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Implications of urbanization, consumer awareness, and income trends on future food supplies in Senegal

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INTRODUCTION

While there is general agreement that our food systems are failing us (Global Panel 2016; Béné et al. 2019a; von Braun et al. 2021), different perspectives exist on the exact nature of this failure. Béné et al. (2019a) identify four main narratives, which can be summarized as the system's inability to feed future populations with healthy diets in a socially just and environmentally sustainable way. At the same time, food systems are undergoing rapid and structural changes at an ever-increasing pace (von Braun et al. 2021). "Traditional" food systems were mainly local with short supply chains between smallholder farmers and local markets, where basic staples were sold with little value addition. In contrast, "modern" food systems range from local to global, with possibly longer supply chains connecting industrial food producers, processors, and retailers, while serving international markets and supermarkets with a wide variety of unprocessed and processed foods (Ericksen 2008).

Apart from attenuating or neutral effects, most of the ongoing and future drivers affecting the functioning of food systems carry multiple risks that could aggravate the degree of failure (von Braun et al. 2021). For example, the expected growth in household incomes will increase overall demand for food (including more nutritious and animal-source foods), which will not only widen the yield and nutrient gaps of current food production but will also increase its environmental footprint. Likewise, the intensification and homogenization of agricultural production may certainly help to feed a growing population, but will contribute to a deterioration of soils and agroecological conditions (Béné et al. 2019b).

Confronted with this extending failure and culminating in the UN Food Systems Summit (UNFSS), a broad coalition of national governments, international organizations, civil society, the private sector, and scholars embarked on the ambitious agenda of transforming today's food systems (von Braun et al. 2021). This resulted in a call for paradigm shifts (Ruben et al. 2021), the expansion of food security frameworks from four to six pillars (Clapp et al. 2022), and the development of new definitions and food system frameworks to better understand, in a holistic and integrated manner, the multiple nonlinear linkages between drivers, activities, and outcomes to be able to assess trade-offs and inform policy design (Béné et al. 2019b; David-Benz et al. 2022; Ericksen 2008; FAO 2018; FS-TIP 2021; Global Panel 2016; HLPE 2017; Ingram 2011; Lawrence et al. 2015; Njuki et al. 2022; Pinstrup-Andersen and Watson 2011; Sobal, Kettel Khan, and Bisogni 1998; von Braun et al. 2021).

Compared to the energy and creativity surrounding the development and advocacy of new concepts and frameworks, concrete empirical applications that fully align with these insights remain rare. This observation stems from the lack of both high-quality data and related tools. Indeed, in many low- and middle-income countries (LMICs), data on several food system components are unreliable, irregular, anecdotal, or simply missing. This especially relates to the more hidden midstream segments of the agrifood supply chain (Reardon, Liverpool-Tasie, and Minten 2021), the informal nature of LMIC economies, including their cross-border trade (Gaarder, Luke, and Sommer 2021; Bouët, Cissé, and Traoré 2020), the estimation of food losses and waste (Delgado, Schuster, and Torero 2023), and various aspects shaping food environments where consumers procure their food (Downs et al. 2020). This said, several initiatives at global and local level have been undertaken or are underway to help fill this data gap, such as the food system dashboard (FSD) developed by the Global Alliance for Improved Nutrition and Johns Hopkins University (Fanzo et al. 2020) and the compilation of an informal cross-border trade database for West Africa (Bouët et al. 2021). Similarly, scholars and development practitioners struggle with genuine operationalization of the food system approach, which combines the critical features of comprehensiveness, nonlinearity, and interconnectivity. Apart from developing entirely new approaches, some existing tools have the potential to be reassembled or redesigned as tools for food system analysis, such as the Rural Investment and Policy Analysis (RIAPA) data and modeling system and the spatial food and nutrition security (FNS) typologies, both developed by IFPRI (International Food Policy Research Institute) researchers.[1]

This research report aims to identify major food supply implications and potential entry points for a more efficient, nutritious, sustainable, and equitable transformation of Senegal's food system. Inspecting key indicators from the FSD,[2] Senegal's food system is indeed failing to provide healthy diets to the population in an inclusive and sustainable manner. For example, total food supplies are estimated to be energy-insufficient (below 2,500 kilocalories (kcal) per capita per day in 2013), lacking diversity (especially in terms of fruit and pulses, with supplies of only 53 and 15 grams (g) per capita per day in 2019, respectively), and potentially threatening soil biodiversity. Therefore, it is unsurprising to observe that 46 percent of the population in 2020 was unable to afford a healthy diet and 49 percent was moderately or severely food insecure. This is also reflected in the poor performance of dietary indicators for infants and children, as well as the high anemia prevalence in women.

Contrary to this straightforward assessment, it is less clear what food system transformation should precisely look like in terms of required volumes and composition of food supplies, and how current and expected trends of urbanization, consumer awareness, and income will affect future food demand. Inspired by Brouwer et al. (2021) and constrained by the data and information available, this report on strategic knowledge generation of macro trends in Senegal's food system development adopts a healthy diet perspective. This "reverse thinking" focuses first on innovations and strategies at the individual level and in food environments to motivate consumers to make more heathy food choices, which in turn should stimulate the supply of corresponding food items upstream. To operationalize this logic, we make use of a representative household food consumption dataset from 2017/18, a recently developed and more precise global healthy diet specification (Beal, Ortenzi, and Fanzo 2023), and a series of three compounding simulations related to changing demographics (including increased urbanization), consumer awareness, and income growth. Conditional upon the accuracy of these simulations, we study the required changes in Senegal's food supply by 2040 to close the yield and nutrient gaps for a healthy diet, while providing entry points for and identifying challenges to a more inclusive and environmentally sustainable functioning of the country's food system.

DATA AND METHODS

The secondary data used for this analysis are compiled from several modules of the 2017/18 *PAPA* (Agricultural Policy Support Project) survey, implemented as part of a collaborative United States Agency for International Development-funded research project between a network of Senegalese researchers, Michigan State University (MSU), and IFPRI.[3] The food consumption data of this survey cover more than 200,000 individual transactions by 2,231 urban households in 2017 and 4,338 rural households in 2018 on more than 100 different food items that were bought (90 percent), consumed from own production (9 percent), or received in kind (1 percent), using a recall period of seven days.[4] Following the survey sampling design, the data are spatially representative of the urban and rural areas in each of the country's 14 regions.[5]

Given the number of missing and outlier observations related to direct declarations, food quantities are indirectly obtained by converting all monetary outlays into their corresponding metric weight using a matrix of standardized regional food prices. Making use of eight aggregate food groups (cereals, legumes and nuts, vegetables and tubers/roots, fruit, meat and fish, dairy, oil, and sugar products),[6] these food quantities are then used to draw diet profiles for urban and rural residents. To derive associated nutrient profiles, the metric quantities of each household diet are expressed into their corresponding food components using the United Nations Food and Agriculture Organization's (FAO) West African Food Composition Table (FCT), the latter of which allows to account for inedible food portions (Stadlmayr et al. 2012).[7] The food components considered in this analysis are calories, protein, calcium, iron, zinc, folate, vitamin B12, and vitamin A. To assess nutrient adequacy, an Adult Male Equivalence (AME) scale is computed for each food component based on recommended intake levels by age and sex, as defined by FAO/World Health Organization (WHO)/United Nations University (UNU) Joint Panels (FAO 2001; WHO 2004, 2007).[8]

Based on the following three socioeconomic drivers of food demand, we build several scenarios to study their impact on nutrient adequacy and examine future food supply implications.

The first driver, population growth, is estimated using data from the 2002 and 2013 national population and housing census (ANSD 2008, 2014). More specifically, we first derive intercensus region- and area-specific growth rates to estimate the population distribution in Senegal in 2040.[9] The following equation summarizes this linear projection of population growth.

$$pop_{r,a}^{2040} = pop_{r,a}^{2013} \left(\frac{pop_{r,a}^{2013}}{pop_{r,a}^{2002}} \right)^{27/11}$$

for each region $r = 1 \ldots 11$, and area $a = \{\text{urban, rural}\}$, where pop^{2013} and pop^{2002} refer to the total population obtained from the respective national census data, and pop^{2040} is the estimated population size of 2040.

The corresponding simulation pursued in this study then concerns the volume and composition of food demanded by the estimated population of 2040. In operational terms, the simulation involves a proportional adaptation of the population sampling weights associated with the PAPA survey. This linear extrapolation, although geographically sensitive, does not account for any substantial real or administrative fluctuation that may have occurred between or after the last census, for example a large influx of people following a crisis or conflict, or a political decision to relabel certain areas as urban or rural.

The second driver, increased consumer awareness, is simulated by reprojecting current food purchasing power over the same eight food groups, so that the resulting diet composition reflects the weight proportions of Beal, Ortenzi, and Fanzo's (2023) hypothetical micronutrient adequate diet (hereafter called the BHMA diet).[10] Lacking information and compared to the previous simulation, which was based on observed demographic changes, this simulation takes a much more normative stance in that it assumes that people are fully aware of the need to consume healthy diets. Table 1 presents the composition of the BHMA diet, aggregated from the original 30 food groups into the eight key food groups previously identified. Despite the corresponding loss in precision, this aggregation is an operational condition used to perform the optimization; that is, to be able to find enough observations in each food group across most households.

Table 1: Beal, Ortenzi, and Fanzo's hypothetical micronutrient adequate diet

Food group	Daily macronutrient intake (g)	Daily caloric intake (kcal)	Weight share	Energy share
Cereals	239	400	15.1%	18.0%
Legumes & nuts	113	286	7.1%	12.8%
Vegetables & tubers	432	278	27.3%	12.5%
Fruit	222	126	14.0%	5.7%
Meat & fish	258	414	16.3%	18.6%
Dairy	239	153	15.1%	6.9%
Oil	30	120	1.9%	5.4%
Sugar	51	450	3.2%	20.2%
Total	1584	2227	100.0%	100.0%

Source: Beal, Ortenzi, and Fanzo (2023).

For each household, this simulation then involves solving a system of eight equations with eight unknown food group expenditures (E_1 to E_8).

$$\begin{cases} E_1 + E_2 + E_3 + E_4 + E_5 + E_6 + E_7 + E_8 = Y_F \\ (E_i/p_i)/(E_1/p_1 + E_2/p_2 + E_3/p_3 + E_4/p_4 + E_5/p_5 + E_6/p_6 + E_7/p_7 + E_8/p_8) = BHMA_i \end{cases}$$

for all i = 1...7, where Y_F is the total food budget, p_1 *to* p_8 are the implicit metric food group prices observed for each individual household, and $BHMA_i$ are the weight shares derived in Table 1.

