CHAPTER 5

2023 ATOR: The Call for Nutrition-Smart Food Systems

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Introduction

A shift from agriculture to manufacturing was one of the hallmarks of job creation, poverty reduction, and rapid growth in low-income countries during the latter half of the 20th century. This experience in earlier decades of structural transformation was characterized by labor-absorbing, productivity-increasing manufacturing. Recent structural change in African countries has been markedly different—productivity gains are realized through reallocation of economic activity away from agriculture without the accompanying within-sector productivity growth in nonagriculture, and manufacturing in particular (Diao, McMillan, and Rodrik 2019; Diao et al., 2021; McMillan and Zeufack 2022). This chapter examines the extent to which agrifood processing follows these trends.

A nutrition-smart food system is one that effectively and sustainably addresses both hunger and malnutrition, from undernutrition to micronutrient deficiencies and overnutrition. Such a system ensures that food production, processing, distribution, consumption, and waste disposal are optimized for human health while being environmentally sustainable. It emphasizes a variety of crops rather than monocultures to increase dietary diversity, which is crucial for supplying all essential nutrients (Herforth and Harris 2014). It also addresses issues in storage, transportation, and consumption to minimize food waste, thereby ensuring that more nutrients are retained in the food system. A nutrition-smart food system ensures that the food available to consumers is not only sufficient in quantity but also in quality, emphasizing nutrient-rich foods (Hawkes et al. 2020). Additionally, nutrition education and public campaigns can influence healthier food choices. A nutrition-smart food system incorporates nutrition goals into agricultural policies and practices, which involves selecting specific crops for cultivation based on their nutritional profiles or improving soil health for better nutrient content in crops. A shift to nutrition-smart food systems can also help to mitigate adverse environmental impacts by promoting sustainable agricultural practices and reducing food waste (Willett et al. 2019) and can contribute to economic growth and efficiency (Bloom et al. 2011).

In Africa, gradual but steady improvements in food security and nutrition over the past two decades have recently faltered. The prevalence of overall population undernourishment and child malnutrition declined consistently from the early 2000s to the mid-2010s, but undernourishment subsequently increased in the second half of the 2010s (see chapter 13, this volume). The COVID-19 crisis beginning in 2020, followed by the Ukraine-Russia war and associated food price inflation in 2022 have provoked increases in hunger and malnutrition which could persist for years to come (FAO et al. 2023). In addition to undernutrition, Africa also faces growing prevalence of overnutrition, with increases in overweight and obesity that are associated with increased risk of noncommunicable diseases such as diabetes and heart disease (Global Nutrition Report 2023).

Africa also faces serious problems of micronutrient deficiencies (also referred to as "hidden hunger") resulting from inadequate intake of vitamins and minerals. Micronutrient deficiencies can coexist with both undernutrition and overnutrition (Kim et al. 2019), impeding healthy growth, development, and functioning and causing or contributing to serious illness and death (Bailey, West, and Black 2015). Comprehensive data on micronutrient deficiencies for large population groups are lacking, but available evidence suggests that deficiencies are severe and widespread in Africa. In their study of global death and disease burdens due to micronutrient deficiencies, Muthayya and others (2013) found high concentrations of burden in Africa south of the Sahara. Han and colleagues (2022) estimated that central and eastern Africa had the highest rates of vitamin A deficiency in the world in 2019, with age-standardized prevalence rates of more than 20 percent compared to the global rate of under 7 percent. Western Africa had one of the highest estimated rates of dietary iron deficiency (after South Asia) at more than 21 percent, compared to around 14 percent globally (based on 2019 data).

Although nutrition-smart food systems have the potential to address all forms of malnutrition, their promotion can be challenging due to political, economic, and cultural barriers and knowledge and infrastructure gaps. Often, nutrition does not receive the political priority it deserves, with initiatives for healthier food systems competing with other political priorities. The economic structure of many food systems is such that unhealthy, highly processed foods are often cheaper and more readily available than healthier alternatives, due to subsidy patterns, the difficulty of storing and transporting nutrient-dense foods, and other factors. Exposure to different types of food in the environment, food marketing, lack of nutrition knowledge, and misinformation on nutrition also shape consumer preferences and can contribute to poor dietary choices (Chandon and Wansink 2012; Hawkes et al. 2015).

This chapter focuses on the issue of micronutrient deficiencies, examining nutrient adequacy at multiple stages to identify priority strategies to enhance nutrition throughout food systems. To better understand the scale of challenges regarding micronutrient deficiencies in African countries, it is important to examine the availability of micronutrients at different segments in food systems. Nutrients can enter food at multiple stages—during food production, during processing through industrial fortification, and through at-home fortification—and can also leave at multiple stages, including processing, storage, and cooking. Addressing micronutrient deficiencies and strengthening the ability of food systems to provide adequate nutrition requires understanding the nutritional content of food at multiple stages in food systems and identifying key points at which interventions can stem nutrient loss or enhance nutrient conservation or gain.

In this chapter, we implement an approach to assess nutrient adequacy at multiple stages in food systems as a first step to identifying priority strategies to enhance nutrition. The evidence provided in this chapter can, within the framework of the Comprehensive Africa Agriculture Development Programme M&E system, help to better identify the challenges in terms of eradicating hunger and guide efforts to better integrate nutrition into the design of the post–Malabo Declaration agenda. We select two countries—Senegal in western Africa and Rwanda in eastern Africa— to highlight the needs for context specific strategies while rolling out nutrition-smart food systems strategies. Indeed, several factors can contribute to the differences in the nature of micronutrient deficiencies between the two countries, including differences in dietary habits, food availability, socioeconomic factors, cultural practices, agricultural systems, and public health interventions. For instance, regions that rely heavily on a single crop (monoculture) may lack diversity in their diet, leading to certain micronutrient deficiencies (Welch and Graham 2004). Countries that fortify staple foods with micronutrients might have lower prevalence of certain deficiencies (Bhutta, Salam, and Das 2013).

In this chapter, we use household survey data to examine nutrient consumption against nutritional requirements as well as agricultural production data to assess the production of nutrients. Comparing nutrient production adequacy with overall consumption adequacy as well as adequacy at the household level serves

BOX 5.1—ROLES OF KEY NUTRIENTS EXAMINED IN THE CHAPTER

The nutrients examined in this chapter are essential for healthy growth and functioning, and deficiencies are a major cause of reduced productivity, poor health, disability, and mortality in developing countries. Key roles of the nutrients examined are briefly summarized below:

- Proteins are essential components of the human body and are necessary for many bodily functions. Deficiencies can cause poor growth, loss of muscle, reduced immune function, and other issues.
- Calcium protects bone health and helps to prevent negative pregnancy outcomes, preterm birth, and neonatal mortality.
- Iron has major impacts on cognitive function and productivity; deficiencies contribute to maternal mortality and low birth weight.
- Vitamin A is necessary for immune system functioning; deficiencies cause increased maternal and childhood mortality and are a major cause of childhood blindness.
- Riboflavin deficiencies impede digestion of carbohydrates, protein, and fat as well as iron absorption and can cause growth delay and other developmental issues.
- Vitamin B12 is essential for cellular metabolism, red blood cell production, and neurological functioning.
- Zinc deficiency impairs overall growth and development and is associated with increased maternal and infant mortality.
- Folate deficiency can cause anemia and contribute to birth defects and other negative outcomes.
- Vitamin C helps the body to fight infections and heal from injuries and is necessary for the production of collagen and some hormones.
- Niacin aids enzymatic reactions, repairs DNA, plays a role in converting nutrients found in food into energy, and may help to maintain brain health.
- Thiamin is essential for cellular growth and function; deficiencies can cause heart failure, cognitive issues, and muscle loss.

Source: Authors analysis based on Bailey, West, and Black 2015; Conti et al. 2019; Green et al. 2017; Harvard 2023; Mahabadi, Bhusal, and Banks 2023; and WHO 2023.

as a first step to identifying areas where nutrients may be entering or exiting the system. This can help to guide efforts to address nutrient gaps, whether by enhancing production of nutrients through biofortification or crop selection, increasing availability of nutrients through imports or food fortification, or enhancing households' access to nutritious foods through price or income interventions. As both production and consumption adequacies can differ markedly within countries, we examine adequacy patterns both at the national and subnational levels (that is, departments for Senegal and districts for Rwanda). The chapter assesses adequacy for energy and protein as well as ten micronutrients (calcium, iron, zinc, folate, vitamin A, vitamin B12, vitamin C, riboflavin, niacin, and thiamine).[1] Box 1 provides a summary of the key functions of these nutrients.

The remainder of the chapter is structured as follows: Section two describes our analytical approach, methodology, and data sources; section three reports nutrient adequacy results and maps adequacy patterns at the subnational level; section four discusses policy implications and potential strategies to fill nutrient gaps; and the final section provides our conclusions.

Methodology and Data

Analytical Approach

Following the work of Marivoet and Ulimwengu (2022) and Marivoet and colleagues (2021), this chapter carries out analysis on three types of nutrient adequacy measures: nutrient production adequacy (NPA), nutrient market adequacy (NMA), and nutrient household adequacy (NHA). NPA expresses the ratio of the total quantity of a nutrient produced in an area to the total requirements of its population. On the consumption side, NMA shows the ratio of the total quantities of nutrients consumed in an area to total population requirements without accounting for unequal distribution between households, while NHA is the ratio of average household-level consumption to requirements. Thus, NPA provides an overview of the adequacy of production, NMA shows the adequacy of the availability of nutrients for consumption in markets, and NHA shows the adequacy of consumption at the household level (see Magne Domgho et al. 2023 for more details). While NPA, NMA, and NHA do not capture all food systems segments, they provide a simplified framework to assess nutrient adequacy at key milestones and serve as an entryway to identify possible areas of intervention to improve nutrition.

In order to carry out the analysis of NPA, NMA, and NHA, we first converted the quantities of food consumed by households into nutrient equivalents. The results obtained enabled us to identify the localities with high nutrient gaps and highlight the main foods consumed that contribute most to nutrient intake. Then, to provide information on the dynamics of household food consumption, we applied a Quadratic Almost Ideal Demand System (QUAIDS) model to derive elasticities of demand for nutrients with respect to income and to prices of different food groups (see Ulimwengu et al. 2023 for details).

Estimating Nutrient Production, Market, and Household Adequacy

To convert the quantities of food consumed into nutrient equivalents, we applied an edible conversion factor to each food item and matched it with the most suitable record within the appropriate food composition table (FCT): the Food and Agriculture Organization of the United Nations' (FAO's) West African FCT (Vincent et al. 2020) for Senegal, and Kenya's FCT for Rwanda (FAO, Kenya Ministry of Health, and Kenya Ministry of Agriculture and Irrigation 2018).[2] Finally, we estimated for each food consumption line the total quantity of energy, proteins, calcium, iron, zinc, folate, vitamin A, vitamin B12, vitamin C, riboflavin, niacin, and thiamine (as well as vitamin B6 for Senegal).

As a first step to estimating NHA, nutrient intake estimates for each household member were computed by applying the corresponding adult male equivalent (AME)[3] factors (FAO 2001) to account for differences in the age and gender composition of households. We assume that food is distributed to members in proportion to each member's share of energy requirements. After calculation, households that fall outside a plausible consumption range of 500–5000 kcal consumption per person per day (Voortman et al. 2017) were removed from the survey sample. Actual nutrient intakes were compared

1 We also include vitamin B6 for Senegal only due to data availability.

2 For Rwanda, the Kenya FCT was completed by information from food composition tables for Tanzania (Lukmanji et al. 2008) and Uganda (Hotz et al. 2012) as well as the West Africa FCT.

