Retail prices for sustainable, healthy diets: are foods with lower environmental impacts and healthier nutritional profiles also more expensive?

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Abstract

Background

Affordability is a key barrier to shifting to healthier, more environmentally sustainable diets. Nutrient-dense foods are more expensive for meeting daily energy needs compared to less healthy food groups, and some strategies for reducing environmental impacts of food systems can increase food prices. Still, healthy, environmentally sustainable diets may be less expensive in some contexts. We provide the first global test of how food prices relate to the environmental impacts and nutritional value of food items within and between food groups.

Methods

We use retail food prices from the World Bank International Comparison Program (ICP) from 181 countries in 2011 and 2017. We match ICP food items to estimates of GHG emissions, water footprint, and nutritional profile from published research. We use visualizations and OLS regression to estimate the relationship between prices per kilocalorie and GHG emissions, water footprint, and nutrient profile of retail food items.

Findings

We find food items with lower emissions and water footprint are less expensive ways to meet dietary needs in all food groups, with large heterogeneity between food groups. Food items with healthier nutritional profile are significantly more expensive in most but not all food groups, and different aspects of healthfulness drive this association for different food groups.

Price per kilocalorie is most strongly associated with environmental impacts and nutritional profile for animal source foods, where a 50% increase in price per kilocalorie is associated with an 8.7 gram CO_2-equivalent per 100 kilocalories increase in GHG emissions, 19.7 liter per 100 kilocalorie increase in water footprint, and 4.0 point increase in Food Compass Score.

Interpretation

Less expensive food items tend to have lower environmental impacts but also lower nutritional profiles. Still, there are inexpensive, low-impact options within each food group. Accounting for these differences in environmental harm, health impacts and cost by type of food could help guide policy interventions towards healthier and more environmentally sustainable options for all.

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Introduction

Food systems have significant impacts on the health of our planet, contributing to environmental crises including climate change, water scarcity, biodiversity loss, and pollution. Food systems account for as much as one third of anthropogenic greenhouse gas (GHG) emissions (Crippa et al. 2021) and 70 percent of freshwater withdrawals (FAO 2021), as well as about 32 percent of terrestrial acidification and 78 percent of aquatic eutrophication (Poore and Nemecek 2018). At the same time, inadequate and poor-quality diets contribute to hunger, food insecurity, and rising prevalence of diet-related chronic diseases, while also exacerbating environmental crises (Willett et al. 2019; FAO et al. 2022; Clark et al. 2019).

Many have called for shifts towards healthier, more environmentally sustainable diets to address these challenges (Tilman and Clark 2014; Willett et al. 2019). However, food prices are a key barrier to consuming healthy, sustainable diets for many people. For people to shift their food choices, healthy, environmentally sustainable foods must be affordable, yet healthy diets remain unaffordable for over three billion of people globally (FAO et al. 2022).

Analyses of agricultural and food policy often assume, either implicitly or explicitly, that more environmentally sustainable and healthier diets are more expensive for consumers (FAO et al. 2022; Willett et al. 2019; Lindgren et al. 2018). Narratives about the cost of healthy, environmentally sustainable foods are partially driven by consumers’ perceptions. Many consumers are willing to pay a premium for products marketed with health or sustainability claims, which may drive both beliefs about the relative prices of these products (Dolgopolova and Teuber 2018; Alsubhi et al. 2023; S. Li and Kallas 2021) and the higher prices often charged for them (J. Li and Hooker 2009), which consumers may extrapolate to the mistaken belief that all healthier foods are more expensive (Haws, Reczek, and Sample 2017).

Many past studies on the relationship between food price and environmental impacts of food systems have focused on trade-offs between reducing environmental impacts of food systems and improving food security and diets. For instance, evidence from modelling studies indicates that land-based strategies to mitigate GHG emissions (e.g., reducing land use change to protect forested land, growing crops for bioenergy, or switching to climate-smart production practices) can increase land scarcity and production costs, thus increasing food prices (Stevanović et al. 2017; Fujimori et al. 2022; Doelman et al. 2019). Policies that aim to improve the sustainability of groundwater use are also predicted to reduce total agricultural production, thus increasing food prices (Calzadilla, Rehdanz, and Tol 2010).

There can also be trade-offs between the healthfulness and cost of foods. At retail food outlets, fruits, vegetables, and other nutrient-rich food groups are more expensive on average than starchy staples, vegetable oils, sugars, and other less healthy foods for meeting daily energy needs (Headey and Alderman 2019; Carlson and Frazão 2012). Evidence from Belgium, Mexico, and the United States also suggests that higher-quality diets that are closer to meeting dietary guidelines are more expensive per kilocalorie and per day (Vandevijvere et al. 2020; Curi-Quinto et al. 2022; Conrad et al. 2021).