Within each food group, the same expenditure shares are maintained as initially observed for the individual food items. As a result, the simulation indicates what a more nutritious diet could look like for each household using current budget constraints, while aligning with observed preferences in terms of individual food items within each food group. Aggregated over all households, it shows the total volume and composition of food demanded by nutritionally aware consumers. It should be noted, however, that nutrient adequacy of the resulting diets is not necessarily guaranteed, not only due to the loss in precision when aggregating diet requirements from 30 to 8 food groups, but also to possibly suboptimal choices made within these same food groups. In addition, this simulation is only based on a reallocation of current food budgets to match the relative weight proportions of each food group in the healthy diet, which of course offers no guarantee that absolute intakes are sufficient (see next driver). Despite these shortcomings, this optimization approach provides for a contextual translation of an international reference diet to any specific setting.

The third driver, increased incomes, is simulated by increasing the total daily food portion size to exactly 1,584 g, which is needed to reach micronutrient adequacy following Beal, Ortenzi, and Fanzo's (2023) calculations. In line with Engel's Law, the simulated increase is only applied to those with a current food portion below 1,584 g per day, leaving those with higher total food intakes unaffected. Again, this simulation adopts a rather normative viewpoint in that it assumes that incomes in Senegal will sufficiently increase and/or that food prices will sufficiently decrease such that all people are able to afford a fully nutritious diet. The corresponding simulation of this driver involves the total volume and composition of food demanded by households whose income increases to a certain nonidentified level, taking into account differences in income elasticities for food and nonfood goods, to allow for a daily food budget to cover the cost of a fully healthy diet weighing 1,584 g. Implicitly, the approach assumes that poor people will take up more equitable, productive, and thus remunerative positions in future food systems. Based on estimations from an ongoing project, called AgroEco-2050, implemented by ISRA-BAME (Institut sénégalais de recherches agricoles-Bureau d'analyses macro-économiques), CIRAD (French Agricultural Research Centre for International Development), and FAO, the latter assumption is most likely to be met when a fully agroecological vision is adopted for Senegal's agriculture sector by 2050. In such case, higher agricultural incomes will profit twice as many people compared to an intensification fully based on an agroindustrial model (Prudhomme et al. 2023).

Based on the above simulation for each driver, Table 2 develops and summarizes the following three scenarios:

Table 2: Drivers, simulations, and scenarios

	Driver 1: Population growth	Driver 2: Increased consumer awareness	Driver 3: Income growth
Simulation	Volume/composition of food demanded by 2040 population	Volume/composition of food demanded by nutrition-aware consumers	Volume/composition of food demanded by income-secure consumers
Description	Based on extrapolation of spatially specific intercensus growth rates to 2040	Based on scaling of current food preferences to reflect the weight proportions of the BHMA diet	Based on implicit income growth to guarantee a daily food budget to access the BHMA diet
Scenario 1	Included	Excluded	Excluded
Scenario 2	Included	Included	Excluded
Scenario 3	Included	Included	Included

Source: Author's compilation.

Scenario 1 considers only the simulation related to population growth; that is, a continuation of past demographic trends using the region- and area-specific growth rates. Scenario 2 builds on the first one but adds the simulation on increased consumer awareness, approached by a scaling of current food preferences to reach the weight proportions of the BHMA diet. Scenario 3 again considers the previous one but adds the simulation on progressive income growth to the analysis, thus assuring that all people have access to the BHMA diet. This last compounding scenario roughly indicates the types of food and corresponding quantities likely to be demanded by the Senegalese population in 2040, if (i) current demographic trends continue, (ii) nutrition awareness campaigns are successful, and (iii) people's overall living standards improve. It is important to highlight that most attention in this report is devoted to Scenario 3, which combines the three simulations, while only providing key insights for Scenarios 1 and 2.

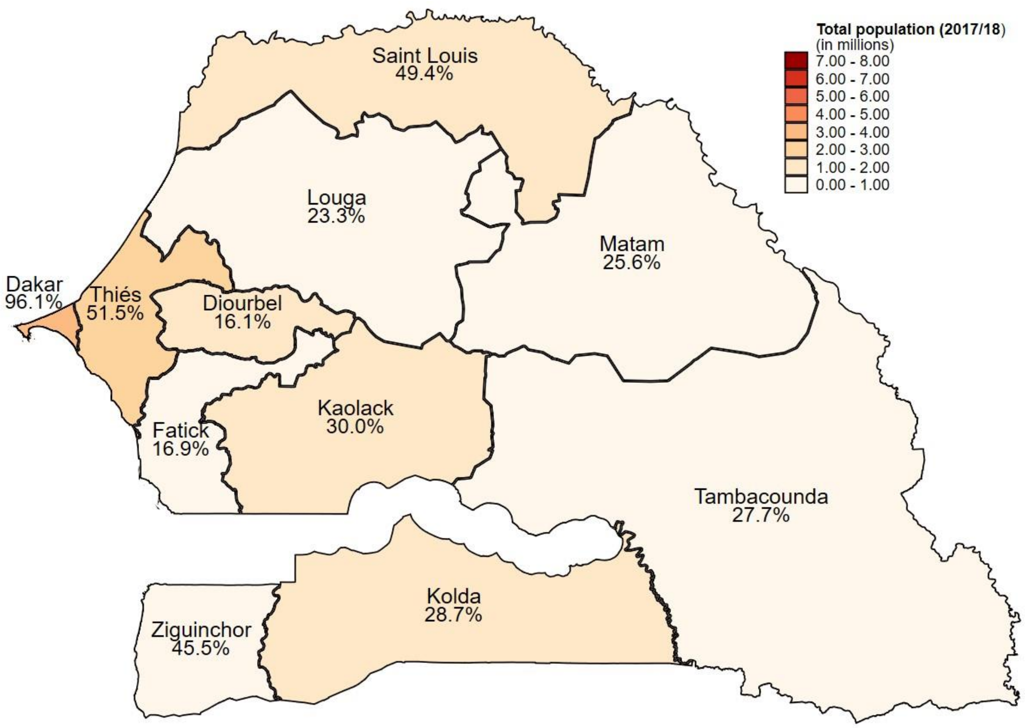
To identify potential entry points for sustainable and equitable transformation, food demand profiles are derived for the baseline and Scenario 3, with special attention to various food groups, their origin of production (import, national or local production), and their level of processing (processed or unprocessed). Most of this profiling information stems from the item descriptions linked to the predefined food list within the PAPA food consumption module.[11] These profiles will be important to guide future investments in transport, storage, cooling, and processing capacity, while pointing to import substitution opportunities and environmental concerns.

RESULTS

Baseline 2017/18

In 2017/18, when the PAPA survey was implemented, Senegal had an estimated population of 15.7 million, of which almost one-quarter lived in the Dakar region. The second most populated region was Thiés, located east of Senegal's capital city. Both regions also display the highest urbanization rates: 96.1 percent for Dakar and 51.5 percent for Thiés. Following Figure 1, which shows the demographic profile of Senegal, one can roughly state that regions located farther from Dakar are on average less populated and less urbanized. However, a few exceptions exist. For example, the region of Saint-Louis in the northernmost part of Senegal is also relatively populated and urbanized, while the region of Fatick, despite its proximity to Dakar, is rather scarcely populated and far from urbanized.

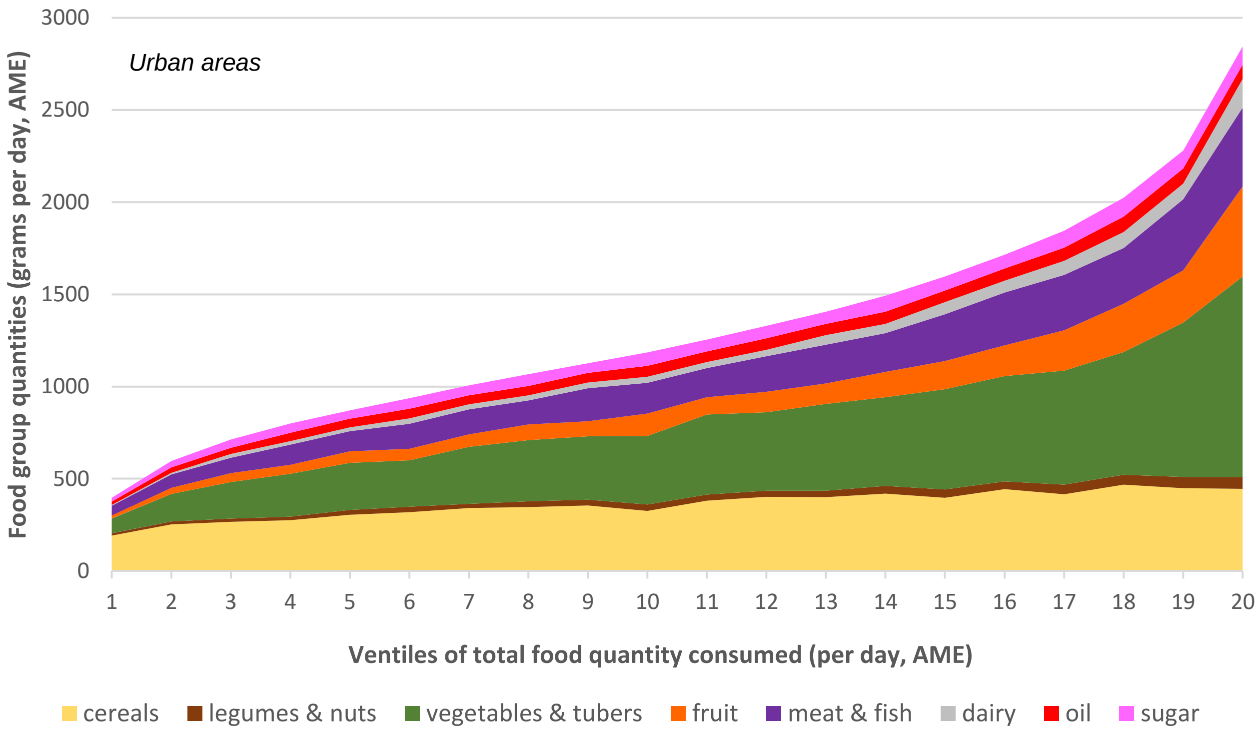
Figure 1: Population distribution and urbanization rate, Senegal (2017/18)