3 Adult male equivalents (AME) express energy requirements on the basis of gender, age, and physiological status as a proportion of the energy requirements of an average adult male (Weisell and Dop 2012).

to recommended daily nutrient intakes defined in WHO and FAO (2005) to determine nutrient adequacy ratios (NARs). As some households exceeded recommended intakes and others had deficits, household NARs were truncated at 100 percent before calculating average adequacy levels—referred to in our analysis as NHA—in order to avoid households with surplus intakes masking nutrient deficiencies. We calculated NMA based on overall consumption for an area divided by recommended intakes, without truncating, in order to express the adequacy of the total supply of nutrients available for consumption. For NPA, quantities produced of crops and animal products were similarly converted into nutrient equivalences using the same food composition tables listed above. Nutrients produced were compared to recommended daily intakes in WHO and FAO (2005) to calculate NPA.[4]

Several limitations of the analysis should be noted. Estimated nutrient adequacy levels take into account the varying demographic makeup of households; however, as food consumption data were collected at the household level, the analysis cannot account for potential disparities in shares of food allocated to different household members.[5] In addition, actual nutrient intake may differ from what is suggested by the data due to differences in cooking methods used by households that affect nutrient content of foods, as well as varying bioavailability of nutrients. When comparing NPA with NMA and NHA, it should be noted that some differences may be related to the different data sources used, as discussed in the next section.

Data Sources

The NPA analysis for Senegal is based on crop production data from the country's annual agriculture survey, *Enquête Agricole Annuelle,* carried out by the Directorate of Analysis, Forecasting and Agricultural Statistics (DAPSA) in 2017–2018. The DAPSA data are complemented by data from FAOSTAT, the Ministry of Fisheries and Maritime Production (MPEM), the Ministry of Livestock and Animal Production (MEPA) on palm oil, fishery, and livestock production, and the Directorate of Water, Forests, Hunting and Soil Conservation (DEFCCS) on nontimber forest products, respectively. Production data for most crops and animal products are available at the national and subnational levels; however, information on the production of palm oil and most fruits is only available at the national level. The NMA and NHA analysis for Senegal is based on household survey data collected in 2017–2018 as part of the Projet d'Appui aux Politiques Agricoles (PAPA) led by Senegal's Ministry of Agriculture and Rural Equipment, the International Food Policy Research Institute, and Michigan State University with funding from the USAID.

Nutrient production data for Rwanda uses the crop production module from the fifth Rwanda Integrated Household Living Conditions Survey (EICV 5), which was conducted by the National Institute of Statistics of Rwanda (NISR) between October 2016 and October 2017. The data is complemented by data from Ministry of Agriculture and Animal Resources (MINAGRI) and from the Rwanda Agriculture Board (RAB) on livestock and fishery production, respectively. The NMA and NHA analysis for Rwanda is based on the food consumption module of the EICV 5.

Results: Nutrient Production, Market, and Household Adequacy

In this section, we compare NPA, NMA, and NHA at the national level for Senegal and Rwanda for all nutrients. We also identify key foods contributing to the production and consumption of nutrients, compute price and income elasticities of demand for nutrients, and map the three adequacy measures at the subnational level for selected nutrients. Comparing NPA, NMA, and NHA can provide an entry point to identifying potential sources of nutrient loss in food systems. Differences between NPA and NMA reflect loss or entry of nutrients between the production and market stages. For example, nutrients can leave the food system after production due to postharvest losses or other uses of production besides human consumption (for example, as animal feed). Industrial fortification of food can add nutrients and contribute to greater market adequacy than production adequacy. Trade, both domestic and international, can also cause differing

4 Further methodological details are available from Magne Domgho et al. (2023).

5 Relatively little research has been carried out on intrahousehold food allocation due to the difficulty of collecting consumption data at the individual level. A study by De Vreyer and Lambert (2019) does not indicate evidence of disparities in food allocation within Senegalese households, but results from Fadare and colleagues (2018) suggest that men are more likely than women and children to benefit from relatively diverse diets in Nigerian households. In Rwanda, focus groups indicate that men receive larger quantities and more preferred foods such as meat (Rwanda, Ministry of Health 2005).

levels of NPA and NMA, as some nutrients produced in a region are transported outside of the region and others produced elsewhere are purchased and consumed in the region. Differences between NMA and NHA reflect unequal distribution of nutrients among households in a given locality. This can result from limited purchasing power or limited access to markets among some households.

Senegal

Table 5.1 and Figure 5.1 present NPA, NMA, and NHA for energy (Kcals), protein, and 11 micronutrients at the national level for Senegal. NPA is over 100 percent for most nutrients, suggesting that, on average, sufficient levels of nutrients are produced in Senegal to adequately feed the entire population. Adequacy levels of protein, folate, niacin, and thiamin are particularly high at over 200 percent. Despite this general pattern, production falls short of national requirements for calcium and riboflavin.

A very different pattern emerges in terms of consumption adequacy at national and average household levels, with NMA and NHA values significantly lower than NPA for most of the nutrients. For iron, zinc, vitamin B6, folate, niacin, and thiamin, NMA and NHA levels are less than half those of NPA. While some differences may be due to data and measurement issues, this also suggests that significant shares of the nutrients produced in Senegal do not make their way to households' tables, potentially due to limited purchasing power, food exports, postharvest crop losses, and other nutrient losses after production or during the cooking process. Exceptions to this pattern include calcium, with slightly higher NHA than NPA, and vitamin B12, for which NMA is slightly higher than production adequacy. Higher levels of NMA than NPA suggest that Senegal may have increased supplies of this nutrient through trade with other countries.

NHA is lower than NMA for most nutrients, indicating that national-level nutrient consumption is not distributed evenly among households. The difference between NMA and NHA is largest for vitamin A and vitamin B12, suggesting that there are significant disparities in households' access to foods rich in these nutrients (which include palm and other vegetable oils, and fish and meat, respectively).

Key Foods Contributing to Energy and Nutrient Consumption and Production for Senegal

Table 5.2 lists the top five food items that contribute to Senegalese households' intake of energy as well as selected nutrients and budget shares of each key food. Cereals, particularly rice and millet, represent households' principal sources of energy and key micronutrients including iron and calcium. Millet grain is especially rich in iron but accounts for a small share of budgets; the bulk of households' cereal budgets are allocated to broken and whole rice, followed

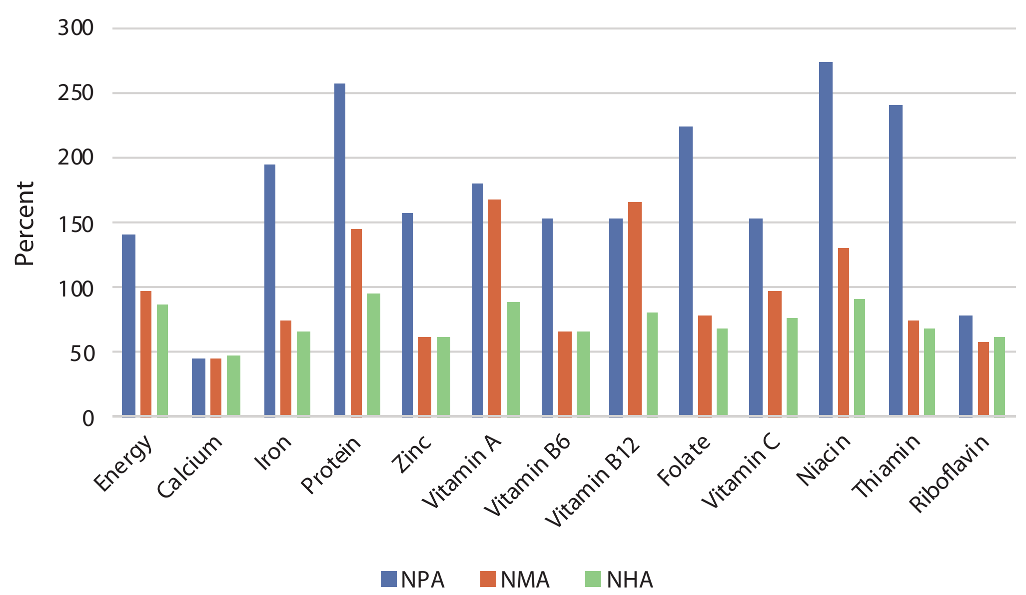
TABLE 5.1—NATIONAL ENERGY AND NUTRIENT PRODUCTION, MARKET, AND HOUSEHOLD ADEQUACY, SENEGAL (2017–2018)

	Production per day, AME	Consumption per day, AME	Recommended intake per day, AME	NPA (%)	NMA (%)	NHA (%)
Energy (Kcal)	3,855.8	2,848.6	2,750.0	140.2	97.3	86.5
Calcium (mg.)	449.0	485.0	1,000.0	44.9	43.9	47.0
Iron (mg.)	53.6	21.1	27.4	195.8	74.5	65.0
Protein (g.)	128.5	78.1	50.0	257.1	145.2	94.3
Zinc (mg.)	21.9	9.2	14.0	156.8	62.0	60.9
Vitamin A (mcg.)	1,084.8	1,118.3	600.0	180.8	167.9	89.1
Vitamin B6 (mg.)	3.1	1.4	2.4	152.7	66.7	66.4
Vitamin B12 (mcg.)	3.7	4.5	400.0	153.6	165.2	80.0
Folate (mcg.)	897.7	331.8	60.0	224.4	79.0	68.3
Vitamin C (mg.)	91.4	64.7	20.0	152.4	96.0	75.6
Niacin (mg.)	54.9	27.7	1.5	274.6	129.4	91.5
Thiamin (mg.)	3.6	1.2	2.5	241.1	73.3	68.8
Riboflavin (mg.)	1.3	1.1	3.5	77.7	58.3	60.6

Source: Authors' calculations; market and household adequacy are based on Projet d'Appui aux Politiques Agricoles (PAPA) (2017–2018) data, and production adequacy is based on data from Directorate of Analysis, Forecasting and Agricultural Statistics (DAPSA) (2017–2018), Food and Agriculture Organization of the United Nations (FAO) (2018), Ministry of Livestock and Animal Production (MEPA) (2018), Ministry of Fisheries and Maritime Production (MPEM) (2018), and Directorate of Water, Forests, Hunting and Soil Conservation (DEFCCS) (2018).

Note: AME = adult male equivalents; NPA = nutrient production adequacy; NMA = nutrient market adequacy; NHA = nutrient household adequacy.

FIGURE 5.1—ENERGY AND NUTRIENT PRODUCTION, MARKET, AND HOUSEHOLD ADEQUACY, SENEGAL (PERCENT)



Source: Authors' calculations; market and household adequacy are based on Projet d'Appui aux Politiques Agricoles (PAPA) (2017–2018) data, and production adequacy is based on data from Directorate of Analysis, Forecasting and Agricultural Statistics (DAPSA) (2017–2018), Food and Agriculture Organization of the United Nations (FAO) (2018), Ministry of Livestock and Animal Production (MEPA) (2018), Ministry of Fisheries and Maritime Production (MPEM) (2018), and Directorate of Water, Forests, Hunting and Soil Conservation (DEFCCS) (2018).

Note: NPA = nutrient production adequacy; NMA = nutrient market adequacy; NHA = nutrient household adequacy.

by processed millet.[6] Strategies to combat deficiencies in iron could include a focus on increasing consumption of millet as well as cowpeas, which are also rich in these key micronutrients and currently account for a very small share in households' budgets. Households in Senegal also spend very little on the foods richest in calcium (smoked and dried fish and powdered milk), as reflected in low adequacy levels for that micronutrient.

Table 5.3 summarizes the major crops accounting for Senegal's production of nutrients. It shows the dominant role of peanuts in national nutrient production, accounting for 20 percent of annual crop production in terms of volume and representing an even larger share of many major nutrients. Peanuts account for nearly 40 percent of all energy produced in Senegal as well as significant shares of calcium, and iron.[7] Cereals—millet, rice, and maize—are also among the major sources of energy, protein, and most micronutrients. Millet is rich in several key nutrients, representing 55.8 percent of national production of iron, compared to 12.5 percent of total crop production in terms of volume.[8]

Calcium is among the few nutrients examined for which production is insufficient to cover national nutritional requirements. Peanuts account for the largest share of Senegal's production of calcium, followed by cow milk. Calcium supplies could be increased by augmenting national production of milk, as well as of sesame, which is extremely rich in calcium and currently represents only 0.2 percent of national crop production.