When we consider both the healthfulness and environmental sustainability of foods and diets, the evidence is more mixed. The EAT-Lancet reference diet, a dietary pattern intended to be healthy for both people and the planet, is unaffordable for many, especially in lower-income countries (Hirvonen et al. 2020; Willett et al. 2019). Still, studies of modelled or observed diets in specific countries show that some healthier, more environmentally sustainable dietary patterns tend to be less expensive (Springmann et al. 2021; Curi-Quinto et al. 2022; Conrad et al. 2023). Modelling global data, Springmann et al. (2021) suggest that vegetarian and vegan diets are less expensive compared to current diets, especially in wealthier countries (Springmann et al. 2021). Examining dietary surveys from Mexico, Curi-Quinto et al. (2022) show that healthier, more environmentally sustainable diets are less expensive, and adults with lower socioeconomic status are more likely to consume these diets (Curi-Quinto et al. 2022). Analyzing the diets of individuals in the United States who follow popular dietary patterns, Conrad et al. (2023) find that plant-based diets have low GHG emissions and relatively low cost, yet there are trade-offs between cost, diet quality, and environmental impacts of other dietary patterns (Conrad et al. 2023).

However, many of these theoretical dietary patterns differ markedly from what most people currently consume and do not necessarily reflect the breadth of foods available at retail food outlets globally (Hirvonen et al. 2020; Willett et al. 2019; Springmann et al. 2021). This study provides the first global test of how market prices relate to the environmental impacts and nutritional value of food items within and between food groups. We combine retail food prices from 181 countries with estimates of the GHG emissions, water footprint, and nutritional profile of these food items, to assess whether healthier, more environmentally sustainable diets are more expensive. Identifying which healthier or more sustainable foods are actually less expensive, within and between food groups, could help in the design of policy interventions that achieve environmental and health goals at lower cost to consumers.

Methods

We use food item availability and retail prices from the World Bank's International Comparison Program (ICP) global and regional food lists in 2011 and 2017. The ICP provides average prices in local currency units (LCU) for 869 food items in 177 countries in 2011 and 732 food items in 175 countries in 2017, as reported by national statistical organizations (The World Bank 2023). We convert to prices in 2017 United States dollars (USD) using purchasing power parity (PPP) exchange rates for individual consumption expenditure by households, provided by the ICP. We exclude 5 countries and territories (Anguilla, Bonaire, Cuba, Montserrat, and Taiwan) for which PPP exchange rates were not available.

The ICP reports prices per reference quantity (e.g., 1 kilogram of rice, 500 grams of bread, 1 liter of olive oil, etc.). We convert prices per reference quantity to prices per kilogram using information available in food item descriptions provided by the ICP. We match the ICP food items to food composition data – kilocalories per 100g and edible portion – from the USDA Standard Reference Release 28 (SR-28), the USDA Food Products Database, the West Africa Food Composition Table, the Bangladesh Food Composition Table, and the USDA Food Products Database, and the FAO/INFOODS Global food composition database for fish and shellfish (uFish 1.0). We use food composition data to calculate prices per kilogram and per kilocalorie of edible matter. (See equations in Appendix 1a.)

We classify food items into food groups based on the Healthy Diet Basket (HDB), a set of globally comparable recommended intakes of six key food groups developed based on national dietary guidelines from 10 countries. HDB food groups include starchy staples; animal-source foods (ASFs); legumes, nuts and seeds; vegetables; fruits; and oils and fats (Herforth et al.

2022). We calculate prices per recommended daily intake by adjusting prices per kilocalorie of edible matter by the HDB recommended intake of each food group. (See Appendix 1b for recommended intakes of each HDB food group.) We categorize sugars, sweets, and candies into an additional food group, for which there is no recommended intake. We exclude alcoholic beverages, non-caloric beverages, coffee, tea, culinary ingredients, spices, herbs, condiments, mixed dishes with unclear composition, and infant foods.