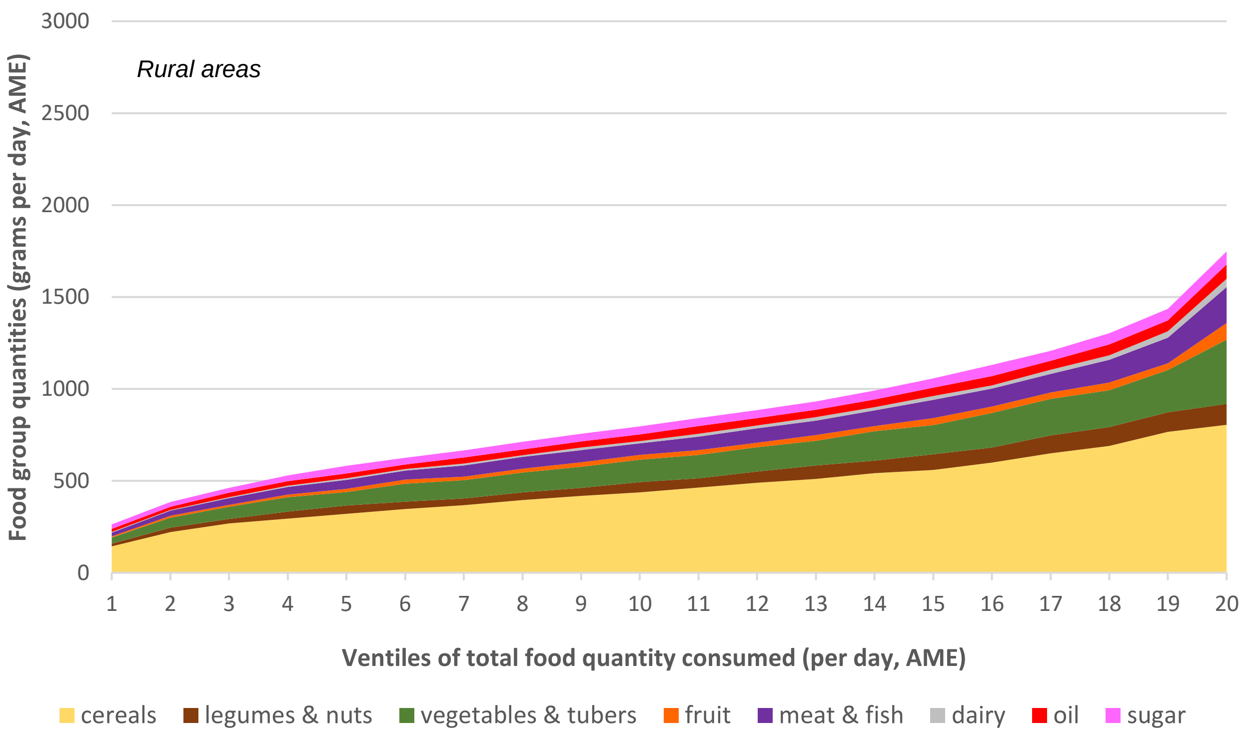


Note: Urbanization rates for each region are displayed as a percentage on the map.
Source: Author's depiction using RGPH (*Recensement Général de la Population et de l'Habitat*) census data (2002 and 2013).

Expressed in daily metric quantities, Figure 2 displays for increasing levels of total food intake the average diet profile along the eight key food groups observed in urban and rural areas. As such, it depicts for both areas the main sources of food and their corresponding absolute weights from the smallest to the biggest total food portion. Most salient is the sharp difference in total food quantity consumed in each area: on average, an urban meal appears to be roughly twice as big as a rural meal. In addition to quantity, the urban diet appears more diversified, especially when total portion size increases. Whereas cereal consumption in urban areas largely remains stable, the intake of vegetables and tubers, meat and fish, and fruit gradually increases with increasing levels of food intake. In rural areas, diet diversification is much less pronounced, with higher food intake merely resulting in eating more cereals, while the consumption of items from other food groups increases only marginally.

Figure 2: Diet composition by food group and total portion size, Senegal (2017/18)





Source: Author's analyses using PAPA survey data (2017/18).

Table 3 presents the nutritional outcome of the urban and rural diet profiles by listing the adequacy levels for food energy, protein, and six key micronutrients. Overall, Senegal is clearly suffering from hidden hunger, resulting from an inadequate intake of micronutrients. Indeed, compared to calories and protein, where Senegalese households on average consume at least three-quarters of what is recommended, micronutrient deficiencies are much more problematic. In urban areas, consumption adequacies barely amount to 57 percent for zinc and folate and are as low as 40 percent (for vitamin B12), 30 percent (for iron), and 25 percent (for calcium) of recommended levels. Remarkably, vitamin A adequacy for urban families is much higher, with levels around 86 percent. Except for iron, where adequacy levels amount to 48 percent, as well as for zinc and folate, for which adequacy rates are roughly similar, rural families perform considerably worse for vitamin A (54 percent), vitamin B12 (18 percent), and calcium (18 percent) compared to their urban counterparts.

Table 3: Food energy and nutrient adequacy levels, Senegal (2017/18)

Food component	Urban	Rural	Total
Kilocalories	81.6%	76.1%	78.7%
Protein	88.4%	87.4%	87.9%
Calcium	25.3%	17.9%	21.4%
Iron	29.5%	47.9%	39.2%
Zinc	57.3%	57.5%	57.4%
Folate	56.6%	55.5%	56.0%
Vitamin B12	39.7%	17.8%	28.2%
Vitamin A	86.2%	53.5%	68.9%

Source: Author's analyses using PAPA survey data (2017/18).

Reinspecting Figure 2, calorie adequacy is only slightly lower in rural areas despite their much smaller food portions due to the dominance of energy-rich cereals in the rural diet. Likewise, protein adequacy is very similar across both areas, which results from a combination of relatively higher meat and fish consumption and lower intakes of pulses and cereals in urban areas, while the opposite is true in rural areas. The difference in calcium intake stems from the net difference in consumption of dairy products, which is slightly higher in urban compared to rural areas. Given that vitamin B12 is only found in animal products, the previous observations on meat, fish, and dairy consumption explain why nutrient adequacy for this vitamin is two times higher in urban compared to rural areas. Finally, the markedly higher vitamin A adequacy levels observed in cities relate directly to the higher share of vegetables and tubers and, to a lesser extent, (palm) oil.

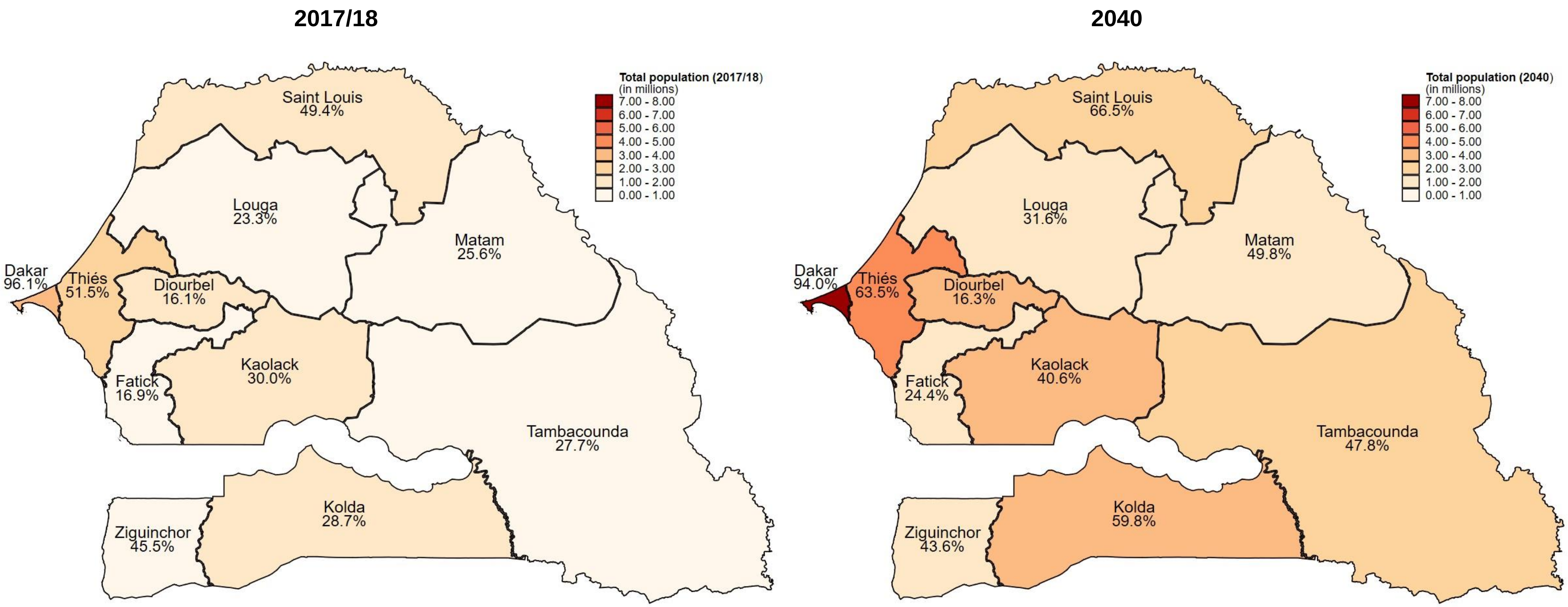
Three compounding scenarios of future food demand

Using the intercensus growth rates explained above, Figure 3 displays the major demographic trends to be expected between 2017/18 and 2040. Whereas the total population of Senegal will roughly double from 15.7 million to 32.1 million people over the period considered, the urban subpopulation is likely to increase faster (by a factor of 2.5), while the rural subpopulation is expected to increase by a factor of 1.7. This increasing urbanization will be most pronounced in the regions of Kolda and Matam, where the share of the urban population is likely to double in the next 22 years. A similar observation, but to a lesser extent, applies to the urban areas of Tambacounda and Saint-Louis, which are expected to grow significantly faster than their rural areas.