Elasticities of Demand for Energy and Nutrients

Changes in incomes and in food prices affect households' food consumption patterns. As foods differ in terms of nutrient content, income and price changes also affect micronutrient consumption patterns. However, as the links are indirect, it is not always obvious to policymakers how price and income policies affect the consumption of individual

6 When results are disaggregated by rural and urban consumers, some interesting differences emerge. Rural households devote substantially larger budget shares to iron-rich millet grain than urban households; this likely contributes to rural households' higher nutrient household adequacy levels (a contrast to the general pattern of higher adequacies for urban households). Results for rural and urban households are available upon request from the authors.

7 Peanuts also account for large shares of national production of niacin, thiamin, protein, vitamin B6, folate, and riboflavin (not shown in in Table 5.3). Peanuts play an important but less prominent role in nutrient consumption; they figure among the top five dietary sources of protein, folate, niacin, and thiamin, and peanut oil is a major source of vitamin A (Table 5.2).

8 This analysis does not take into account differing levels of bioavailability of nutrients. Bioavailability is complex and depends on multiple factors, including an individual's health and nutrition status, overall diet composition, and the source of each nutrient. It is important to note that the bioavailability of iron and zinc from cereals is lower than from other sources (Arafsha et al. 2023).

TABLE 5.2—TOP FOODS CONTRIBUTING TO ENERGY AND NUTRIENT INTAKE, SENEGAL (NATIONAL AVERAGE)

	Food item	Nutrient intake share	Nutrient content per 100 grams	Budget share
Energy (Kcal)	Rice (broken)	18.7%	356.7	7.5%
	Rice (whole)	14.5%	352.3	5.8%
	Millet (processed)	7.9%	353.5	4.3%
	Vegetable oils	7.8%	900.0	4.9%
	Sugar	7.5%	400.0	4.8%
Calcium (mg.)	Dried fish	17.7%	1,939.0	1.2%
	Milk powder	15.5%	925.0	2.6%
	Rice (broken)	11.5%	35.5	7.5%
	Smoked fish	7.1%	1,133.0	1.0%
	Rice (whole)	4.1%	16.3	5.8%
Iron (mg.)	Millet (grains)	32.5%	15.2	2.5%
	Millet (processed)	16.3%	5.6	4.3%
	Rice (whole)	9.2%	1.7	5.8%
	Cowpea	4.9%	6.6	1.2%
	Maize (grains)	3.1%	3.3	1.2%
Vitamin A (mcg.)	Palm oil	35.8%	5,720.0	1.3%
	Vegetable oils	19.4%	850.0	4.9%
	Peanut oil	11.5%	850.0	2.3%
	Carrot	10.0%	637.0	1.3%
	Other vegetable oils	5.6%	856.3	1.0%
Vitamin B12 (mcg.)	Dried fish	59.7%	60.0	1.2%
	Fresh fish	24.3%	3.3	10.8%
	Meat (beef, sheep, and goat)	10.0%	2.2	7.1%
	Milk powder	3.3%	1.8	2.6%
	Poultry	1.5%	0.4	4.9%

Source: Authors' calculations based on Projet d'Appui aux Politiques Agricoles (PAPA) (2017–2018) data.

Note: Results for additional nutrients (protein, Vitamin B6, Vitamin C, folate, riboflavin, niacin, and thiamin) available upon request from the authors.

TABLE 5.3—TOP FOOD PRODUCTS CONTRIBUTING TO ENERGY AND NUTRIENT PRODUCTION, SENEGAL (NATIONAL AVERAGE)

	Product	Nutrient production share	Nutrient content per 100 grams	Share of production
Energy (Kcal)	Peanut	36.6	574.0	20.0
	Millet	18.7	365.0	12.5
	Rice	16.0	347.5	14.5
	Maize	7.4	345.3	5.9
	Cassava	4.5	109.5	10.7
Calcium (mg.)	Peanut	24.6	45.0	20.0
	Cow milk	12.3	191.0	n. a.
	Cassava	10.1	29.0	10.7
	Millet	10.1	23.0	12.5
	Sesame	5.0	777.0	0.2
Iron (mg.)	Millet	55.8	15.2	12.5
	Peanut	16.0	3.5	20.0
	Rice	5.0	1.5	14.5
	Sorghum	4.7	5.2	3.1
	Maize	3.6	2.4	5.9
Vitamin A (mcg.)	Oil palm fruit	82.3	5,310.0	1.8
	Mango	3.9	203.3	1.7
	Watermelon	3.7	25.0	16.8
	Cassava	2.9	20.0	n. a.
	Carrot	2.0	637.0	n. a.
Vitamin B12 (mcg.)	Sardinella, round	40.6	8.3	n. a.
	Sardinella, flat	29.9	8.3	n. a.
	Sheep meat	6.7	3.0	n. a.
	Spanish mackerel	6.1	10.0	n. a.
	Beef	4.7	1.7	n. a.

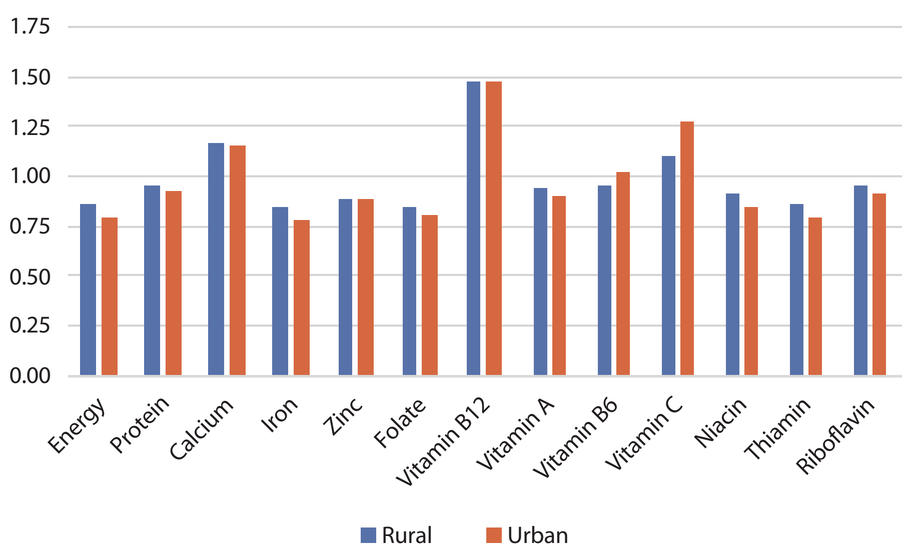
Source: Authors' calculations based on data from Directorate of Analysis, Forecasting and Agricultural Statistics (DAPSA) (2017–2018), Food and Agriculture Organization of the United Nations (FAO) (2018), Ministry of Livestock and Animal Production (MEPA) (2018), Ministry of Fisheries and Maritime Production (MPEM) (2018), and Directorate of Water, Forests, Hunting and Soil Conservation (DEFCCS) (2018).

Note: Share of production refers to share in the volume of annual crop production in kilograms, not including livestock and fisheries. N. a. = not applicable.

micronutrients. As a first step to assessing the impacts of changes in incomes or food prices on micronutrient consumption, the analysis estimated income and price elasticities of different food categories (see Ulimwengu et al. 2023 for methodological details). These elasticities were then used to derive elasticities of demand for the micronutrients contained in these foods with respect to incomes and food prices.

Figure 5.2 shows estimated income elasticities of energy and micronutrients in urban and rural areas of Senegal. Elasticities are all positive, meaning that demand for and consumption of all micronutrients is expected to increase with incomes. Elasticity values greater than one indicate that for a 1 percent increase in income, demand will increase by more than 1 percent; the opposite is true for elasticity values under one. Demand for vitamin B12, vitamin C, and calcium in both urban and rural areas is the most responsive to changes in household income, with more than proportionate increases expected to result from income growth. This reflects generally high income elasticities associated with animal-source foods and other higher-value food products in Africa (Colen et al. 2018). Income elasticities are lowest for energy, zinc, thiamine, niacin, folate, and iron. Low elasticities suggest that modest income increases may not be sufficient to overcome nutrient deficiencies quickly.

FIGURE 5.2—INCOME ELASTICITIES OF DEMAND FOR ENERGY AND KEY MICRONUTRIENTS, RURAL AND URBAN SENEGAL



Source: Authors' calculations based on Projet d'Appui aux Politiques Agricoles (PAPA) (2017–2018) data.

Price changes of food products also strongly impact households' consumption of micronutrients. Figure 5.3 shows estimated elasticities of demand for energy and selected micronutrients with respect to the prices of different food categories in rural and urban areas. Most elasticities are negative, indicating that demand for the micronutrient is expected to decline as food prices increase. Micronutrient elasticities capture households' changing food consumption patterns resulting from price changes; positive price elasticities may indicate that a price increase in a given food caused households to substitute or supplement other foods that are richer in that micronutrient.

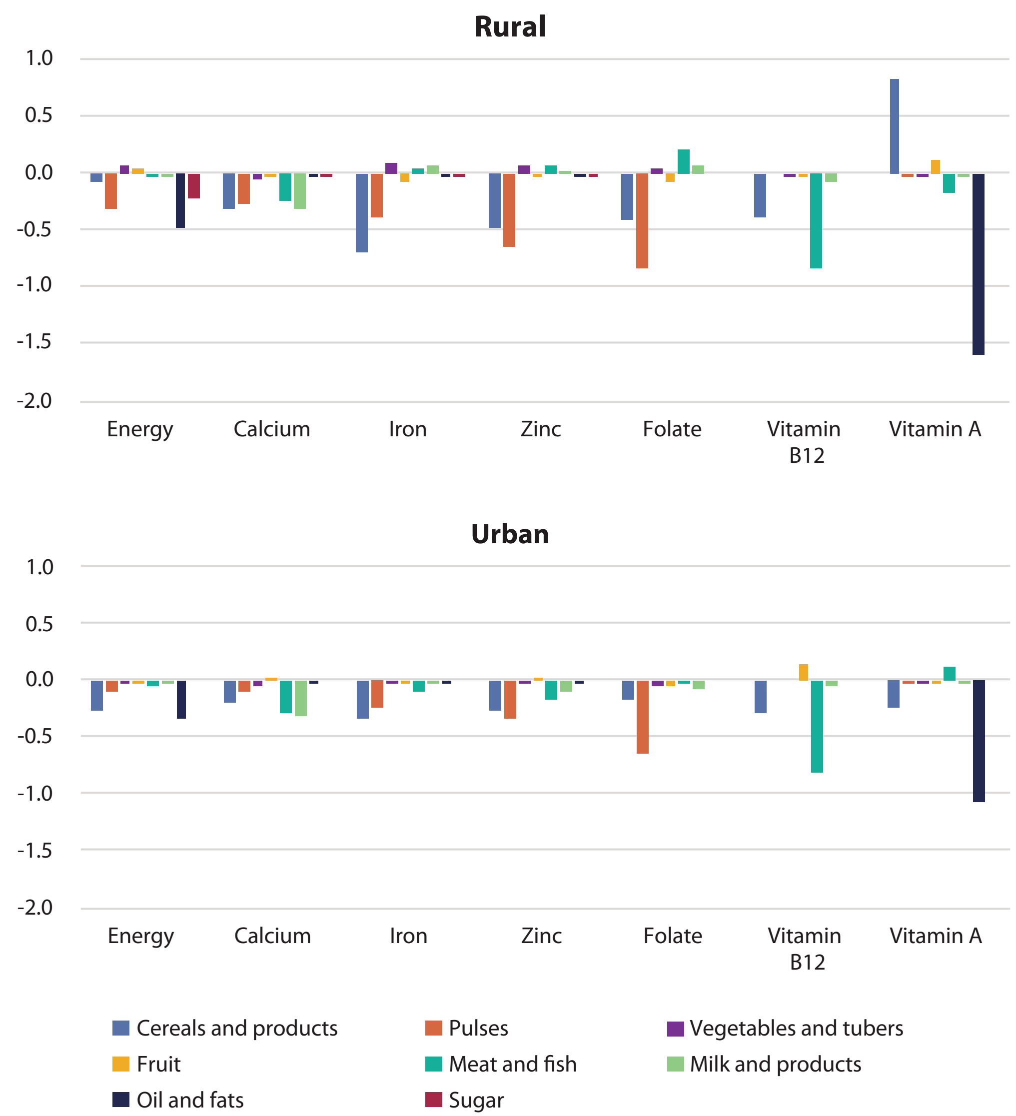
In both rural and urban areas, demand for vitamin A is highly sensitive to the price of oil; its absolute value is greater than one, indicating that price increases would provoke more than proportionate decreases in demand. The elasticity of vitamin B12 with respect to the prices of meat and fish is also among the highest elasticities in both urban and rural areas. Increases in the prices of pulses are expected to provoke significant decreases in demand for several micronutrients, especially for thiamin, niacin, and zinc in rural areas and folate in rural and urban areas. Demand for iron in rural areas is sensitive to the price of cereals.

