition, as well as from the perpetuation of acute food insecurity and malnutrition associated with frequent and recurring emergencies, and the critical interrelations between these phenomena. Then, several agencies should be linked to it working as action fields in charge of developing strategies aiming to 1. support sustainable agricultural systems (e.g. the Secretariat of Agriculture, SAGARPA); 2. assess the environmental impacts of these systems (e.g. the Secretariat of Environment and Natural Resources, SEMARNAT); 3. promote changes in food consumption patterns (e.g. Secretariats of Education and of Finances: SHCP, SEP). The transversal policy should balance nutrition, agricultural production, environmental and social

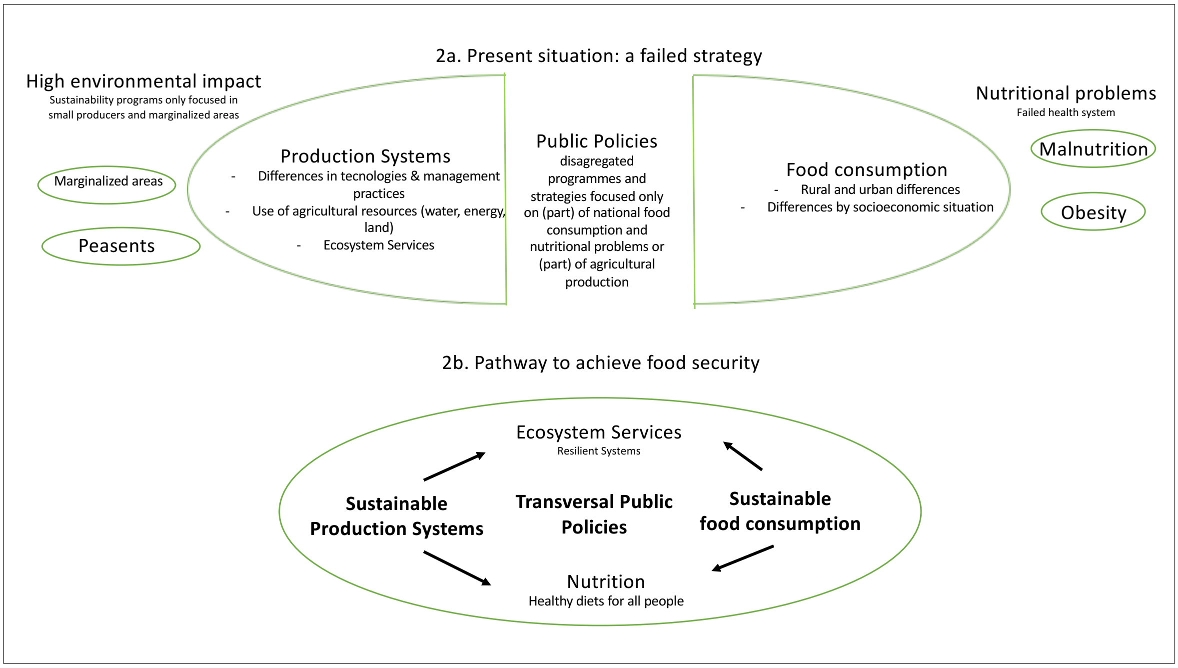

Figure 4. Theoretical framework: food security in Mexico. 2a. Current status: a failed strategy 2b. Pathway to achieve food security.

costs; these issues include designing these policies and identifying mechanisms to reach at sustainable solutions regarding food security at a national level. It is essential to consider: 1. the ecosystem services associated with production systems (Table 1) to reduce the environmental impacts of agriculture and increase the resilience of production systems; 2. the nutritional status of the population, to reach healthy diets; 3. the sustainability of food patterns, to reduce the *per-capita* environmental impact.

In order to identify the production-consumption system and reach food security, a more detailed analysis is needed, similar to the analysis in section 2.4. For production systems, due to the ecological heterogeneity of the country, an analysis of the ecosystem services for each region should be conducted considering the specific agro-climatic and socioeconomic context in each region. Most important, the system has to be resilient. As regards consumption patterns, diets such as the *milpa* diet (section 2.3), which involves a low consumption of animal products and a diversity of nutritious food, is the ideal combination to reach a healthy diet under a low *per-capita* use of resources.

A sustainable agricultural system in Mexico is a need to ensure a safe and high-quality supply of agricultural products, and safeguard the livelihood and well-being of farmers and their families. This should involve the collaboration between the government and food companies, ensuring consistency between policies focused on agriculture, health, nutrition, biodiversity and climate change.