In contrast, the urbanization rates of Dakar, Ziguinchor, and Diourbel will remain roughly stable, which is evident for the capital city but somewhat surprising for the other two regions, where important and dynamic cities are located. The stagnant urbanization rate of Diourbel is very peculiar in this respect since the religious city of Touba (located in Diourbel) is considered to be the second largest in the country. In May and June 2023, Senegal implemented its fifth general population and housing census (RGPH-5). These new census data, when they become available, will allow us to not only update the region- and area-specific growth rates and related demographic trends in general, but also to check and verify particular observations.

Regarding future food demand, a doubling of the total population will require that total food supplies roughly double as well, despite some nuances in their exact composition linked to differences in diet preferences across locations. Given the increasing rates of urbanization throughout most of the country, the increased food supplies should come from proportionally less populated but more productive rural areas. Apart from removing typical constraints to increase farmers' productivity, this observation may also imply the development of agricultural growth poles or other forms of increased specialization based on prevailing biophysical conditions, as well as an increased reliance of food imports. In addition, it is to be noted that the four regions with the highest jumps in urbanization rates (Kolda, Matam, Tambacounda, and Saint-Louis) are also the most peripheral areas of the country. For food to arrive to those more remote regions, additional investments in transport and storage infrastructure may be required.

Figure 3: Demographic trends, Senegal (2017/18 and 2040)



	2017/18	2040	Growth factor
Urban	7,422,628	18,418,204	2.5
Rural	8,264,175	13,658,701	1.7
Total	15,686,803	32,076,904	2.0

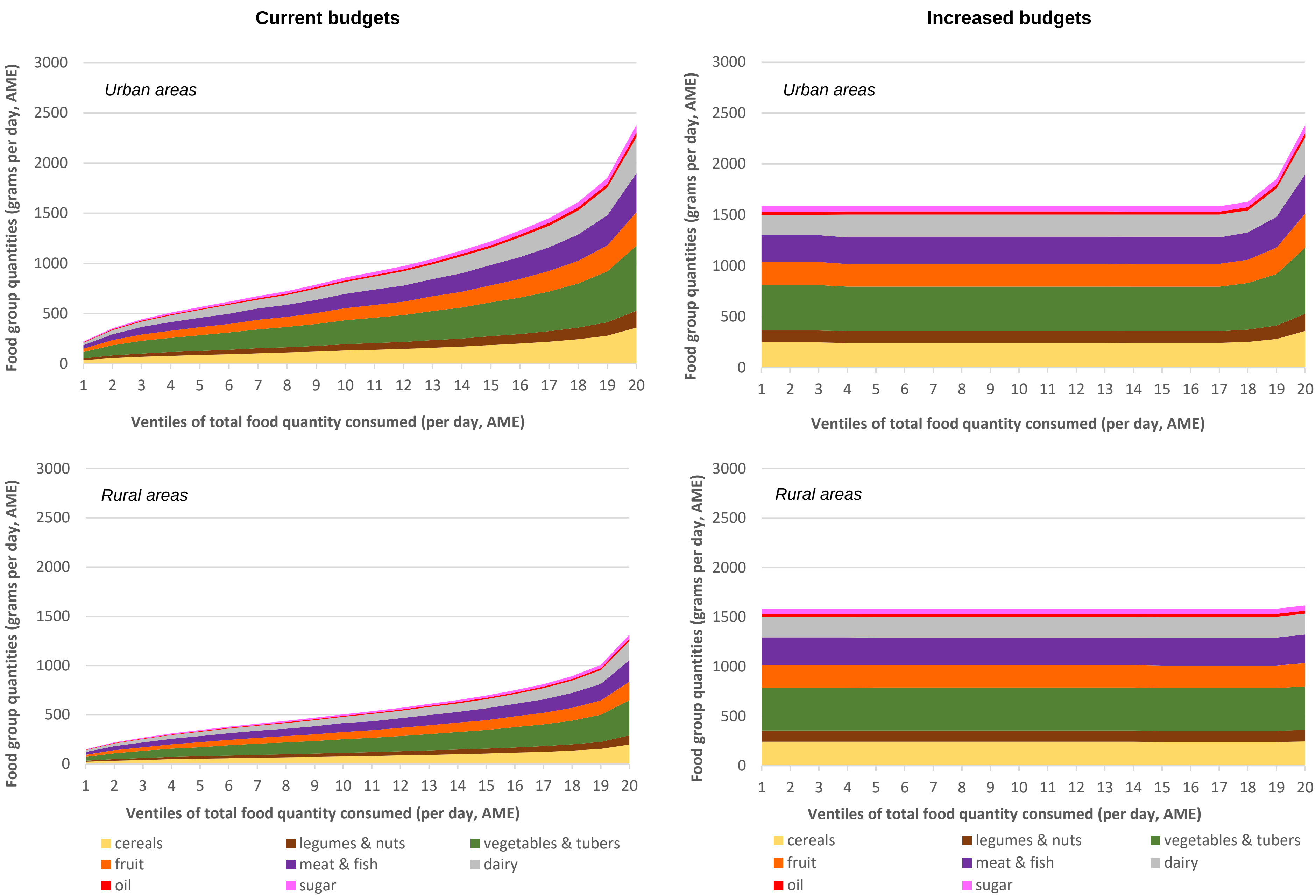
Note: Urbanization rates for each region are displayed as a percentage on the map.
Source: Author's analyses using RGPH census data (2002 and 2013).

Apart from changing demographics, consumer preferences are likely to change too. Given the multiple individual and societal benefits of healthy diets and the corresponding attention devoted by public actors,[12] Figure 4 displays daily food group quantities as reflected by the weight shares of the BHMA diet, for both urban and rural areas, for increasing levels of total food intake. Whereas the left-hand panels depict the absolute quantities based on current available food budgets (Scenario 2), the right-hand panels illustrate the diet composition when food budgets increase to a level allowing for a daily food intake of 1,584 g (Scenario 3). Comparing Figure 2 with the left-hand panels of Figure 4, we observe that shifting to a more balanced healthy diet under current budget constraints will lead to a marked reduction in total daily portion size. On average, this reduction amounts to 325 g in urban areas and 292 g in rural areas, mainly the result of more consumption of animal-based food items, which are on average more expensive, thus leaving less budget for other food groups. Therefore, this shift to healthier diets, irrespective of the quality of nutrition awareness campaigns, is unlikely to happen for most Senegalese if not accompanied by increased budgets, as reflected in the right-hand panels of Figure 4.

Moving from current diets to healthy diets (that is, from Figure 2 to Figure 4) mainly involves a substitution of cereals by animal-based food items. Whereas the relative consumption of cereals in urban areas on average should be almost halved (from 28 percent to 15 percent), the intake of dairy products should substantially increase. A similar but much more pronounced observation applies to rural populations: their relative intake of cereals should decrease from 55 percent to 15 percent on average, while corresponding intakes of dairy, meat, and fish should dramatically increase. In addition to animal-based food items, rural dwellers should consume relatively more fruit, vegetables, and tubers. To ensure not only that the right balance is found but also that the right absolute quantities of each food group are consumed, people's available food budget should substantially increase as well. This applies to virtually all Senegalese living in rural areas and to all but the 15 percent richest urban dwellers (that is, ventiles 1–17).

To ensure that all people in Senegal eat a healthy diet in both absolute and relative quantities, people's purchasing power of food must increase significantly, through higher incomes (especially of poorer households) and/or lower food prices (especially of items lacking in poor people's diets). To achieve this, Senegal's food system should become more equitable and efficient, so that poorer households can not only take up more remunerative positions in the food system but can also contribute to higher overall productivity levels. Considering the diet shift needed, future transformative policies should devote relatively less attention to the cereal subsector for human consumption, and more to the livestock, fishing, and horticulture subsectors. Given the perishable nature of products in the latter subsectors, these transformations may require corresponding investments in storage, cooling, and processing infrastructure to avoid decay and extend shelf life.

Figure 4: Diet composition of projected healthy diets with current and increased food budgets, Senegal (2040)



Source: Author's analyses using PAPA survey data (2017/18); RGPH census data (2002 and 2013).

Table 4 summarizes the impact on food energy and nutrient adequacy of the three compounding scenarios of urbanization, consumer awareness, and increased incomes. Relative to the baseline results discussed above, the adequacy rates under Scenario 1 are largely similar for individual urban and rural areas, which is evident given that the same PAPA survey data are used but with adjusted population sampling weights to reflect the demographic changes over the period considered. The very minor differences only stem from differences in performance and changing relative weights *within* each of the area types. The adequacy rates under Scenario 1 for both areas combined are slightly different from the baseline, however, and basically reflect the differential performance of urban compared to rural areas; that is, higher adequacies for calories, calcium, vitamin B12, and vitamin A, and lower adequacies for iron.

Moving from Scenario 1 to Scenario 2, in which people shift to a more balanced diet but without any increase of available food budget, the problem of hidden hunger becomes one of overall hunger. Indeed, due to the reduction in overall portion size, calorie and protein adequacies drop substantially, from 79 percent and 88 percent to 46 percent and 76 percent, respectively. Similar reductions in adequacy rates are observed for iron, zinc, and folate. In contrast, following the increased consumption of animal-based food items under Scenario 2, adequacy rates of calcium and vitamin B12 improve markedly, from 22 percent and 30 percent to 41 percent and 57 percent, respectively. In other words, advocating for a more balanced diet without sufficient resources being present in the household might not only be an unrealistic strategy but also a harmful one, despite deficiencies generally being more levelled out. The differential performance between urban and rural households largely stems from their different income levels.

Table 4: Impact on food energy and nutrient adequacy, Senegal (2017/18 and 2040)

Food component	Baseline			Scenario 1			Scenario 2			Scenario 3		
	Urban	**Rural**	**Total**	**Urban**	**Rural**	**Total**	**Urban**	**Rural**	**Total**	**Urban**	**Rural**	**Total**
Kilocalories	81.6%	76.1%	78.7%	81.6%	76.5%	79.4%	55.9%	32.9%	46.1%	96.2%	91.4%	94.2%
Protein	88.4%	87.4%	87.9%	88.7%	87.7%	88.2%	83.9%	66.0%	76.3%	99.5%	99.4%	99.5%
Calcium	25.3%	17.9%	21.4%	24.6%	17.9%	21.8%	48.1%	30.4%	40.5%	72.4%	65.2%	69.4%
Iron	29.5%	47.9%	39.2%	30.0%	48.3%	37.8%	21.9%	16.8%	19.7%	40.4%	50.4%	44.7%
Zinc	57.3%	57.5%	57.4%	57.3%	57.5%	57.4%	49.7%	29.6%	41.1%	87.2%	83.6%	85.7%
Folate	56.6%	55.5%	56.0%	56.1%	55.7%	55.9%	58.8%	38.0%	50.0%	93.7%	92.6%	93.3%
Vitamin B12	39.7%	17.8%	28.2%	38.6%	17.7%	29.7%	64.7%	45.8%	56.7%	84.1%	77.0%	81.1%
Vitamin A	86.2%	53.5%	68.9%	85.9%	52.9%	71.9%	84.7%	56.3%	72.6%	96.8%	89.8%	93.8%

Source: Author's analyses using PAPA survey data (2017/18); RGPH census data (2002 and 2013).