Mapping of Nutrient Production, Market, and Household Adequacies

Figure 5.4 maps nutrient production, market, and household adequacies at the department level for energy, iron, vitamin A, and calcium.[9] Spatial patterns of the two adequacy measures differ markedly, with much lower levels of NHA than of NPA. For production adequacy, a similar geographical distribution appears for energy and zinc, as well as several other nutrients not shown in Figure 5.4 (folate, thiamin, niacin, protein, vitamin B6, and zinc). For these nutrients, there is sufficient production

9 We used forest area at the departmental level as a proxy to disaggregate production data on palm oil and nontimber forest products, which were only available at the national level.

FIGURE 5.3—ELASTICITIES OF DEMAND FOR ENERGY AND MICRONUTRIENTS WITH RESPECT TO FOOD PRICES, RURAL AND URBAN SENEGAL



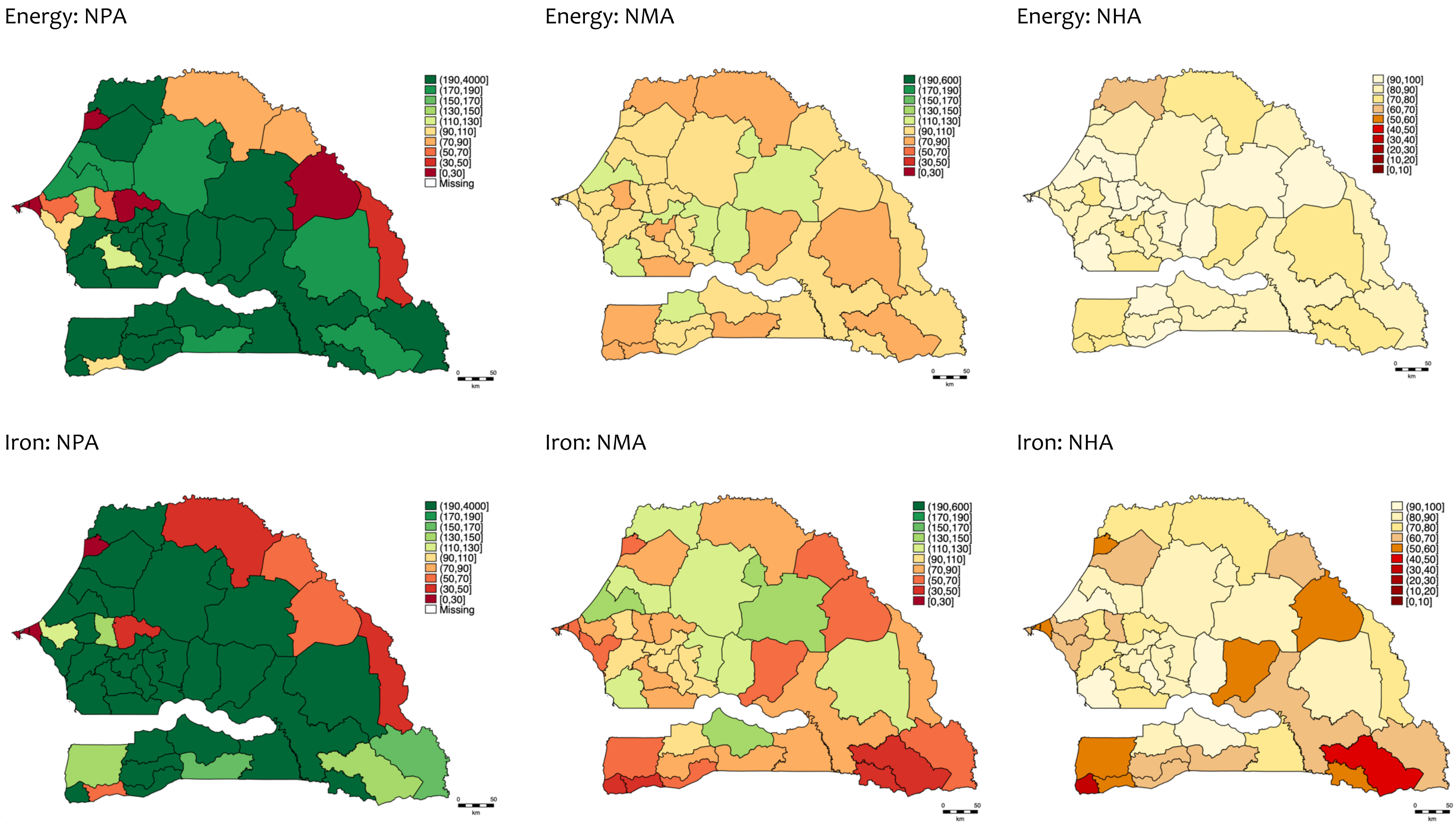
Source: Authors' calculations based on Projet d'Appui aux Politiques Agricoles (PAPA) (2017–2018) data.
Note: Elasticity results for additional nutrients are available upon request from the authors.

across a good part of the national territory, although there are some areas of high concentration in the northwest, center, and southern parts of the country. The departments located in the valley of the Senegal River (Bakel, Kanel, Matam, and Podor) and the Dakar region, as well as Mbacké, Saint-Louis, Thiès, and Ziguinchor tend to have a very low level of production adequacy. Indeed, these departments produce less than 70 percent of the recommended intake level per day and per AME for many of the nutrients examined.

However, there are significant geographical differences in the coverage of requirements for different micronutrients. For example, the iron maps show higher levels of adequacy in areas where millet, which is particularly iron-rich (Table 5.3), is widely cultivated (that is, the groundnut basin area, north of the Gambian border); for this nutrient, there is thus a certain correlation between areas with a high surplus of production and areas with larger quantities available in markets. However, the marketed quantities are below the quantities produced in most cases. This can be interpreted to result from food losses between production sites and markets, or from interdepartmental or cross-border trade.

Vitamin A production surpluses are observed in southern Senegal where oil palm is most concentrated. The departments of Goudiry, Kédégou, and Saraya, in spite of their production surplus, show the lowest levels of household nutrient adequacy in vitamin A, suggesting that much of the vitamin A produced in these departments may be consumed elsewhere. When considering the production and household adequacy of calcium, there is no doubt that the lack of domestic production of calcium-rich foods is a major concern, as only the department of Koumpentoum produces a large surplus of calcium. Market adequacy is low, especially in eastern Senegal where less than 30 percent of the recommended calcium level is available in the market.

FIGURE 5.4—MAPPING OF NUTRIENT ADEQUACY AT THE DEPARTMENT LEVEL, SENEGAL

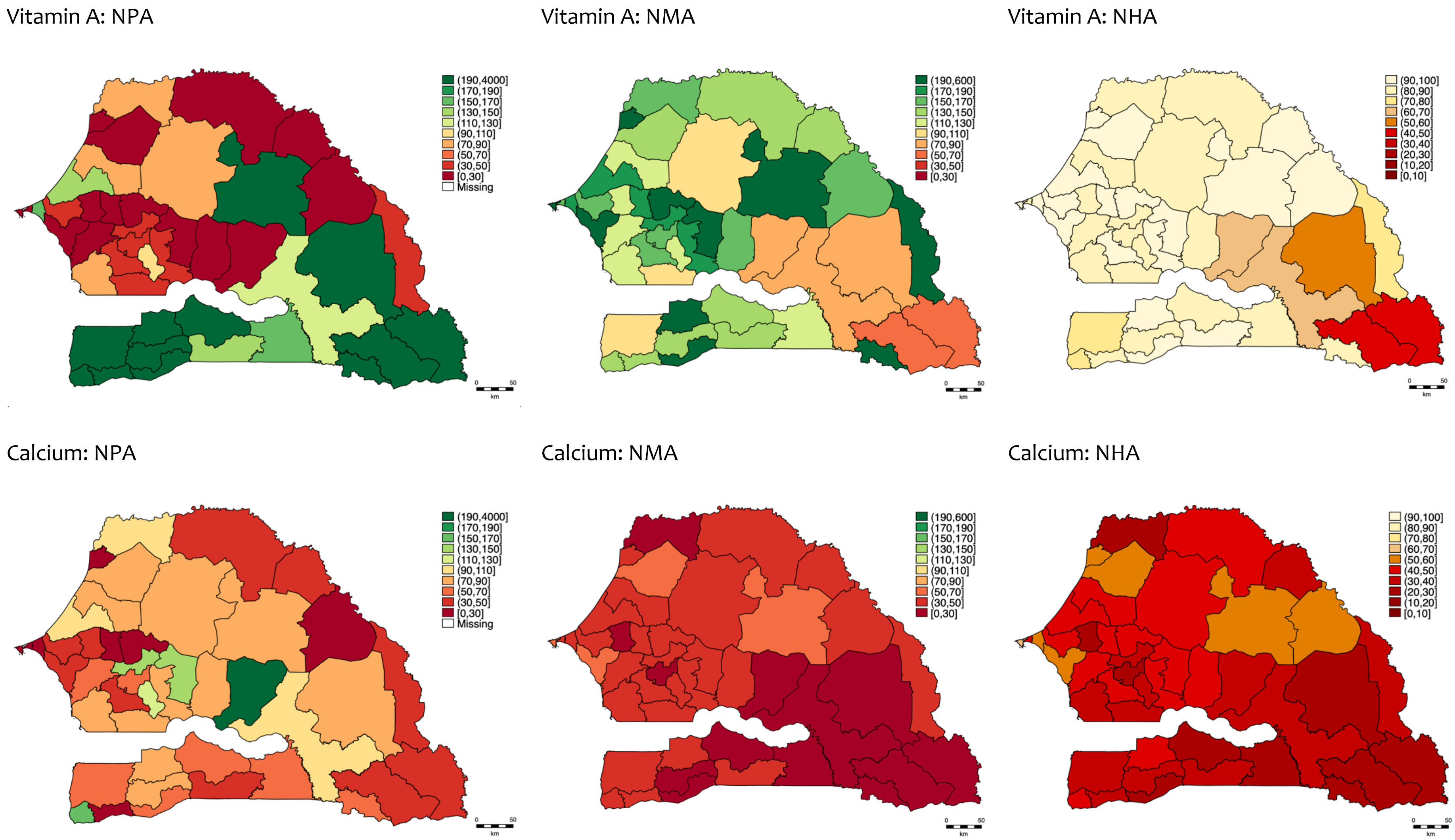


Source: Authors' calculations; market and household adequacy are based on Projet d'Appui aux Politiques Agricoles (PAPA) (2017–2018) data, and production adequacy is based on data from Directorate of Analysis, Forecasting and Agricultural Statistics (DAPSA) (2017–2018), Food and Agriculture Organization of the United Nations (FAO) (2018), Ministry of Livestock and Animal Production (MEPA) (2018), Ministry of Fisheries and Maritime Production (MPEM) (2018), and Directorate of Water, Forests, Hunting and Soil Conservation (DEFCCS) (2018).