We draw estimates of greenhouse gas (GHG) emissions and water footprint of food items from a database created by Petersson et al. (2021). GHG emissions estimates represent all emissions from production and distribution of each food item; water footprint estimates represent all water use and pollution from production and distribution of each food item, including ground and surface water (blue water) and rain water (green water) (Harris et al. 2020). These estimates reflect environmental impacts of food items to the consumer stage, including post farm gage impacts such as processing, packaging, and transport but excluding post-market impacts such as cooking. This database includes estimates of GHG emissions in carbon dioxide equivalents (CO_2e) per kilogram of food for 324 food items and estimates of water footprint in liters of water per kilogram of food, based on the Global Water Footprint Standard, for 320 food items. (See Appendix 1d for detailed methodology for matching GHG emissions and water footprint estimates to ICP food items.) We convert GHG emissions to CO_2e per kilocalorie of food and water footprint to liters per kilocalorie of food using food composition data.

We estimate the nutritional profile of food items using established metrics, including Food Compass Score (FCS) (Mozaffarian et al. 2021), Nutri-Score (Santé Publique France 2023), and Health Star Rating (Australian Government 2023). FCS is a nutrient profiling system that rates the healthfulness of foods on a scale of 0 to 100 based on 9 domains relevant to health outcomes, including nutrient ratios (ratios of unsaturated to saturated fat, fiber to carbohydrates, and/or potassium to sodium), vitamins, minerals, food-based ingredients, additives, processing, specific lipids, total fiber and protein, and phytochemicals (Mozaffarian et al. 2021). (See Appendix 1d for descriptions of the 9 FCS domains.) Nutri-Score, created by Santé Publique France, is a nutritional rating between 0 and 5 based on the food item's content per 100g of nutrients and foods to promote, including dietary fiber, protein, fruits, vegetables, pulses, nuts, and plant oils, and nutrients to limit, including total sugar, saturated fat, sodium, and total energy. The Nutri-Score is translated into a letter from A to E for use on a color-coded front-of-pack label (Santé Publique France 2023). The Health Star Rating is a nutritional rating that scores foods between 0.5 and 5 to inform front-of-pack food labels with 0.5 to 5 stars. Health Star Ratings are based on the food item's total energy; content of nutrients associated with chronic disease, including saturated fat, sodium, and sugar; and content of nutrients and foods associated with improved health outcomes, including fiber, protein, fruits, vegetables, nuts, and legumes (Australian Government 2023). We match the ICP food items to estimates of the Health Star Ratings and Nutri-Score of USDA FNDDS 2015-16 food items from Mozaffarian et al. (Mozaffarian et al. 2021) and to updated FCS of USDA FNDDS 2017-18 food items provided by the Food Compass research team.

We visualize the relationship between GHG emissions, water footprint, and nutrient profile and price per kilocalorie using scatter plots and line graphs. Due to the large number of price observations, we use binned scatter plots, where each point represents the mean of the x-axis and y-axis variables across 100 equal-sized bins of the x-axis variable. Line graphs show average GHG emissions, water footprint, and nutrient profile by decile of price per kilocalorie; deciles represent deciles of price by food group, country, and year. We estimate the associations between price per kilocalorie and GHG emissions, water footprint, and nutritional profile using the following OLS regression model:

$$Y = \beta_0 + \beta_1 * \ln(price) + \varepsilon$$

Where Y is a vector of measures of environmental impacts and nutritional profiles of each ICP food item, including GHG emissions in kilograms of carbon dioxide-equivalents per kilocalorie of food, water footprint in liters per kilocalorie of food, Food Compass Score on a scale from 0 to 100, each of the 9 component domains of FCS, Health Star Rating on a scale from 0 to 5, and Nutri-Score on a scale from 1 to 5 (letter scores of E are converted to 1, D to 2, etc.), and price is the price per kilocalorie of each ICP food item. Regression models include country fixed effects and are stratified by HDB food group. Visualizations and analyses are executed in Stata SE 16.

Results

We find that food items with lower emissions and water use are less expensive ways to meet dietary needs in all food groups, with large heterogeneity between food groups. Food items with healthier nutritional profile scores are significantly more expensive in most but not all food groups, and the relationship between price and nutritional profile varies between the different measures of healthfulness that make up the FCS.

GHG emissions and retail food prices

The GHG emissions associated with retail food items varies distinctly between food groups. ASFs have much higher GHG emissions per kilocalorie on average, and the most within-group variation in GHG emissions. Though some vegetables have lower GHG emissions, there is a wide range of GHG emissions associated with different vegetables, including some high-emissions vegetables such as tomatoes and mushrooms that have higher GHG emissions than inexpensive, low-emissions ASFs such as sardines and anchovies.