Shifting to Scenario 3, which assumes that all households can afford the BHMA diet, food energy and nutrient adequacy rates significantly improve across the board. Apart from calcium and iron, all adequacy rates for both areas combined are (well) above 80 percent. While the use of the BHMA diet leads to higher adequacy rates compared to the EAT-*Lancet* reference diet (Willett et al. 2019), it is no guarantee to reach full adequacy, which relates to the precise methodological setup of this exercise.[13] This said, Scenario 3 undoubtedly reflects better nutrition outcomes, which we use as a reference in the next section to identify the immediate implications on future food supplies as well as possible entry points for food system transformations.

Food supply implications and possible entry points

Table 5 indicates the required changes in today's food supply, expressed in total tons per year, to provide all Senegalese in 2040 with a healthy diet.

To be able to properly feed the entire Senegalese population in 2040, total food supplies should more than triple, from around 4.6 million to 15.3 million tons per year. Knowing that the total population will double and become more urbanized, this increase in food supplies will require a substantial increase in overall food system productivity. This observation aligns with the preliminary results of the AgroEco-2050 study mentioned above: maintaining current productivity levels while converting more land for agricultural purposes is not only environmentally unsustainable, but the corresponding agricultural output will also cover only 50 percent of total food needs (Prudhomme et al. 2023).

Taking 2 as a reference value (corresponding to a doubling of the population by 2040), the local production of cereals and legumes as well as the current supply of peanut and vegetal oil do not require any exceptional policy attention as long as their future supplies increase in line with expected demographic growth. Indeed, what is roughly needed is for total supplies of these food items to increase from 1.4 million tons to 2.8 million tons between 2017/18 and 2040. This means that if current policies related to the rice, millet, sorghum, cowpea, peanut, and vegetal oil subsectors are maintained, supplies in 2040 can be expected to be roughly adequate as part of future healthy diets. However, given that most local production takes place in particular areas of the country (for example, rice is typically grown in the Senegal River Valley and in the Casamance region, and legumes in the Peanut Basin), some attention should be devoted to the functioning of markets, distribution chains, and storage infrastructure. Luckily, since cereals and legumes typically leave the farm in dry condition, their transport over longer distances is less complicated compared to more perishable food items. The same remark applies to vegetal oil, which mainly involves imported soja and sunflower oil, coming in through the harbor of Dakar and which should find its way to different consumption centers in the country.

With required growth factors well below 2, the supplies of imported cereals and legumes, maize (one-half of which is imported), and sugar (mostly local production) should still increase, but at a much lower rate than expected by current population trends. Indeed, the total supplies of these food items should increase from roughly 1 million tons in 2017/18 to only 1.4 million tons per year in 2040, much less than the expected doubling of the population over the same period. This means that current policies covering these subsectors do not need to be particularly strengthened or even that some disengagement might be appropriate given that their future output will likely be more than sufficient to cover the corresponding needs of a healthy diet for all. Such disengagement might be less pronounced if a strategy of import substitution is pursued. In such instances, corresponding efforts should be put in place to accurately increase the local production of cereals, legumes, and maize beyond what is expected through current population growth. Similarly, given the self-sufficiency and high-yield status of sugar in Senegal, a more appropriate strategy might be to maintain or even increase overall production levels, not as a basic ingredient of a healthy diet, but rather to improve the country's terms of trade and bring in more hard currencies from increased exports. The policy implications suggested here deserve further investigation, especially given their interconnected nature, the level of uncertainty surrounding several food system drivers, and the country's priorities. This additional investigation falls outside the scope of this report, however.

Table 5: Required food supply changes between baseline and Scenario 3, Senegal (2017/18 and 2040)

Food type	Baseline			Scenario 3			Growth factor (Scenario 3/ baseline)
(tons/year)	**Urban**	**Rural**	**Total**	**Urban**	**Rural**	**Total**	**Total**
BELOW EXPECTED POPULATION GROWTH							
Cereals/legumes: import and pro-cessed	258,217	403,786	662,003	468,627	397,747	866,374	1.31
Maize: unprocessed	20,986	87,935	108,921	33,924	69,858	103,782	0.95
Maize: processed	34,228	45,174	79,402	63,652	38,086	101,738	1.28
Sugar	114,356	86,539	200,896	169,647	123,106	292,753	1.46
SUBTOTAL	427,788	623,435	1,051,222	735,850	628,798	1,364,648	1.30
AROUND EXPECTED POPULATION GROWTH							
Cereals/legumes: local and unpro-cessed	71,989	371,096	443,085	424,640	513,779	938,418	2.12
Cereals/legumes: local and processed	423,996	299,901	723,897	1,004,451	416,291	1,420,742	1.96
Peanut oil	18,585	49,458	68,043	37,538	101,308	138,846	2.04
Vegetal oil	99,346	37,964	137,310	199,862	76,111	275,972	2.01
SUBTOTAL	613,916	758,418	1,372,335	1,666,490	1,107,489	2,773,979	2.02
ABOVE EXPECTED POPULATION GROWTH							
Horticulture: local and unprocessed	913,548	337,037	1,250,585	3,153,118	2,442,976	5,596,094	4.47
Horticulture: local and processed	28,671	11,206	39,877	96,280	80,648	176,927	4.44
Horticulture: import and unprocessed	146,348	22,463	168,811	423,400	166,520	589,921	3.49
Horticulture: import and processed	2,819	0	2,819	9,581	0	9,581	3.40
Ruminants and pork	45,014	18,792	63,806	205,324	128,962	334,285	5.24
Poultry and eggs	61,856	12,800	74,657	249,020	111,946	360,965	4.84
Fish: unprocessed	200,162	111,292	311,454	690,278	676,707	1,366,986	4.39
Fish: processed	72,371	32,951	105,322	306,056	213,708	519,764	4.94
Dairy: unprocessed	7,631	14,286	21,917	59,730	131,315	191,045	8.72
Dairy: processed	76,713	21,646	98,360	1,163,719	717,914	1,881,634	19.13
Palm oil	16,769	12,521	29,291	50,723	31,857	82,579	2.82
SUBTOTAL	1,571,903	594,993	2,166,897	6,407,229	4,702,553	11,109,781	5.13
Other/undefined	0	5,509	5,509	0	8,178	8,178	1.48
TOTAL	2,613,607	1,982,355	4,595,962	8,809,569	6,447,017	15,256,586	3.32

Note: Given that the predefined food list of the PAPA consumption module allows to distinguish processed and unprocessed forms of maize, the latter cereal is excluded from the more general categories of cereals/legumes.
Source: Author's analyses using PAPA survey data (2017/18).

Compared to the previous food types discussed, future food supplies from the livestock (especially dairy), fish, and horticulture subsectors should dramatically increase. For processed dairy products, the current annual supplies of around 100,000 tons should increase 19-fold, to more than 1.8 million tons, to ensure that the Senegalese population has a sufficient intake by 2040. Similarly, unprocessed dairy (that is, fresh milk) should increase by almost a factor of 9, from around 22,000 tons to 191,000 tons. Table 6 presents a generic account of potential strategies to increase total cow milk production and meet the required dairy supply of 2 million tons per year by 2040. According to recent estimates by the Directorate of Analysis, Forecasting, and Agricultural Statistics (DAPSA), total cow milk production in 2020/21 was 120,000 tons, realized by around 500,000 dairy cows with an average yield rate of 0.232 tons/year/animal. This total milk production falls roughly within the same range as the total demand for dairy products estimated using the 2017/2018 PAPA survey, despite differences in years and product coverage. If no particular action is taken to strengthen the dairy subsector, then total milk production will accrue to around 181,000 tons per year with the natural reproduction rate of dairy cattle. This output will remain far below the required dairy supply of 2 million tons/year.

To close this gap, various strategies could be pursued, ranging from a focus on increasing total herd size, increasing the productivity of dairy cows, or a combination of both. Without any yield improvement, the number of dairy cattle should drastically increase to almost 9 million animals, which involves a multiplication by a factor of 11, in addition to the natural increment from 518,000 to 781,000 dairy cows between 2020/21 and 2040. In contrast, an exclusive focus on increasing productivity from the current yield rate of 0.232 to 2.654 tons/year/animal would be sufficient to reach the required dairy supply of 2 million tons/year in 2040, conditional on the natural increment of dairy cattle. This yield improvement could be pursued through improved breeding, feeding, veterinary, and other livestock practices. This targeted productivity rate of 2.654 tons/year/animal is slightly lower than the world average (2.749 tons/year/animal) observed between 2000 and 2022, and far below the technological frontier, as several countries (such as Israel, Saudi Arabia, the United States, and other highly developed countries) reach average levels above 10 tons/year/animal. Intermediate strategies involve a combination of herd size and yield increases (Table 6). For example, increasing productivity levels from 0.232 to 0.249, 0.360, 0.423, and 1.389 tons/year/animal, which correspond to the average yield rates observed in West Africa, Niger, Mauritania, and Sierra Leone, respectively, would gradually reduce the required increase in herd size from 8.3 million to 1.5 million dairy cows.

Table 6: Strategies to meet required dairy supply in Senegal by 2040

	2020/21	2040						
Strategy		**No action**	**Increase herd size**	**Increase yield rate**	**Combination of herd size and yield increases using different reference yield rates**			
Dairy cattle (number)	518,004	781,037 (natural)	8,938,061	781,037 (natural)	8,324,012	5,757,442	4,899,950	1,492,209
Yield rate (tons/year/animal)	0.232	0.232	0.232	2.654	0.249 (W. Africa)	0.360 (Niger)	0.423 (Mauritania)	1.389 (Sierra Leone)
Cow milk production (tons/year)	120,122	181,117	2,072,679	2,072,679	2,072,679	2,072,679	2,072,679	2,072,679

Note: Natural refers to the natural reproduction of dairy cattle as estimated based on FAOSTAT data using the average growth rate observed for Senegal between 2000 and 2022.