Note: NPA = nutrient production adequacy; NMA = nutrient market adequacy; NHA = nutrient household adequacy.

continued

FIGURE 5.4—MAPPING OF NUTRIENT ADEQUACY AT THE DEPARTMENT LEVEL, SENEGAL



Source: Authors' calculations; market and household adequacy are based on Projet d'Appui aux Politiques Agricoles (PAPA) (2017–2018) data, and production adequacy is based on data from Directorate of Analysis, Forecasting and Agricultural Statistics (DAPSA) (2017–2018), Food and Agriculture Organization of the United Nations (FAO) (2018), Ministry of Livestock and Animal Production (MEPA) (2018), Ministry of Fisheries and Maritime Production (MPEM) (2018), and Directorate of Water, Forests, Hunting and Soil Conservation (DEFCCS) (2018).

Note: NPA = nutrient production adequacy; NMA = nutrient market adequacy; NHA = nutrient household adequacy.

Rwanda

Table 5.4 provides an overview of the absolute level of nutrient production and consumption in Rwanda, as well as the recommended amounts, and the three measures of nutritional adequacy for energy, protein, and 10 micronutrients at the national level. Figure 5.5 graphically presents the three measures of adequacy.

Rwanda's production covers the recommended levels of some nutrients (protein, vitamin B12, folate, vitamin C, and riboflavin). The highest surpluses are observed for vitamin C (production adequacy of 202 percent), folate (148 percent), and protein (133 percent). For the remaining nutrients, production is insufficient to cover daily nutrient requirements. The situation is even more critical for vitamin A, with less than 50 percent NPA.

NHA is far lower than NPA for most nutrients, suggesting high levels of nutrient loss between production and consumption. Except for folate, protein, and vitamin C, for which households reach at least half of the recommended levels, the average Rwandan diet seems insufficient. Vitamin C is the only nutrient with a level of market adequacy greater than 100 percent. However, the high level of availability of this nutrient in the market does not translate into sufficient consumption at the household level. The large difference between NMA and NHA for vitamin C suggests that there are significant disparities in households' access to foods rich in this nutrient.

Aside from vitamin C, NHA tends to be similar to NMA for most of the nutrients examined, suggesting that national-level nutrient consumption is distributed fairly evenly among households. In general, the three levels of adequacy combined clearly indicate that the risk of micronutrient nutrient deficiency could be an issue in Rwanda.

Key Foods Contributing to Energy and Nutrient Production and Consumption for Rwanda

TABLE 5.4—NATIONAL ENERGY AND NUTRIENT PRODUCTION, MARKET, AND HOUSEHOLD ADEQUACY, RWANDA (2016)

	Production per day, AME	Consumption per day, AME	Recommended intake per day, AME	NPA (%)	NMA (%)	NHA (%)
Energy (Kcal)	1,622.2	1,350.8	2,750	59.0	47.0	47.1
Calcium (mg.)	668.5	386.1	1,000	66.8	36.3	36.6
Iron (mg.)	20.3	13.2	27.4	73.9	45.4	45.8
Protein (g.)	66.6	28.3	50	133.3	53.7	51.4
Zinc (mg.)	10.8	4.4	14	77.1	29.9	30.9
Vitamin A (mcg.)	291.0	259.9	600	48.5	40.1	37.5
Vitamin B12 (mcg.)	2.7	1.2	2.4	110.9	47.1	38.1
Folate (mcg.)	590.8	258.4	400	147.7	61.1	58.6
Vitamin C (mg.)	121.0	82.4	60	201.6	130.6	83.8
Niacin (mg.)	18.8	5.5	20	94.0	25.9	27.1
Thiamin (mg.)	1.3	0.5	1.5	86.5	30.6	31.9
Riboflavin (mg.)	1.7	0.5	1.7	101.7	25.8	25.8

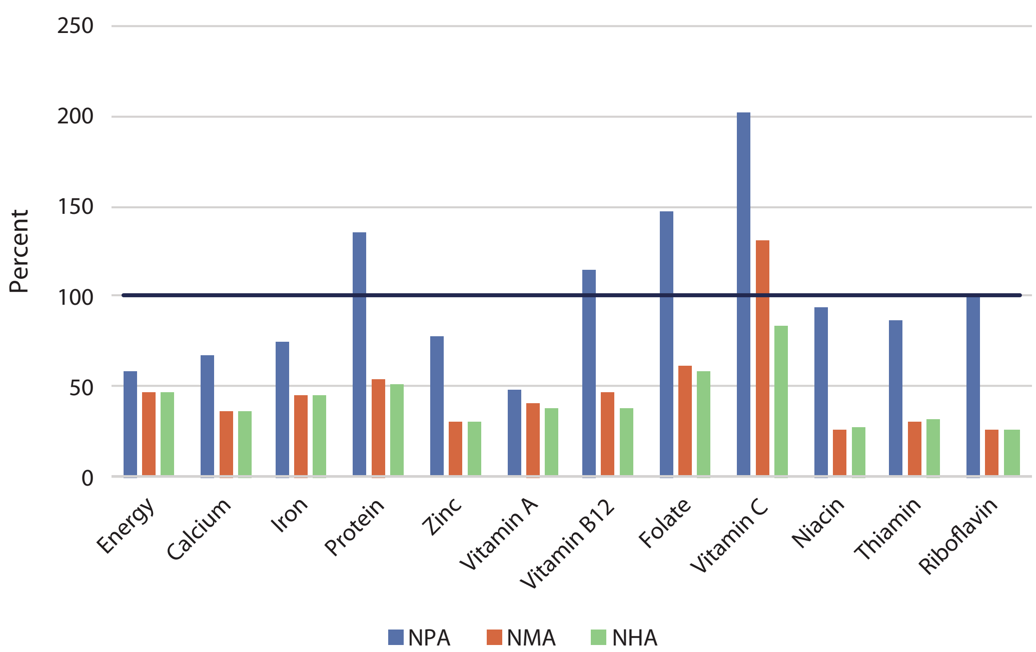
Source: Authors' calculations; market and household adequacy are based on data from National Institute of Statistics of Rwanda (NISR) (2016–2017); production adequacy is based on data from NISR (2016–2017), Ministry of Agriculture and Animal Resources (MINAGRI) (2017), and Rwanda Agriculture Board (RAB) (2017).

Note: AME = adult male equivalents; NPA = nutrient production adequacy; NMA = nutrient market adequacy; NHA = nutrient household adequacy.

Table 5.5 lists the specific food items that contribute to households' micronutrient intake as well as budget shares of each key food. The top sources of energy reflect the importance of roots and tubers in Rwandan diets, with Irish potatoes, cassava flour, and sweet potatoes together accounting for 28 percent of total energy. Corn flour is the largest single contributor to energy, accounting for 14 percent of energy consumed, but is not among top sources of any of the other nutrients. Roots and tubers also represent major sources of several micronutrients despite not being particularly rich in these nutrients, due to their large food budget shares. For example, Irish potatoes, the second highest source of energy, are also major sources of iron. Cassava flour is an important contributor of calcium and iron, and sweet potatoes are among the top sources of iron.

Calcium adequacy is extremely low, particularly in rural areas, where households consume only 33 percent of requirements on average. Amaranth is the highest contributor to calcium

FIGURE 5.5—ENERGY AND NUTRIENT PRODUCTION, MARKET, AND HOUSEHOLD ADEQUACY, RWANDA (PERCENT)



Source: Authors' calculations; market and household adequacy are based on data from National Institute of Statistics of Rwanda (NISR) (2016–2017); production adequacy is based on data from NISR (2016–2017), Ministry of Agriculture and Animal Resources (MINAGRI) (2017), and Rwanda Agriculture Board (RAB) (2017).

Note: NPA = nutrient production adequacy; NMA = nutrient market adequacy; NHA = nutrient household adequacy.

intake but accounts for less than 1 percent of food budgets; increasing amaranth consumption could potentially contribute to addressing calcium deficiencies. Similarly, dried or smoked fish represent an important source of calcium and are extremely high in calcium content, but account for only slightly more than 1 percent of food expenditures. In addition to calcium, amaranth is also the top source of vitamin A, and dried or smoked fish is the top source of vitamin B12, both nutrients with severe nutrient consumption adequacy gaps.

Other foods of note include dried beans, which are the top contributors of zinc and are among the top five sources of iron. Palm oil is very rich in vitamin A and is the second largest source of vitamin A in diets. Rice accounts for the highest budget share of a single food product, 8.7 percent, but is not among the top sources of any nutrient (except for niacin, not shown in Table 5.5).

Table 5.6 summarizes the five most important national crops accounting for Rwanda's production of selected nutrients. Beans play an even more important role in terms of production than in consumption: Although they are not the dominant crop in terms of volume, they are by far the largest contributor to the production of several nutrients. Beans account for nearly 15 percent of all energy produced in Rwanda and more than 20 percent of national production of iron and zinc. The important but less prominent role of beans in nutrient consumption may reflect exports of beans produced in Rwanda to neighboring countries (FAO 2023).

The table demonstrates the dominant role of sweet potatoes in national production in terms of volume. Sweet potatoes account for 15 percent of annual crop production volume and play significant roles as sources of energy, calcium, and vitamin A; this reflects mainly their large share in production, as sweet potatoes have relatively low nutrient content for calcium and vitamin A compared with other top sources.

Cereals—millet and sorghum—are also among the main sources of energy, protein, and many of the micronutrients examined. Maize is among the top five sources of all nutrients shown except vitamins A and B12 and calcium. Animal and fishery products are the main sources of vitamin B12 production in Rwanda and also contribute significantly to the production of several other nutrients, with milk representing a major source of energy, calcium, and vitamin A and cattle meat among the top sources of iron.

Calcium and vitamin A are among the nutrients for which production is inadequate to meet national requirements. Maize and sorghum are high in energy but account for less than 6 percent and 3 percent respectively of production in Rwanda. Cassava leaves and green vegetables (*inyabutongo*) each represent less than 2 percent of crop production but provide 280 milligrams or more of calcium for every 100 grams consumed. Cassava leaves and green vegetables are also important sources of vitamin A production, after carrots. Increased production

TABLE 5.5—TOP FOOD CONTRIBUTING TO ENERGY AND MICRONUTRIENT INTAKE, RWANDA (NATIONAL AVERAGE)

	Food item	Nutrient intake share	Nutrient content per 100 grams	Budget share
Energy (Kcal)	Corn flour	14.3%	355.0	6.3%
	Irish potato	11.1%	105.0	7.9%
	Cassava flour	9.4%	341.0	4.4%
	Peanut oil	9.2%	900.0	4.5%
	Sweet potato	7.5%	92.0	5.3%
Calcium (mg.)	Amaranth	18.8%	346.0	0.9%
	Dried or smoked fish	9.6%	1,248.1	1.2%
	Fresh milk	8.2%	119.0	1.6%
	Cassava leaves	6.8%	298.0	0.6%
	Cassava flour	6.6%	66.0	4.4%
Iron (mg.)	Irish potato	14.2%	1.3	7.9%
	Dried beans	13.4%	2.8	7.7%
	Amaranth	12.9%	8.3	0.9%
	Cassava flour	5.7%	2.0	4.4%
	Sweet potato	5.5%	0.6	5.3%
Vitamin A (mcg.)	Amaranth	29.9%	362.0	0.9%
	Palm oil	22.2%	5,490.0	0.4%
	Carrot	11.8%	552.0	0.6%
	Cassava leaves	10.0%	287.0	0.6%
	Tomato	4.5%	26.0	3.3%
Vitamin B12 (mcg.)	Dried or smoked fish	57.4%	23.8	1.2%
	Fresh milk	12.7%	0.6	1.6%
	Beef meat	12.6%	2.3	3.0%
	Fresh fish	3.8%	2.9	0.7%
	Milk powder	2.4%	3.2	0.1%

Source: Authors' calculations based on data from National Institute of Statistics of Rwanda (2016–2017).
Note: Results for additional nutrients available on request from authors.