More expensive food items have significantly higher GHG emissions per kilocalorie for all food groups except fruits (Figure 2). The magnitude of this association is largest for ASFs and vegetables. A 50% increase in price per kilocalorie is associated with an increase in GHG emissions of 8.659-grams CO_2-equivalent per 100 kilocalories for ASFs and 3.086-grams for vegetables. In fact, the emissions associated with the most expensive of ASFs and vegetables in each country are over twice as high as the emissions associated with the cheapest foods in each food group (Figure 3).

Starchy staples, legumes, nuts, and seeds, oils and fats, and sugars, sweets, and candies have lower GHG emissions per kilocalorie compared to vegetables and ASFs across all deciles of price per kilocalorie (Figure 3). Still, there is a smaller but significant association between price and GHG emissions per kilocalorie in each of these food groups. A 50% increase in price per kilocalorie is associated with an increase in GHG emissions of 1.634-grams CO_2-equivalent per 100 kilocalories for sugars, sweets, and candies, a 0.115-gram increase for starchy staples, a 0.0845-gram increase for legumes, nuts, and seeds, and a 0.956-gram increase for oils and fats.

Water footprint and retail food prices

There is wide variation in the magnitude of water footprint per kilocalorie between food groups. On average, starchy staples, oils and fats, and sugars, sweets, and candies have the lowest water footprint. In comparison, more nutrient-dense food groups, including animal-sources foods, legumes, nuts, and seeds, fruits, and vegetables have higher water footprint and larger variation in water footprint between food items within each food group (Figure 1b).

Retail food prices per kilocalorie are positively associated with water footprint for every food group except for starchy staples (Figure 1b, Figure 2). The magnitude of association between price and water footprint is largest for ASFs, followed by legumes, nuts, and seeds, and vegetables. On average a 50% increase in price per kilocalorie is associated with a 19.659-liter higher water footprint per 100 kilocalories for ASFs, an 18.157-liter increase for legumes, nuts, and seeds, and a 13.042-liter increase for vegetables. Though fruits have relatively high water footprint on average, the association between price and water footprint is slightly smaller; a 50% increase in price per kilocalorie is associated with a 4.394-liter higher water footprint (Figure 2).

For ASFs, the direction of the relationship between price and water footprint varies somewhat as price increases (Figure 1b, Figure 3). While some relatively expensive ASFs have high water footprint, such as fresh and cured beef products, some of the most expensive ASFs in each country have comparatively low water footprint, such as certain cheeses and fresh fish fillets. For vegetables, fruits, and legumes, nuts and seeds, the relationship between price per kilocalorie and water footprint is somewhat more even across deciles of price (Figure 3). More expensive food items within each food group generally have higher water footprint compared to less expensive alternatives.

Nutrient profile and retail food prices

There is wide variation in nutrient profile between food groups. For most food groups, price is positively associated with healthfulness, and the magnitude of this association is largest for ASFs, followed by sugars, sweets, and candies, starchy staples, and vegetables. In contrast, higher price is associated with lower healthfulness for oils and fats (Figure 1c, Figure 2).

Vegetables, fruits, and legumes, nuts, and seeds have high nutrient profile across all deciles of price per kilocalorie (Figure 3). There is a small but significant positive association between price and nutrient profile for these three food groups, though the magnitude of this association is relatively small (Figure 2). A 50% increase in price per kilocalorie is associated with a 1.551-point increase in FCS for vegetables, a 1.186-point increase for fruits, and a 0.363-point increase for legumes, nuts, and seeds, all relatively small on a scale from 0 to 100.

Starchy staples and sugars, sweets, and candies have lower nutrient profile on average across all deciles of price per kilocalorie, though more expensive options within each group do tend to be more nutritious (Figure 1c, Figure 3). Still, there is a small but significant positive association between price and nutrient profile for these food groups. A 50% increase in price per kilocalorie is associated with a 1.925-point increase in FCS for starchy staples and a 2.080-point increase for sugars, sweets, and candies.

Higher price is most strongly associated with higher nutrient profile for ASFs. A 50% increase in price per kilocalorie of ASFs is associated with a 4.049-point increase in FCS. However, much of this association is driven by a smaller set of highly nutritious ASFs that are expensive in many countries, including fresh fish like grouper, snapper, and sole (Figure 1c, Figure 3).

The price per kilocalorie of oils and fats is negatively associated with nutrient profile. A 50% increase in the price of oils and fats is associated with a 7.879-point decrease in FCS. This trend is primarily driven by the high cost of butter, ghee, and margarine in many countries, which have much lower nutrient profile than comparatively inexpensive plant oils.

Results comparing other measures of nutrient profile, including Health Star Rating and Nutri-Score to food prices per kilocalorie, are generally consistent with results on Food Compass Score (see Appendices).