Source: Author’s analyses using the 2020–2021 Annual Agricultural Survey (EAA) (DAPSA 2021) for the most current dairy statistics of Senegal, and FAOSTAT for the dairy reproduction and yield rates of Senegal and other selected West African countries.

Although less pronounced but still far beyond what is expected by demographic growth, current supply levels of other animal-based food items (meat and fish) and horticultural products should on average increase by factors of 5 and 4, respectively (Table 5). The considerable increase in the required supply of animal-source foods is related not only to the high current deficiency rates observed for vitamin B12, calcium, and iron, but also because it is difficult to ensure a sufficient intake of these micronutrients based on other food items (Beal, Ortenzi, and Fanzo 2023).

Development of the livestock and fish subsectors poses various environmental challenges (especially in the Sahelian context), which relate to dwindling fertile land and fresh water resources as well as overfishing and declining biodiversity. In addition, when slaughtering an animal, milking a cow, goat, or sheep, or capturing fish, issues of perishability quickly kick in, which in turn requires adequate investments in storage infrastructure, cold chains, processing facilities, and/or quick transportation and distribution networks. Similar perishability concerns and mediating investments apply to the horticulture subsector (Merrey and Mukherji 2023). For the onion subsector, for example, loss rates of around 30 percent of total production are typically cited (David-Benz and Seck 2018). In addition, because current production of livestock, fish, and horticulture is very site-specific, the location of these investments should be well chosen to maximize overall cost-effectiveness and reduce travel times between production and consumption centers.[14]

More generally, environmental concerns will be key when designing future policies on agricultural intensification. A good starting point to guide these policies is the latest insights on seven major technological areas to increase productivity of the agrifood sector while reducing greenhouse gas emissions, improving natural ecosystems, and strengthening smallholder farmers' resilience (Mukherji et al. 2023). Although several of these technologies require extra research and development before they can be implemented in LMIC settings, the following four are more immediate approaches that can be adopted in the context of Senegal.

First, more attention should be paid to restoring and managing healthy soils to reverse current forms of land degradation. This objective could be pursued through integrated soil fertility management, combined with the 4R principles (using the right fertilizer, at the right time, in the right amount, and in the right place), agroecological techniques (such as increased use of organic fertilizer, reduced tillage, and legume intercropping), and salinity control practices (Sapkota et al. 2023; Sow et al. 2016).

Second, agroecological and other sustainable farming approaches should be adopted more widely to help transition to more sustainable food systems. In addition to the soil health management mentioned above, these approaches involve agroforestry, biodiversity conservation, and water harvesting techniques, which are all based on natural or circular processes to improve resource efficiency, productivity, and resilience (Mockshell et al. 2023). In Senegal, adopting the right mix of such measures through corresponding agricultural extension will not only be more environmentally sustainable, but yield rates are expected to more than double, according to recent estimates (Prudhomme et al. 2023).

Third, given the high perishability level of food items whose supply should substantially increase by 2040, more attention should be devoted to reducing food losses throughout the entire food system. Whereas preharvest losses could be reduced using the same improved agricultural extension, simple techniques or fairly inexpensive investments could help avoid decay or deterioration at production, processing, transport, and distribution stage. These involve: timely or piecemeal harvesting; using more appropriate digging tools; avoiding direct contact with soils; and using hermetically sealed bags or other improved packaging and handling material (Merrey and Mukherji 2023). However, when dealing with horticultural products and animal-based food items, investing in cool and cold storage infrastructure is often indispensable and more expensive.

Fourth, given the decent Internet coverage and abundant sunshine for off-grid electricity production in Senegal, digital agricultural and climate services should be expanded to help transform the country's food system at all levels. These include: climate information and weather forecasting; index-based crop insurance; advice on best farming and livestock practices; and market information (Merrey and Loboguerrero 2023).[15]

Apart from environmental sustainability, food system transformations should result in more socially inclusive outcomes, especially regarding the most economically disadvantaged groups in society. In general, such outcomes are best guaranteed if future food system policies and institutions are able to correct for horizontal inequalities in access and control over productive resources, such as land, credit, information, and technology, while at the same time, a broader set of societal processes is set in motion to change restrictive social norms and effectively increase people's agency (Njuki et al. 2022). Given that discrimination manifests in different forms depending on the exact context, no blueprint exists for the exact types of policies and societal processes needed to reverse it. Nonetheless, several principles underpinning the agroecological approach precisely aim to create more inclusive and socially just communities, thereby adding a social dimension to sustainability.[16] As mentioned, this social equity component of agroecology is also reflected by its capacity to absorb and provide viable livelihoods for many young people who enter the labor market each year, as opposed to more capital-intensive approaches, where resources and revenues are concentrated in the hands of fewer actors (Prudhomme et al. 2023).

In addition to agroecology, future policies could target certain value chains or subsectors, which are disproportionally populated by economically vulnerable groups, such as women and young people, and then promote certain technologies that are more likely to benefit those groups. In Senegal, women and young people are either already involved or could be attracted to several subsectors where total supplies should substantially increase by 2040, such as horticulture, small livestock, poultry, fish, and dairy. For example, women in the Fatick region are highly involved in processing and marketing cow and goat milk, providing one of few income-earning opportunities. However, policies to stimulate this subsector should account for women's particular constraints, which relate to land access, time allocation, and underrepresentation in policy design (Habanabakize et al. 2022). Horticulture also has potential to yield more inclusive outcomes. This already appears to be the case for the export industry in Senegal, which offers relatively good-quality jobs to women, youth, and migrants (Fabry, Van den Broeck, and Maertens 2022) without jeopardizing domestic food security (Van den Broeck, Van Hoyweghen, and Maertens 2018). Building on this experience, (young) entrepreneurs could aim to copy this model and supply domestic markets, either with more regular fruit and vegetables or by developing high-value markets, such as for cherry tomatoes and strawberries (CTA 2019). However, given the labor-intensive nature of this subsector, concerns of economic exploitation should receive due attention when designing policies. These concerns are closely related to how social norms on labor allocation travel from patriarchal households to workplaces (Baglioni 2022). The poultry subsector might be another area of interest in future food transformation policies. On the one hand, it allows for an increase of supply in animal protein with a lower environmental footprint compared to other forms of livestock production. On the other hand, Senegal's poultry subsector has become very dynamic, especially after the sanitary import ban in 2006, which stimulated national production, created additional employment opportunities, and reinforced an existing preference for domestic chicken (Boimah and Weible 2021).

Pursuing more equitable food systems not only has intrinsic value, but also activates several demand mechanisms in Scenarios 2 and 3 (on consumer awareness and income growth) to actually transpire. As a matter of fact, improving the economic livelihoods of those with the least resources or those most directly involved in the immediate nutritional well-being of the family (that is, women, through food purchases and preparation) will likely increase household food budgets and improve household members' diet quality (Alderman and Headey 2017; Njuki et al. 2022).

A defining characteristic of food system transformations is that the suggested approaches and technologies to help feed future populations of Senegal in a sustainable and inclusive way should be pursued in a comprehensive and holistic fashion. Apart from more research on exact trade-offs between investment options, this will require tremendous effort in terms of policy coordination from the very local to the global level. At the national level, Senegal is already endowed with several multisectoral policies and institutions (such as the Emerging Senegal Plan (PSE) and the Executive Secretariat of the National Council of Food Security (SE-CNSA)) that are important anchors and spaces to define, design and implement future agendas on food system transformation. Following the 2021 UNFSS, this need for a multisectoral and cross-disciplinary approach is further enshrined in country roadmaps, which cover future policy commitments as well as the establishment of implementing agencies and monitoring and evaluation systems. Despite its high-level and general language, the Senegal roadmap already mentions several fiscal measures that align with the need to drastically intensify agricultural production, improve nutrition outcomes, introduce new technologies, promote agroecology, and stimulate the development of innovative startups for young entrepreneurs (MAER 2021). In addition, both the Agro-Sylvo-Pastoral Orientation Act (LOASP) and PSE have (almost) reached their expiry date and should therefore be renewed or replaced, which provides excellent policy opportunities to substantiate the ongoing food system transformation agenda.

An important aspect in the current policy discourse is the pursuit of food self-sufficiency or food sovereignty, which implicitly implies a full substitution of all current food imports. Given the substantial quantities of additional supply needed by 2040 (except perhaps for cereals, legumes, and maize), a general strategy of import substitution is both unrealistic and not expedient, especially in the case of dairy (mainly in the form of milk powder) and horticultural products (mainly onions, potatoes, and bananas). In addition, the protective measures to help develop these domestic subsectors involve aggregate welfare losses due to suboptimal resource allocation and must be considered against the immediate impacts on people's access to food and corresponding nutrient intake. For example, given that small sachets of imported milk powder allow for cheap, convenient intake of dairy, increasing import barriers to protect the milk subsector in Senegal might result in increased deficiencies of calcium and vitamin B12 across the country.

CONCLUSIONS

Based on three compounding scenarios of urbanization, consumer awareness, and income growth, this research report provides a rough overview of the required evolution in future food supplies in Senegal. These scenarios assume that current population and urbanization trends will continue up to 2040, and that all people by then will not only be able to afford but will also actually choose to consume a healthy diet. In methodological terms, this healthy diet is based on a scaling of actual food preferences at item level, as observed in the 2017/18 PAPA survey, to reach total daily food group quantities, as proposed by Beal, Ortenzi, and Fanzo's (2023) hypothetical micronutrient adequate diet. When these scenarios come true, the current problem of micronutrient deficiency (especially with respect to calcium, iron, and vitamin B12) will be significantly reduced.

Comparing current and simulated food supplies for different food types, this study identifies the following main implications and potential entry points for a more efficient, nutritious, sustainable, and equitable transformation of the country's food system.

First, to provide the entire Senegalese population with a heathier diet in 2040, total food supplies need to triple, from around 5 million to 15 million tons of food per year. Given that the population will naturally accrue by a factor of only 2 and that urbanization will increase by 10 percentage points, it follows that relatively fewer (rural) people will be responsible for producing and supplying much more food, which in turn implies that the overall food system should be organized more efficiently.