TABLE 5.6—TOP FOOD PRODUCTS CONTRIBUTING TO ENERGY AND MICRONUTRIENT PRODUCTION, RWANDA (NATIONAL AVERAGE)

	Food item	Nutrient production share	Nutrient content per 100 grams	Share of production
Energy (Kcal)	Bean	14.7%	303.0	7.6%
	Milk	12.2%	70.0	n. a.
	Maize	11.8%	342.5	5.4%
	Sweet potatoes	8.3%	101.0	15.4%
	Sorghum	6.1%	338.5	2.8%
Calcium (mg.)	Milk	50.5%	119.0	n. a.
	Bean	10.4%	88.7	7.6%
	Cassava leaves	4.5%	298.0	1.0%
	Green vegetables: *inyabutongo*	4.4%	280.0	1.7%
	Sweet potatoes	4.4%	22.0	15.4%
Iron (mg.)	Bean	27.8%	7.2	7.6%
	Cattle meat	10.7%	7.3	n. a.
	Maize	8.9%	3.3	5.4%
	Sorghum	6.8%	4.7	2.8%
	Potato	5.8%	1.4	9.6%
Vitamin A (mcg.)	Milk	39.9%	41.0	n. a.
	Green vegetables: *inyabutongo*	11.8%	326.0	1.7%
	Cassava leaves	9.9%	287.0	1.0%
	Carrots	5.0%	589.0	0.3%
	Sweet potatoes	3.7%	8.0	15.4%
Vitamin B12 (mcg.)	Milk	63.3%	0.6	n. a.
	Cattle meat	19.7%	1.8	n. a.
	Goat meat	5.0%	3.0	n. a.
	Fish	4.5%	2.1	n. a.
	Pig meat	3.8%	1.0	n. a.

Source: Authors' calculations based on data from NISR (2016–2017), Ministry of Agriculture and Animal Resources (MINAGRI) (2017), and Rwanda Agriculture Board (RAB) (2017).

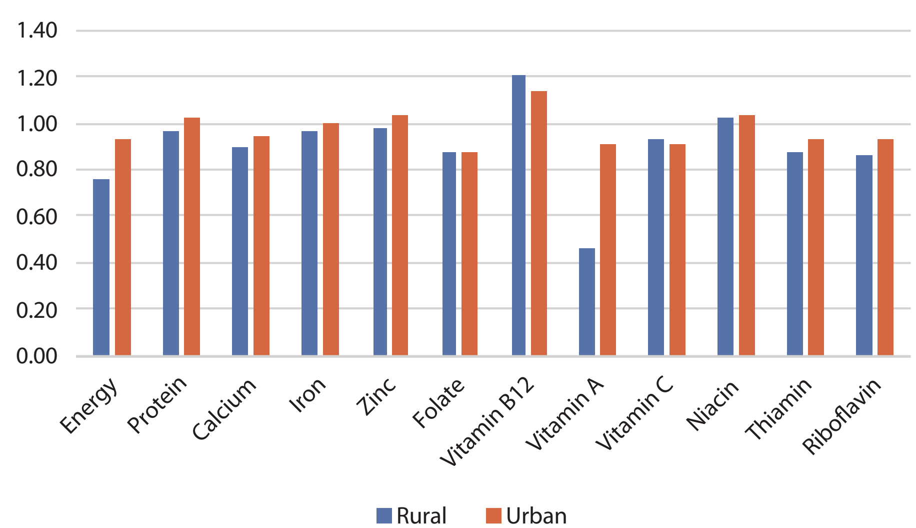
Note: Production share refers to share in the volume of annual crop production in kilograms, not including livestock and fisheries. Results for additional nutrients available upon request from authors. N. a. = not applicable.

of green vegetables and cassava leaves, which are relatively rich in calcium and vitamin A, and maize, which is high in energy, would help to improve production adequacy; enrichment could also provide the opportunity to increase the availability of vitamin A, calcium, and other micronutrients.

Elasticities of Demand for Energy and Nutrients

Figure 5.6 shows estimated income elasticities of energy, protein, and micronutrients in urban and rural areas. Demand for vitamin B12 in both urban and rural areas is the most responsive to changes in household income, with more than proportionate increases expected to result from income growth. Income elasticities are close to 1.0 for several other nutrients, reflecting proportional or slightly less than proportional increases in consumption in response to changes in income.

FIGURE 5.6—INCOME ELASTICITIES OF DEMAND FOR ENERGY AND KEY NUTRIENTS, RURAL AND URBAN RWANDA



Source: Authors' calculations based on data from National Institute of Statistics of Rwanda (2016–2017).

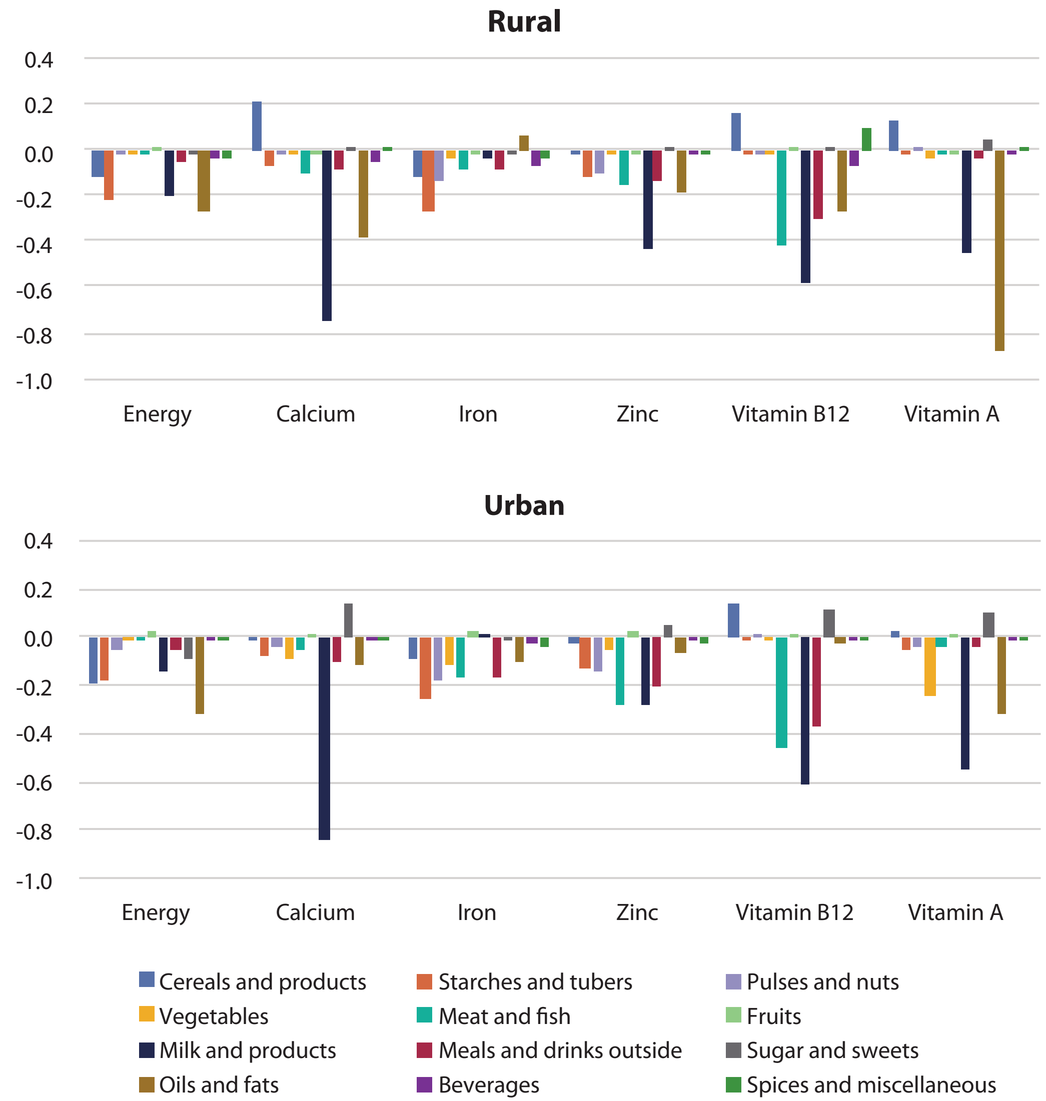
Of all nutrients examined, the lowest income elasticity is that for vitamin A in rural areas. The elasticity value of 0.46 suggests that a given increase in income would result in a significantly smaller increase in vitamin A demand. The low responsiveness of vitamin A demand to income increases suggests that it may be challenging to address extremely low vitamin A adequacy levels in rural areas through cash transfers or other income-increasing interventions alone. In general, income interventions may be most effective at improving nutrition when combined with education efforts or incentives for purchases of nutrient-rich foods.

Price changes of food products also strongly impact households' consumption of nutrients. Figure 5.7 shows estimated elasticities of demand for energy, protein and micronutrients with respect to the prices of different food categories in rural and urban areas. Most elasticities are negative, indicating that demand for the nutrient is expected to decline as food prices increase. As noted earlier, nutrient elasticities capture households' changing food consumption patterns resulting from price changes; positive price elasticities may indicate that a price increase in a given food caused households to substitute or supplement other foods that are richer in that nutrient but less expensive.

A key observation from Figure 5.7 is that the prices of milk and dairy products have strong impacts on demand for several of the nutrients with the highest adequacy gaps, including calcium, zinc, vitamin B12, vitamin A, and riboflavin, in both urban and rural areas. This suggests that actions to lower milk prices through supply increases, cost-reducing technologies, or price subsidies could be effective interventions to increase the consumption of key nutrients. Prices of starches and tubers also show relatively strong effects on demand for several nutrients, including folate, vitamin C, niacin, and thiamin.

The demand for vitamin A is highly responsive to the price of oil in rural areas, and to a lesser extent to that of milk and dairy products; in urban areas, milk prices have the strongest impact on vitamin A demand. Oil prices also have strong impacts on the demand for riboflavin and for calcium in rural areas. Demand for energy is relatively inelastic but is most responsive to prices of oils and fats in both urban and rural areas. Prices of starches and tubers, milk and milk products, and cereal products also impact the demand for energy.

FIGURE 5.7—ELASTICITIES OF DEMAND FOR ENERGY AND NUTRIENTS WITH RESPECT TO FOOD PRICES, RURAL AND URBAN RWANDA



Source: Authors' calculations based on data from National Institute of Statistics of Rwanda (2016–2017).
Note: Elasticity results for additional nutrients are available upon request from the authors.