Furthermore, agricultural systems producing cash crops for exports and no-food crops such as biofuels and fibres should not be considered in the production-consumption system for food security (figure 2). A careful and detail analysis is needed to consider the national trade-offs between these goods and food, as well as the competition for land between them. Crops for livestock feed are indirect , although inefficient, food sources,: in general, 10 protein units from a crop are needed to produce one protein unit of animal origin (Smil 2001). Therefore, diets rich in animal products are considered unsustainable. In our approach, the sustainability of feed crops is addressed from the consumption end, by switching to diets with low-animal food products. In this way, the demand of feed-crops will be reduced.

The Mexican example used in this paper has shown that the interactions between society (nutrition and food consumption patterns) and nature (agro-climatic and ecosystem services) are essential for the design of the most sustainable strategy to achieve food security. This national strategy should be based on the combination of local and national perspectives.Hence, a bottom-up approach is needed. This analysis can only be performed from an integrated geographical perspective. Thus, the challenge to achieve food security is enormous and complex, and therefore the solutions should also be complex as well as long-term and transversal.

Challenges for Reaching a Sustainable Pattern

The change to a sustainable food pattern involves surpassing both cultural and economic barriers. The transition to an urban affluent diet in recent decades has been influenced by the "western consumption pattern" associated with a higher socioeconomic status. Unfortunately, this diet involves a large environmental impact due to its large consumption of animal products, and its reduction could be perceived as a the result of a lower socioeconomic status. In contrast, the new food pattern, the "organic diet", is not perceived as a low-status diet, although it is generally associated with vegetarian consumption and, therefore, with a low consumption of animal products. However, the costs of organic food products are high and they can be an economic barrier for consumers to choose this dietary pattern.

In contrast, the *milpa* diet involves both low costs of food products and a low environmental impact because of the low consumption of animal products, but it involves the perception of a low socioeconomic status pointing to a "peasant-like" ("*campesino*") consumption pattern. A recent study (Ibarrola-Rivas et al.2017) can be used to discuss the potential of the *milpa* diet to attain national food security. The study shows that the diet of the richest 10% of the population (large consumption of animal products) requires 80% more land than the diet of the poorest 10% of the population, who consume a a *milpa*-like diet.

In 2050, assuming all population adopts the rich diet, all Mexican arable land would have to reach the crop yields of intensive systems (with high environmental impacts). In contrast, if all people changes to the basic diet, then it would be possible to produce all food in low-crop yield systems with low environmental impacts (Ibarrola-Rivas et al., 2017). Again, this illustrates that the *milpa* diet could be a solution for reaching food security in Mexico. The challenge of the transversal policy would be to overcome this cultural barrier and promote the benefits for the consumer: preserve a Mexican tradition and a healthy diet (with the lowering of the risks associated with overweight), lower the costs of food products. and reduce the environmental impacts. Some studies have shown that integrated strategies can lead to a shif in the diet (Ranaganathan et al., 2016).

The Need for Further Research

This paper has illustrated the current situation and the potential strategies and challenges to reach sustainable food security in Mexico. Further studies are needed to map the heterogeneity of the country, mainly along two lines: 1.evaluation of the ecosystem services related to agriculture, to quantify the sustainability of agricultural systems; 2. evaluation of the environmental impact of the Mexican diets to link food production and consumption. These types of studies are not currently available for the diversity of diets and production systems in Mexico. These types of studies would make possible the design of the transversal policies needed to reach a sustainable future. This paper is the starting point of a research line leading to a systematic and integral evaluation of food security in Mexico.

CONCLUSION

In order to achieve food security in Mexico, an integrated assessment is needed including the sustainability of both food production and food consumption. This would make possible to design an integrated national strategy to achieve National Food Security; this adaptation process will require the engagement of the various stakeholders and sectors. Transversal policies are needed to implement this strategy involving health, agricultural, economic and federal instances to propose a feasible national solution to reach food security for all people. It is essential to incorporate a geographical approach to consider the Mexican heterogeneity in terms of the socioeconomic, agro-climatic, cultural and political contexts to identify the specific route to achieve food security. Therefore, a national strategy should be designed through a bottom-up approach including strategies for reforming agriculture and food systems, biofuels, agricultural policies and trade, food aid, land tenure, financing, farm insurance and alternative agriculture.

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