Second, future supplies of animal-based food items, fruit, and vegetables need to rise dramatically, as opposed to maize and other imported cereals and legumes, which do not require much policy attention. Apart from an increase of processed and unprocessed dairy products by factors of 19 and 9, respectively, this increase involves the meat, fish, and horticulture subsectors, all of which represent serious challenges in terms of sustainability. As a result, future policies to develop these subsectors need to consider the overall impact on the environment and related use of natural resources. While several promising technologies are being developed, the most realistic options in Senegal relate to management of healthy soils, implementation of agroecological practices, reduction of food losses, and use of digital agricultural and climate services.

Third, given the perishable nature of products generated by the livestock, fish, and horticulture subsectors, combined with the fact that production can often only take place in particular areas due to biophysical constraints, it is crucial to select the right investments and locations for future storage, cooling, and processing capacity to ensure an interrupted supply of major consumption centers.

Fourth, since women and young people are either already active in or could be attracted to several subsectors where total supply should increase by 2040, the upgrading or further development of these subsectors presents an excellent opportunity to create a more equitable food system. This not only entails that public policies and investments by governments and donors focus on the immediate needs of vulnerable groups by ensuring better access and control over productive resources, but also that restrictive social norms are altered to improve effective agency.

Fifth, the current policy landscape in Senegal provides for various anchor points in terms of multisectoral policies and institutions, on which the agenda of food system transformation could be grafted. The pursuit of food self-sufficiency and related import substitution is unrealistic in the short run, however, and less expedient given the substantial required increase in food supplies by 2040. This is especially the case for the dairy and horticulture subsectors, which are critical to ensure a minimal intake of key micronutrients.

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REFERENCES

Alderman, H., and D. D. Headey. 2017. "How Important is Parental Education for Child Nutrition?" *World Development* 94: 448–464. (http://dx.doi.org/10.1016/j.worlddev.2017.02.007)

ANSD. 2008. *Sénégal. Résultats Définitifs du Troisième Recensement Général de la Population et de l'Habitat – (2002). Rapport National de Présentation*. Dakar (Sénégal): Agence Nationale de la Statistique et de la Démographie.

ANSD. 2014. *Recensement Général de la Population et de l'Habitat, de l'Agriculture et de l'Elevage (RGPHAE 2013). Rapport Définitif*. Dakar (Sénégal): Agence Nationale de la Statistique et de la Démographie.

Baglioni, E. 2022. "The Making of Cheap Labour across Production and Reproduction: Control and Resistance in the Senegalese Horticultural Value Chain." *Work, Employment and Society* 36(3): 445–464. (https://doi.org/10.1177/0950017021999569)

Beal, T., F. Ortenzi, and J. Fanzo. 2023. "Estimated Micronutrient Shortfalls of the EAT–*Lancet* Planetary Health Diet." *Lancet Planet Health* 7: e233–237.

Béné, C., P. Oosterveer, L. Lamotte, I. D. Brouwer, S. de Haan, S. D Prager, E. F. Talsma, and C. K. Khoury. 2019a. "When Food Systems Meet Sustainability – Current Narratives and Implications for Actions." *World Development* 113: 116–130. (https://doi.org/10.1016/j.worlddev.2018.08.011)

Béné, C., S. D. Prager, H. A. E. Achicanoy, P. Álvarez Toro, L. Lamotte, C. Bonilla Cedrez, and B. R. Mapes. 2019b. "Understanding Food Systems Drivers: A Critical Review of the Literature." *Global Food Security* 23: 149–159. (https://doi.org/10.1016/j.gfs.2019.04.009)

Boimah, M., and D. Weible. 2021. "Assessing Protectionism and Its Impact from Consumers' Perspective: The Case of Senegal's Poultry Import Ban." *World Food Policy* 7(1): 26–40. (https://doi.org/10.1002/wfp2.12025)

Bouët, A., B. Cissé, D. Kam, E. S. Kanoute, O. A. N. Konombo, J. M. Matitoma, S. Sack, A. Sy, N. Tordina, and F. Traoré. 2021. *The ECO-ICBT Database of Cross-Border Trade in Agricultural Products in ECOWAS*. Agbalépédogan (Togo): West African Association for Cross-Border Trade, in Agro-forestry-pastoral and Fisheries Products (WACTAF). (https://aocta-wacta.org/sites/default/files/2021-12/ECO-ICBT_database_En.pdf)

Bouët, A., B. Cissé, and F. Traoré. 2020. "Informal Cross-Border Trade in Africa." In *Africa Agriculture Trade Monitor 2020*, Eds. Bouët, A., S. P. Odjo, and C. Zaki, pp. 119–148. Washington, DC: International Food Policy Research Institute (IFPRI). (https://doi.org/10.2499/9780896293908_05)

Brouwer, I. D., M. J. van Liere, A. de Brauw, P. Dominguez-Salas, A. Herforth, G. Kennedy, C. Lachat, E. B. Omosa, E. F. Talsma, S. Vandevijvere, J. Fanzo, and M. Ruel. 2021. "Reverse Thinking: Taking a Healthy Diet Perspective Towards Food Systems Transformations." *Food Security* 13: 1497–1523. (https://doi.org/10.1007/s12571-021-01204-5)

Clapp, J., W. G. Moseley, B. Burlingame, and P. Termine. 2022. "Viewpoint: The Case for a Six-Dimensional Food Security Framework." *Food Policy* 106: 102164. (https://doi.org/10.1016/j.foodpol.2021.102164)

CTA. 2019. *Ils L'ont Fait ! Être Jeune et Entreprendre dans le Secteur Agricole*. Wageningen (The Netherlands): Technical Centre for Agricultural and Rural Cooperation. (https://hdl.handle.net/10568/100334)

DAPSA. 2021. *Rapport de l'Enquête Agricole Annuelle (EAA) 2020-2021*. Dakar (Sénégal): Direction de l'Analyse, de la Prévision et des Statistiques Agricoles.

David-Benz, H., and A. Seck. 2018. *Améliorer la Qualité de L'oignon au Sénégal: Contractualisation et Autres Mesures Transversales. Rapport d'Analyse de Politique, SAPAA (Projet de Suivi et Analyse des Politiques Agricoles et Alimentaires).* Rome: Food and Agriculture Organization of the United Nations.

David-Benz, H., N. Sirdey, A. Deshons, and P. Herlant. 2022. *Cadre Conceptuel et Méthode pour des Diagnostics Nationaux et Territoriaux*. FAO, CIRAD, European Union. (https://doi.org/10.4060/cb8603fr)

Delgado, L., M. Schuster, and M. Torero. 2023. "Food Losses in Agrifood Systems: What We Know." *Annual Review of Resource Economics* 15: 41–62. (https://doi.org/10.1146/annurev-resource-072722-025159)

Downs, S. M., S. Ahmed, J. Fanzo, and A. Herforth. 2020. "Food Environment Typology: Advancing an Expanded Definition, Framework, and Methodological Approach for Improved Characterization of Wild, Cultivated, and Built Food Environments toward Sustainable Diets." *Foods* 9: 532. (https://doi.org/10.3390/foods9040532)

Ericksen, P. J. 2008. "Conceptualizing Food Systems for Global Environmental Change Research." *Global Environmental Change* 18(1): 234–245. (https://doi.org/10.1016/j.gloenvcha.2007.09.002)

Fabry, A., G. Van den Broeck, and M. Maertens. 2022. "Decent Work in Global Food Value Chains: Evidence from Senegal." *World Development* 152: 105790. (https://doi.org/10.1016/j.worlddev.2021.105790)

Fanzo, J., L. Haddad, R. McLaren, Q. Marshall, C. Davis, A. Herforth, A. Jones, T. Beal, D. Tschirley, A. Bellows, L. Miachon, Y. Gu, M. Bloem, and A. Kapuria. 2020. "The Food Systems Dashboard is a New Tool to Inform Better Food Policy." *Nature Food* 1: 243–246. (www.nature.com/natfood)

FAO. 2001. *Human Energy Requirements. Report of a Joint FAO/WHO/UNU Expert Consultation*. Rome: Food and Agriculture Organization of the United Nations. (https://www.fao.org/3/y5686e/y5686e.pdf)

FAO. 2018. *Sustainable Food Systems: Concept and Framework*. Rome: Food and Agriculture Organization of the United Nations. (http://www.fao.org/3/ca2079en/CA2079EN.pdf)

FS-TIP. 2021. *Food Systems Analysis Toolkit. A Tool to Accelerate Food Systems Transformation*. Food System Transformative Integrated Policy (FS-TIP) initiative, with funding from the International Development Research Centre and Rockefeller Foundation. (https://www.rockefellerfoundation.org/wp-content/uploads/2022/02/Food-Systems-Analysis-Toolkit.pdf)

Gaarder, E., D. Luke, and L. Sommer. 2021. *Towards an Estimate of Informal Cross-Border Trade in Africa*. Addis Ababa: United Nations Economic Commission for Africa.

Global Panel on Agriculture and Food Systems for Nutrition. 2016. *Food Systems and Diets: Facing the Challenges of the 21st Century*. London.

Habanabakize, E., M. A. Diasse, M. Cellier, K. Toure, I. Wade, K. Ba, A. Diao Camara, P. Cortbaoui, C. Corniaux, and E. Vasseur. 2022. "Caprine Milk as a Source of Income for Women Instead of a Taboo: A Comparative Analysis of the Implication of Women in the Caprine and Bovine Value Chains in Fatick, Senegal." *Agricultural and Food Economics* 10: 32. (https://agrifoodecon.springeropen.com/articles/10.1186/s40100-022-00241-8)

HLPE. 2017. *Nutrition and Food Systems. A Report by the High-Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security*. Rome.

Ingram, J. 2011. "A Food Systems Approach to Researching Food Security and Its Interactions with Global Environmental Change." *Food Security* 3(4): 417–431. (https://doi.org/10.1007/s12571-011-0149-9)

Lawrence, M. A., S. Friel, K. Wingrove, S. W James, and S. Candy. 2015. "Formulating Policy Activities to Promote Healthy and Sustainable Diets." *Public Health Nutrition* 18(13): 2333–2340.