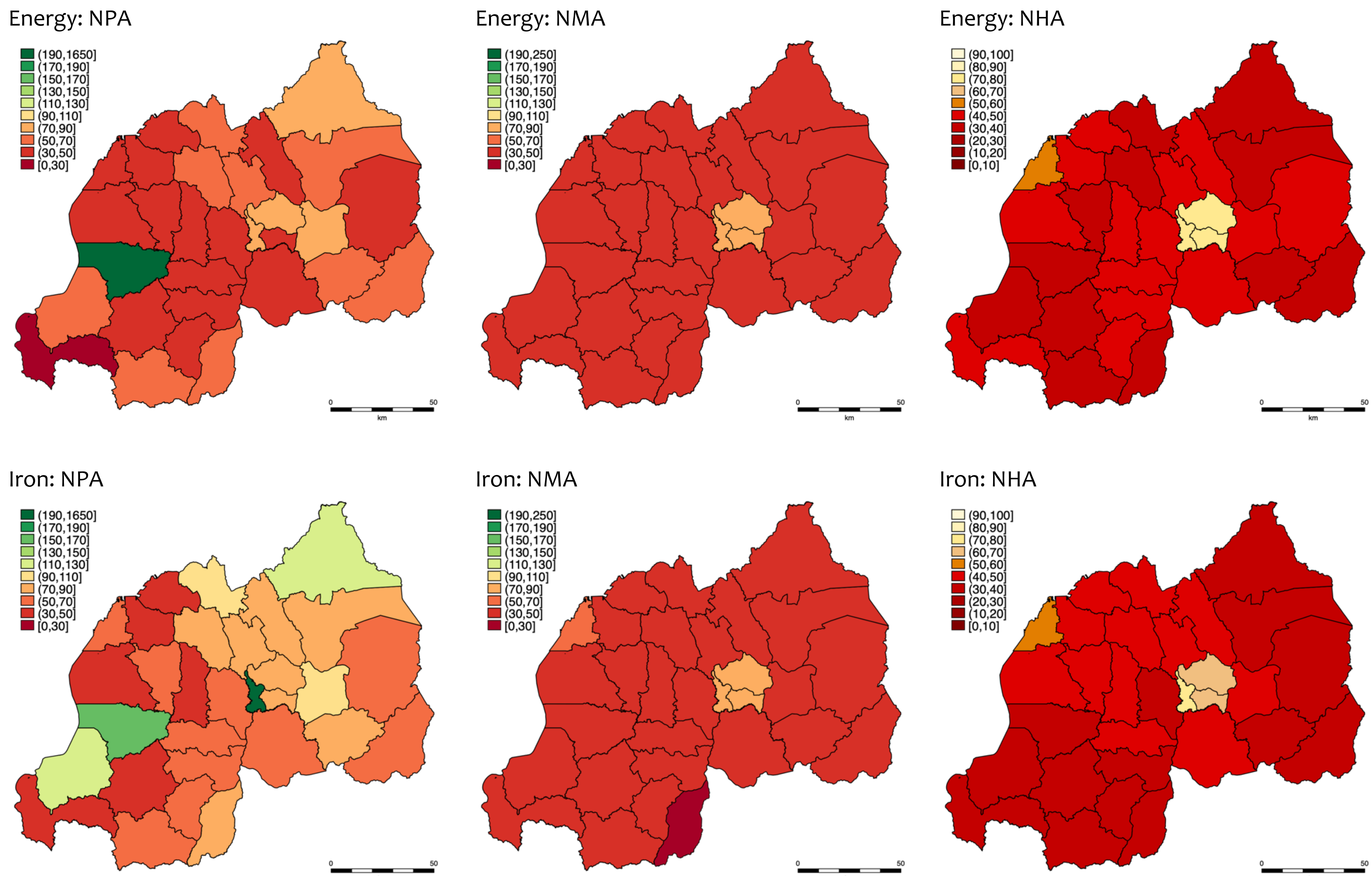
Mapping of Nutrient Production, Market, and Household Adequacies

Figure 5.8 maps NPA, NMA, and NHA at the district level for energy, iron, vitamin A, and calcium. A very different spatial pattern can be observed between production and household adequacy, with much lower levels of household adequacy. The most alarming deficiency is observed for vitamin A, with low production adequacies in most districts (less than 30 percent of intake requirements in much of the country) and correspondingly low levels of consumption adequacy observed at the household level.

The Kigali districts have a much higher level of household adequacy than other districts for most nutrients, and higher production adequacy for several nutrients. The Karongi district of western Rwanda has relatively high production adequacy in each of the nutrients examined, but this does not translate into higher-than-average household adequacy. Aside from the higher levels in Kigali, NHA does not show large variations across the country for most nutrients; for some, including iron (as well as protein, folate, thiamin, and niacin, not shown in Figure 5.8), adequacy is slightly higher in northwestern districts.

As observed for vitamin A, the lack of domestic production of calcium-rich foods appears to be a major concern. In fact, only the districts of Gasabo and Karongi produce a surplus of calcium. In addition, households in Rwanda do not appear to be filling the gap in calcium from sources other than national production, as household adequacy levels are below 40 percent in most districts. Increasing production of calcium-rich foods such as cassava leaves, green vegetables, and milk and increasing access to other calcium-rich foods through trade are among effective strategies to combat calcium deficiencies.

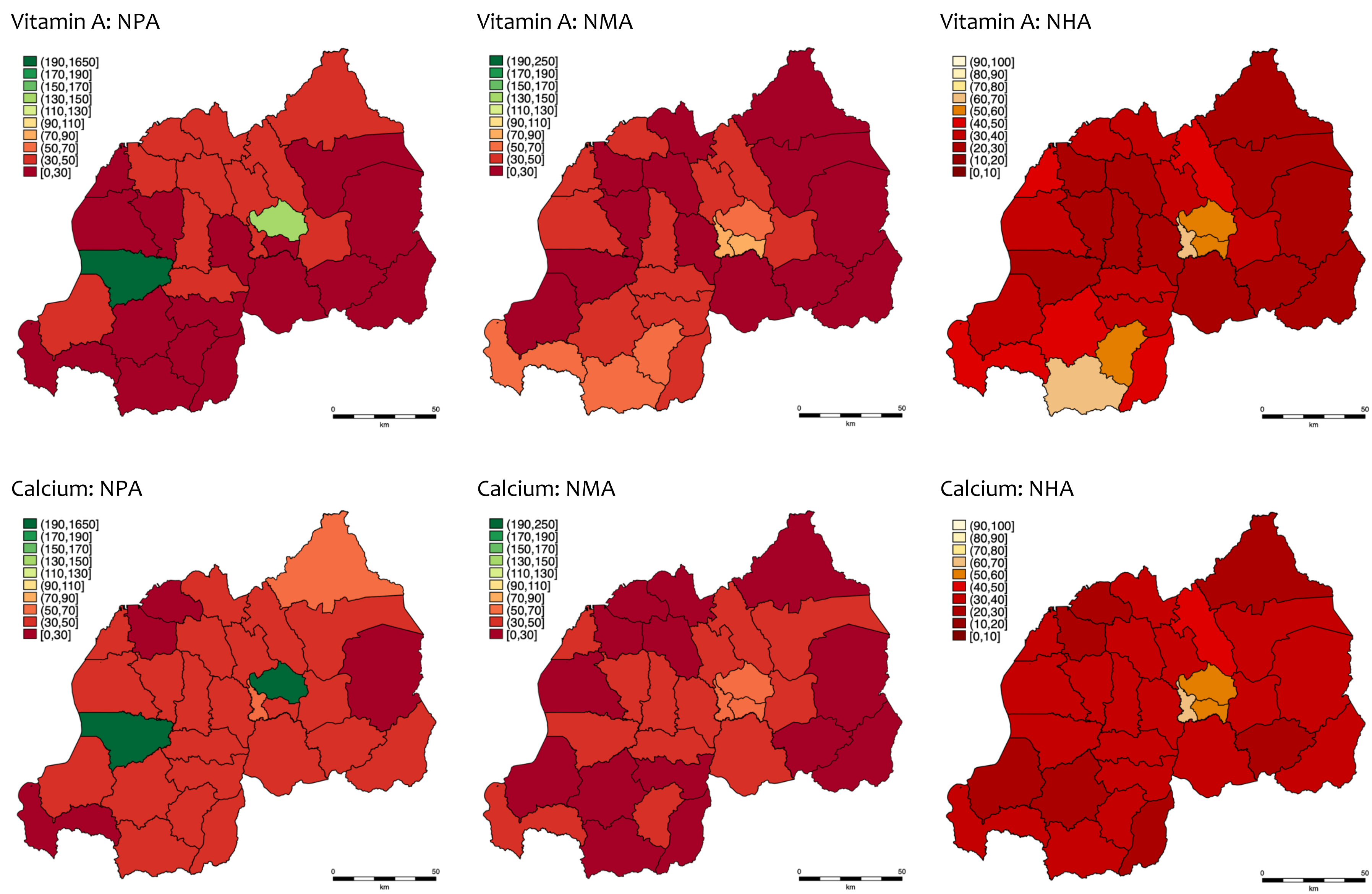
FIGURE 5.8—MAPPING OF NUTRIENT ADEQUACY AT THE DISTRICT LEVEL, RWANDA



Source: Authors calculations; market and household adequacy are based on data from National Institute of Statistics of Rwanda (NISR) (2016–2017); production adequacy is based on data from NISR (2016–2017), Ministry of Agriculture and Animal Resources (MINAGRI) (2017), and Rwanda Agriculture Board (RAB) (2017).

continued

FIGURE 5.8—MAPPING OF NUTRIENT ADEQUACY AT THE DISTRICT LEVEL, RWANDA



Source: Authors calculations; market and household adequacy are based on data from National Institute of Statistics of Rwanda (NISR) (2016–2017); production adequacy is based on data from NISR (2016–2017), Ministry of Agriculture and Animal Resources (MINAGRI) (2017), and Rwanda Agriculture Board (RAB) (2017).

The Case for Country-Specific Nutrition-Smart Food Systems

Senegal and Rwanda face multiple micronutrient adequacy gaps, in many cases severe. Adequacy levels vary by nutrient, by country and subnational area, and by food system segment: for example, NPA, NMA, and NHA tend to differ markedly from each other in Senegal. In Rwanda, NMA and NHA tend to be similar to each other, but substantially lower than production adequacy. Differences between NPA, NMA, and NHA can give a first indication of potential causes for inadequate nutrient intake and suggest context-specific ways for addressing deficiencies. In this section, we review some potential strategies for increasing NPA, NMA, and NHA in Senegal and Rwanda.

To achieve the goal of making nutritious foods more accessible and affordable, all strategies pursued must account for trade-offs and ensure that the system is sustainable both in terms of production and in ensuring the well-being of all stakeholders involved. Trade-offs can manifest in various ways, from environmental and economic perspectives to sociocultural implications. Intensifying production of certain nutritious foods might result in greater environmental degradation if not done sustainably. Overfarming can deplete soils, and overfishing can damage aquatic ecosystems. Lower prices can sometimes mean that smallholder farmers earn less for their produce, potentially increasing economic inequalities. Making nutritious foods cheaper might inadvertently lead to overconsumption of certain nutrients if not balanced with dietary education.

Increasing Nutrient Production Adequacy

For both Senegal and Rwanda, NPA is much higher at the national level than market and household consumption adequacy. Senegal produces more than sufficient levels of nearly all the nutrients examined compared with national requirements, while Rwanda produces sufficient levels of about half the nutrients examined. This could suggest that efforts to increase nutrient consumption should put significant emphasis on increasing the retention of nutrients between the production and consumption stage. However, even though the association between NPA and NMA or NHA is not clear-cut, low levels of consumption adequacy are in some cases likely to be the result of low production adequacy. For example, in Senegal, the two nutrients with the lowest household adequacy levels—calcium and riboflavin—are the only two with inadequate production. Similarly, the lower levels of NMH and NHA in Rwanda compared to Senegal are likely related at least in part to lower NPA. Thus, increasing production adequacy should be part of the portfolio of strategies addressing nutrient intake gaps in both countries, and particularly for Rwanda.

Adjusting the crop production mix could contribute to increased production of key nutrients, depending on the agronomic potential for expanding production in nutrient-rich crops. For example, ongoing efforts to support local dairy industries in Senegal and Rwanda can be complemented with incentives to encourage the production of calcium-rich crops, such as sesame in Senegal and cassava leaves and green vegetables in Rwanda, to lessen shortfalls in calcium production adequacy in both countries. Another important approach to increasing the production of key nutrients is through biofortification. Biofortification is a process through which the nutrient content of crops is enhanced through breeding; it has been found to be a cost-effective way to reach rural populations that might be underserved by other interventions such as supplementation and industrial fortification (Bouis and Saltzman 2017).

Increasing Nutrient Market Adequacy

Efforts to increase the availability of nutrients for consumption can include interventions to increase the share of agricultural production that is ultimately consumed (for example, by reducing postharvest losses and food waste and decreasing nutrient loss during storage and processing) as well as to increase the supply of nutrients from sources other than national production. Here we focus on two such sources with significant potential to increase nutrient adequacy: trade and industrial fortification.

Increasing Nutrient Supply through Trade

Trade should feature among key strategies to address nutrient gaps in both Senegal and Rwanda. Domestic exchange within countries can help allocate nutrients from surplus to deficit zones. While this is true for both countries, interdepartmental variations in nutrient adequacy are particularly noticeable in Senegal. Figure 5.4 shows that adjacent departments often have wide variations in NPA. Variation in terms of NMA is not as large but still apparent, suggesting that there may be scope for increased interdepartmental trade to address nutrient gaps in some areas.

Beyond reallocation within countries, global and intra-African trade has great potential to reduce nutrient gaps in Senegal and Rwanda. Numerous studies underline the positive impacts of trade in enhancing food security in general and increasing micronutrient adequacy in particular. For example, Odjo and Badiane (2018) and Makochekanwa and Matchaya (2019) find that regional cereal production patterns are more stable than national production patterns, suggesting that increased regional trade would increase the market stability and improve resilience to local production shocks. Bonuedi, Kamasa, and Opoku (2020) find that trade facilitation efforts in Africa improve food security by increasing the availability food in markets, reducing volatility of food supplies, and increasing the variety of foods available, as well as helping to reduce postharvest losses. Importantly, trade can increase dietary diversity, which is associated with greater nutrient intake adequacy (Ruel 2003). Dithmer and Abdulai (2017) empirically test the impacts of trade openness on diets and find that greater openness increases dietary diversity as well as calorie consumption.

Several global-level studies have found that international trade can help to increase supplies of micronutrients in areas with production deficits (Ge et al. 2021; Wood et al. 2018). Geyik and colleagues (2021) suggest that the contribution of trade is generally not sufficient to meet requirements in nutrient-deficient low-income countries; however, intra-African trade in particular makes a sizable contribution to supplies of vitamin A and vitamin B6 on the continent. Olivetti and others (2023) find that Africa's global imports make significant contributions to its iron and zinc requirements. While imports from outside the continent supply larger quantities of nutrients than intra-African trade, those intra-African imports represent a relatively sizable share of imported vitamin A and vitamin B12. In Senegal, regional imports may explain the greater availability of vitamin B12 in national markets than would be suggested by national production patterns, with higher NMA than NPA. The contribution of intra-African trade to filling nutrient gaps may be higher than suggested by official trade statistics because a sizable share of cross-border agricultural trade is informal and unrecorded. The portion of trade in nutrient-dense perishable products that takes place informally is thought to be particularly high, as border delays are especially costly for perishable products (Olivetti et al. 2023).

Intra-African trade is limited by numerous obstacles, including lengthy border requirements, lack of harmonization of procedures and requirements, and high transport costs. Trade facilitation efforts such as those associated with implementation of the African Continental Free Trade Area could help to enhance the contribution of intra-African trade to food security and nutrition. Countries should consider trade policies as an important tool to increase supplies of key micronutrients for which local production does not meet requirements. In Senegal, calcium and zinc are not produced in adequate quantities, and these two nutrients as well as riboflavin show the largest shortfalls in household consumption adequacy. Senegal's trade policies should consider the nutrient content of food products and aim to minimize barriers to imports of foods rich in calcium, riboflavin, and zinc. In Rwanda, calcium, vitamin A, iron, and zinc production fall far short of meeting national requirements; trade policies that facilitate the imports of products rich in these nutrients could contribute to filling gaps. It should be noted that trade can also contribute to the increased availability of foods high in fat, salt, sugar, and other substances associated with increased risk of noncommunicable diseases. Policies to mitigate this risk should focus on improving the quality of the entire supply of food rather than on restricting trade—for example, with quality or nutrition standards that apply to domestically produced as well as imported food (Martin and Laborde Debucquet 2018).

Increasing Nutrient Supply through Industrial Fortification

Another way to increase NMA at the post-production level is through industrial fortification, which involves adding nutrients to food products at the processing stage. Fortification has been successfully used in high-income countries for decades to address micronutrient gaps at the population level (Tulchinsky 2015). Fortification is becoming more prominent in low-income countries as well, where it has been associated with large reductions in anemia, goiter, and neural tube defects (Keats et al. 2019).

Both Senegal and Rwanda have identified fortification as a key strategy to combat micronutrient deficiencies. In Rwanda, fortification of maize flour, wheat flour, edible oil, sugar, salt, and cereal-based products became mandatory in 2019; Senegal mandated fortification of oil and wheat flour in 2009 (Nakitto, forthcoming). However, both countries face challenges in enforcing and improving the effectiveness of fortification programs. In Rwanda, enforcement of fortification regulations and standards is lacking, and the current extent of food fortification remains unknown (Guthiga and Kirui 2019; Nakitto, forthcoming). Challenges include the high cost of fortification equipment and inputs, which limits the ability of processors to comply, as well as a substantial share of the population that does not consume commercially processed food. In Senegal, enhancing the reach and effectiveness of fortification efforts is constrained by the fragmented nature of some industries. For example, small-scale salt production and packaging makes salt iodization challenging. Rice is not subject to mandatory fortification despite being a major staple and dominant source of energy (Table 5.2), perhaps due to the disaggregated industry structure in which small-scale mills process most of the rice (Nakitto, forthcoming). Small-scale food fortification could be an important way to reach consumers not served by large-scale food industries, and approaches to overcome the associated challenges should be explored (Philar and Johnson 2005).

Both countries should enhance capacities for fortification monitoring and quality assurance on the part of government bodies, as well as implementation capacities of processors. Efforts should be made to ensure adequate levels of consumption of fortified foods, including through education efforts or price incentives. Finally, more data is needed on the current status of fortification as well as the effectiveness of fortification efforts; these topics should be integrated into existing and new data collection efforts (Nakitto, forthcoming).

Increasing Nutrient Household Adequacy

Even when the overall availability of nutrients is sufficient to meet the population's requirements, some households may not be able access the required nutrients. This is the case, for example, for vitamin A and vitamin B12 in Senegal and vitamin C in Rwanda, each of which show NMA of well over 100 percent but with nutrient household adequacy values of 89 percent, 80 percent, and 84 percent, respectively (Tables 5.1 and 5.4). In many cases, this is likely to be related to households' limited purchasing power and the relatively high cost of nutritious foods. Headey and Alderman (2019) found that nutrient-dense foods such as animal products and fruits and vegetables are relatively expensive compared to starchy staples, especially in low-income countries. FAO and others (2023) estimated that healthy diets supplying adequate energy and micronutrients were financially unattainable for more than 1 billion Africans, nearly 80 percent of the continent's population.

Social protection programs—including income transfers to increase households' overall purchasing power, as well as targeted price interventions—can help to alleviate financial barriers to nutrient access. Increases in income are expected to increase overall food consumption, but impacts on nutrient intake differ by nutrient. Our income elasticity estimates (Figures 5.2 and 5.6) suggest that income increases would produce the largest consumption responses for vitamin B12 in both countries as well as calcium and vitamin C in Senegal. Efforts to increase consumption of these nutrients may find income transfers to be an effective avenue. For some nutrients, such as vitamin A in rural Rwanda, relatively low income elasticities suggest that other types of interventions may be better vehicles for addressing deficiencies.

Strategies to increase intake of specific nutrients could also include price subsidies for key foods. Figure 5.3 suggests that in Senegal, decreases in the prices of oil and of meat and fish could be effective strategies to increase demand for vitamin A and vitamin B12, respectively, while decreases in the price of pulses would raise demand for several key nutrients including thiamin, niacin, folate, and zinc. In Rwanda, demand for several nutrients with large adequacy gaps (including calcium, zinc, vitamin B12, vitamin A, and riboflavin) is fairly responsive to the price of milk products (Figure 5.7). As in Senegal, demand for vitamin A is sensitive to the price of cooking oil in rural Rwanda.

In addition to price and income interventions, nutrition education programs can help to increase households' demand for and consumption of nutritious food. Education efforts can include commercial marketing of healthy foods, maternal nutrition education programs, and community nutrition education outreach programs (FAO 1997; Jardí, Casanova, and Arija 2021). One example of a community outreach program is Rwanda's *One Egg Per Child, Everyday* campaign, launched by Rwanda's National Child Development Agency and UNICEF Rwanda in 2022. The campaign aims to raise awareness among both women and men on the importance of feeding animal source foods to children.

Policymakers in both countries can consider additional education efforts aimed at increasing the consumption of other nutrient-rich foods. For example, in Rwanda, amaranth is an important source of calcium, iron, zinc and vitamin A despite currently accounting for less than 1 percent of households' food expenditures (Table 5.5); increased amaranth consumption could help to fill the large household adequacy gaps for these nutrients. In Senegal, millet represents a smaller share of food expenditures than rice but is significantly richer in iron and zinc (Table 5.2) as well as other key nutrients.

Conclusion

Although micronutrient deficiencies are widespread in African countries, patterns vary by nutrient and by country, as well as within countries. In addition, micronutrient deficiencies can stem from multiple causes. A similar deficiency could be related to low production of a nutrient in one area and from lack of purchasing power in another. The design of strategies to combat micronutrient gaps needs to be guided by detailed evidence on the prevalence and extent of deficiencies as well as by local production, market, and food consumption patterns.

This chapter presents an approach to generate needed evidence to support the design and implementation of nutrition-smart food systems strategies. We find that both Senegal and Rwanda face serious nutrient consumption gaps at the household level, with deeper inadequacies in Rwanda. In both countries, production adequacy is much higher than market adequacy and household adequacy, suggesting that a large share of the nutrients produced do not become available for consumption. In Senegal, production adequacy was well over 100 percent for nearly all nutrients examined; for Rwanda, around half of nutrients showed sufficient production levels. In Senegal, nutrient market adequacies generally exceeded nutrient household adequacies, suggesting that nutrient consumption varies substantially among households. The distribution of nutrients seems to be more evenly allocated in Rwanda. While policymakers in the two countries may wish to put more emphasis on adequacy at different stages in the food system, multiple strategies and approaches, including efforts to increase the production of nutrients, increase nutrient supply through other sources such as industrial fortification and trade, and increase households' access to nutrients in markets, can complement each other in combatting micronutrient deficiencies.

Overall, our findings suggest that there is a strong case for promoting nutrition-smart food systems in Africa. Due to a combination of factors—including climate change, economic disparities, and health issues—many African countries face significant challenges in ensuring adequate nutrition for their populations. A nutrition-smart food system could help tackle these problems by promoting the availability and affordability of healthy, nutritious food, as well as environmental sustainability. However, promoting nutrition-smart food systems in Africa would require addressing multiple challenges, including infrastructural constraints, low agricultural productivity, and policy and institutional barriers.

Future work should extend the analysis to consider the issue of bioavailability. While a nutrition-smart food system aims to provide the necessary nutrients in a form that the body can effectively use, if bioavailability is not accounted for, people might consume enough nutrients according to dietary recommendations but still suffer from deficiencies. Some nutrients can inhibit or enhance the absorption of others. For instance, nonheme iron (found in plant foods) is better absorbed when consumed with foods rich in vitamin C, while phytates in grains and legumes can inhibit its absorption (Hallberg and Hulthén 2000). From a policy and intervention perspective, it is more cost-effective to promote foods with high nutrient bioavailability than to promote those where a significant portion of the nutrients will not be absorbed.

In addition, future analyses should examine in more detail the contribution of trade to meeting nutrient requirements in Africa. Another important area of analysis relates to changes observed in food systems in the past two decades that lead to increased consumption of higher-value foods—including perishable foods such as fruits, vegetables, and animal products that tend to be relatively rich in micronutrients—as well as processed foods, some of which are relatively rich in energy, sugar, and salt. The impacts of this dietary transition on nutrient adequacy are unclear and would be important to explore.