MAER. 2021. *Feuille de Route du Sénégal pour Sommet Mondial sur les Systèmes Alimentaires Durables*. Dakar: Ministère de l'Agriculture et de l'Équipement Rural. (https://summitdialogues.org/wp-content/uploads/2021/07/Feuille-de-route-du-senegal_SENEGAL24072021-TMD-1.pdf)

Marivoet, W., J. M. Ulimwengu, L. M. Sall, A. Gueye, K. Savadogo, and K. Dia. 2021. "Hidden Hunger: Understanding Dietary Adequacy in Urban and Rural Food Consumption in Senegal." IFPRI Discussion Paper 02036. Washington DC: International Food Policy Research Institute. (https://doi.org/10.2499/p15738coll2.134483)

Merrey, D., and A. M. Loboguerrero. 2023. "Digital Services." In *Achieving Agricultural Breakthrough: A Deep Dive into Seven Technological Areas*, Eds. Mukherji, A., et al., pp. 117–130. Montpellier (France): CGIAR. (https://hdl.handle.net/10568/131852)

Merrey, D., and A. Mukherji. 2023. "Reduce Food Loss and Waste." In *Achieving Agricultural Breakthrough: A Deep Dive into Seven Technological Areas*, Eds. Mukherji, A., et al., pp. 53–63. Montpellier (France): CGIAR. (https://hdl.handle.net/10568/131852)

Mockshell, J., M. Quintero, M. E. Narjes, S. Jones, and W. Francesconi. 2023. "Agroecological Approaches." In *Achieving Agricultural Breakthrough: A Deep Dive into Seven Technological Areas*, Eds. Mukherji, A., et al., pp. 98–116, Montpellier (France): CGIAR. (https://hdl.handle.net/10568/131852)

Mukherji, A., et al. (Eds.). 2023. *Achieving Agricultural Breakthrough: A Deep Dive into Seven Technological Areas*. Montpellier (France): CGIAR. (https://hdl.handle.net/10568/131852)

Njuki, J., S. Eissler, H. Malapit, R. Meinzen-Dick, E. Bryan, and A. Quisumbing. 2022. "A Review of Evidence on Gender Equality, Women's Empowerment, and Food Systems." *Global Food Security* 33: 100622. (https://doi.org/10.1016/j.gfs.2022.100622)

Pinstrup-Andersen, P., and D. D. Watson II. 2011. *Food Policy for Developing Countries. The Role of Government in Global, National, and Local Food Systems*. Ithaca NY: Cornell University Press. (https://doi.org/10.7591/9780801463433)

Prudhomme, R., C. S. Fall, V. D. Ahoun, M. Piraux, A. Badiane, O. Lo, Y. Ndour, B. Dorin, and A. Diao Camara. 2023. *Note Technique sur le Projet AgroEco2050-Sénégal*. (https://www.bameinfopol.info/IMG/pdf/note_aux_decideurs_agroeco2050_gizrev.pdf)

Reardon, T., L. S. O. Liverpool-Tasie, and B. Minten. 2021. "Quiet Revolution by SMEs in the Midstream of Value Chains in Developing Regions: Wholesale Markets, Wholesalers, Logistics, and Processing." *Food Security* 13: 1577–1594. (https://doi.org/10.1007/s12571-021-01224-1)

Ruben, R., R. Cavatassi, L. Lipper, E. Smaling, and P. Winters. 2021. "Towards Food Systems Transformation—Five Paradigm Shifts for Healthy, Inclusive and Sustainable Food Systems." *Food Security* 13: 1423–1430. (https://doi.org/10.1007/s12571-021-01221-4)

Sapkota, T., A. Mukherji, J. Kihara, and O. Ortiz. 2023. "Reduced Emissions from Fertilisers." In *Achieving Agricultural Breakthrough: A Deep Dive into Seven Technological Areas*, Eds. Mukherji, A., et al., pp. 22–37. Montpellier (France): CGIAR. (https://hdl.handle.net/10568/131852)

Sobal, J., L. Kettel Khan, and C. Bisogni. 1998. "A Conceptual Model of the Food and Nutrition System." *Social Science and Medicine* 47(7): 853–863. (https://doi.org/10.1016/S0277-9536(98)00104-X)

Sow, S., E. Nkonya, S. Meyer, and E. Kato. 2016. "Cost, Drivers and Action Against Land Degradation in Senegal." In *Economics of Land Degradation and Improvement – A Global Assessment for Sustainable Development,* Eds. Nkonya, E., A. Mirzabaev, and J. von Braun, pp. 577–608. Heidelberg (Germany): Springer Cham. (https://doi.org/10.1007/978-3-319-19168-3)

Stadlmayr, B., R. U. Charrondiere, V. N. Enujiugha, R. G. Bayili, E. G. Fagbohoun, B. Samb, P. Addy, I. Barikmo, F. Ouattara, A. Oshaug, I. Akinyele, G. Amponsah Annor, K. Bomfeh, H. Ene-Obong, I. F. Smith, I. Thiam, and B. Burlingame. 2012. *West African Food Composition Table*. Rome: Food and Agriculture Organization of the United Nations. (https://www.fao.org/3/i2698b/i2698b.pdf)

Van den Broeck, G., K. Van Hoyweghen, and M. Maertens. 2018. "Horticultural Exports and Food Security in Senegal." *Global Food Security* 17: 162–171. (https://doi.org/10.1016/j.gfs.2017.12.002)

von Braun, J., K. Afsana, L. Fresco, M. Hassan, and M. Torero. 2021. *Science and Innovations for Food Systems Transformation and Summit Actions. Papers by the Scientific Group and its partners in support of the UN Food Systems Summit*. (https://sc-fss2021.org/wp-content/uploads/2021/09/ScGroup_Reader_UNFSS2021.pdf)

WHO. 2004. *Vitamin and Mineral Requirements in Human Nutrition (Second edition)*. Geneva: World Health Organization. (https://iris.who.int/handle/10665/42716)

WHO. 2007. *Protein and Amino Acid Requirements in Human Nutrition. Report of a Joint WHO/FAO/UNU Expert Consultation*. Geneva: World Health Organization. (https://iris.who.int/handle/10665/43411)

Willett, W., J. Rockström, B. Loken, M. Springmann, T. Lang, S. Vermeulen, T. Garnett, D. Tilman, F. DeClerck, A. Wood, M. Jonell, M. Clark, L. J. Gordon, J. Fanzo, C. Hawkes, R. Zurayk, J. A. Rivera, W. De Vries, L. Majele Sibanda, … and C. J. L. Murray. 2019. "Food in the Anthropocene: The EAT–*Lancet* Commission on Healthy Diets from Sustainable Food Systems." *The Lancet* 393(10170): 447–492. (https://doi.org/10.1016/S0140-6736(18)31788-4)

ENDNOTES

[1] For more information, see www.ifpri.org/project/riapa-model (for RIAPA) and www.ifpri.org/project/spatial-typologies-targeted-food-and-nutrition-security-interventions (for the spatial FNS typology).

[2] For a broad selection of indicators to assess Senegal's food systems performance, see: www.foodsystemsdashboard.org/countries/sen.

[3] The PAPA dataset and corresponding metadata are available for public use and can be obtained by email from papagriculture@agriculture.gouv.sn.

[4] For this analysis, it is assumed that all food purchases are consumed within the same recall period. Given this one-time snapshot, the data do not allow to control for seasonality.

[5] A first analysis of this dataset was conducted by Marivoet et al. (2021).

[6] Categorizing tubers/roots together with vegetables in one food group has a sociocultural motivation, as the former items are not considered staple foods in Senegal.

[7] As most food items were underspecified in terms of variety, cultivar, color, maturation stage, or biofortification level, assigning a suitable FCT record was not always straightforward.

[8] The reference chosen for these scales is a 30-year-old man with a physical activity level of 1.75, and bioavailability levels of 5 percent for dietary iron and 15 percent for dietary zinc. While estimated average requirement (EAR) levels are used for food energy, the AME scales for all nutrients are based on the recommended dietary allowance (RDA) levels, which respectively provide the intake levels at which the needs of 50.0 percent (EAR) and 97.5 percent (RDA) of the population are met. While these AME scales are useful tools to standardize food needs across population groups, our demographic simulation will not explicitly account for changes in the composition of age groups over time.

[9] Following the administrative reform of 2008, three new regions (Kaffrine, Kédougou, and Sédhiou) were created in Senegal, bringing the total from 11 to 14 regions. As a result, region-specific growth rates could be derived for the initial 11 regions only.

[10] Compared to the EAT-*Lancet* reference diet proposed by Willett et al. (2019) and because of its higher proportion of animal source foods, the BHMA diet is more likely to ensure adequacy for six globally scarce micronutrients, especially vitamin B12, calcium, iron, and zinc. The choice for this reference diet (as opposed to the EAT-*Lancet* diet) also follows from the research setup in which we estimate the food supply implications of closing the yield and nutrient gaps first, before identifying possible entry points for a more inclusive and environmentally sustainable transformation of Senegal's food system.

[11] Unfortunately, this survey module did not cover any information on the precise food environments from where and how consumers acquire their food, which in urban areas involve supermarkets, restaurants, and different types of food service delivery.

[12] The importance attached to healthy diets in Senegal stems from the establishment in 2001 of a unit to fight malnutrition (*Cellule de Lutte contre la Malnutrition (CLM)*, renamed in 2019 as *Conseil National de Développement de la Nutrition (CNDN)*), which is directly placed under the authority of the Prime Minister (see: https://cndn.sn). This importance has been reemphasized on several occasions, and most recently in the roadmap project linked to the 2021 UNFSS (see: https://summitdialogues.org/wp-content/uploads/2021/09/Feuille-de-route-du-senegal_SENEGAL24072021-TMD-1.pdf).

[13] Three main aspects could be cited. First, the scaling procedure based on only eight food groups ignores much of the granularity of the BHMA diet. Second, the BHMA diet (like the EAT-*Lancet* reference diet) is an international reference, which requires contextualization to meet nutrient needs based on local food preferences and cooking habits. Third, the micronutrient adequacies are computed based on the more stringent RDA thresholds, at which the nutrient needs of 97.5 percent of the population are met. Assessing the relative importance of these three methodological aspects falls outside the scope of this analysis, however.

[14] The main livestock production areas are located in the interior of the country; fruit and vegetables are mainly cultivated in the Niayes zone, the Senegal River Valley, and the Casamance region; and fishing activities, for obvious reasons, mainly take place in coastal areas and along inland rivers and waterbodies.

[15] See also: https://aiccra.cgiar.org/regions/senegal

[16] See, for example: https://www.fao.org/agroecology

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