Domains of nutrient profile and retail food prices

FCS is a composite score calculated from sub-scores across 9 domains – nutrient ratios, vitamins, minerals, food-based ingredients, additives, processing, specific lipids, fiber and protein, and phytochemicals. When we look at the associations between price per kilocalorie and each domain of the FCS, we see that certain domains are more strongly associated with price in general, and certain domains drive associations with price for different food groups. In general, the presence of food-based ingredients with proven links to chronic disease outcomes and favorable nutrient ratios (i.e., unsaturated to saturated fat, fiber to carbohydrates, and potassium to sodium) are most strongly associated with price per kilocalorie. Additives and phytochemicals, however, are not strongly associated with price per kilocalorie for any food group.

The associations between FCS and price also vary widely between domains. For vegetables, higher cost is associated with higher content of minerals, vitamins, and fiber, suggesting that less expensive vegetables are lower in these nutrients on average. In contrast, these aspects of healthfulness are not associated with cost for fruits, suggesting that inexpensive fruits are similarly high in minerals, vitamins, and fiber compared to less expensive fruits. For legumes, nuts, and seeds, price is only significantly associated with favorable nutrient ratios, again suggesting that the content of key nutrients such as minerals, vitamins, fiber, and protein is similar across price points within this food group.

Among starchy staples and sugars, sweets, and candies, price per kilocalorie is most strongly associated with favorable nutrient ratios (fiber to carbohydrates and unsaturated to saturated fat, in this case). Thus, inexpensive, less healthful options within these food categories tend to be those high in refined grains, added sugars, and saturated fat.

Higher cost of ASFs is most strongly associated with content of food-based ingredients. For ASFs, seafoods are given positive points towards food-based ingredients and red and processed meats are given negative points, so this association is primarily driven by the high cost of many seafoods, especially shellfish.

Discussion

Comparing retail food prices from 181 countries with estimates of the GHG emissions, water footprint, and nutrient profile associated with each food item, we find that more expensive retail food items tend to be more healthful and have higher environmental impacts. Thus, less expensive foods tend to have lower environmental impacts but are somewhat less nutritious compared to alternatives within the same food group. Higher price is associated with higher GHG emissions in all food groups except for fruits, and the association between price and emissions is largest for ASFs and vegetables. Higher price is associated with higher water footprint for all food groups except for starchy staples, and the association between price and water footprint is largest for nutrient-dense food groups including ASFs, legumes, nuts, and seeds, vegetables, and fruits. Higher price is also associated with higher nutrient profile in all food groups except oils and fats, though different aspects of healthfulness drive the association with price in different food groups. Still, there are healthful, inexpensive options available in each food group, and these options tend to have lower environmental impacts. While nutrient-dense food groups such as vegetables, fruits, and ASFs are more expensive on average per kilocalorie compared to starchy staples, oils and fat, and sugars, there are less expensive, relatively nutritious options within each of these food groups that also have lower environmental impacts.

Past studies showing that healthier, more environmentally sustainable dietary patterns tend to be less expensive (Springmann et al. 2021; Curi-Quinto et al. 2022; Conrad et al. 2023) have primarily focused on trade-offs between food groups, for example consuming less ASFs and more fruits, vegetables, and plant-source protein foods. Our results are consistent with these studies, reinforcing the finding that ASFs have both higher cost and higher environmental impacts on average compared to other food groups. However, calls for broad dietary shifts are often criticized as infeasible because of the difficulty of changing individual and cultural food preferences and the high comparative cost of some nutrient-dense foods (Headey and Alderman 2019).

We show that incentives aiming to lower environmental impacts of diets could instead focus on shifts to less expensive, lower impact foods within each food group. This strategy would be most effective for the nutrient-dense foods groups (ASFs, vegetables, fruits, and legumes, nuts, and seeds) that already have the highest burden of cost and environmental impacts, as well as the largest variation in cost and environmental impacts. Vegetables, fruits, and legumes, nuts, and seeds have comparatively high nutrient profile at all price points, so choosing less expensive options would have little impact on dietary quality. While the most nutritious ASFs are also the most expensive, there are also nutrient-dense options at lower price points.

For consumers to choose healthy, environmentally sustainable options within each food group, however, they need access to information about these attributes. Our results highlight the importance of creating comprehensive, standardized food labeling systems that convey information about both the healthfulness and environmental impacts of foods. Some aspects of nutrient profile are already communicated on food labels in many countries, though not often in ways that are interpretable by consumers, and levels of environmental impact are rarely shown on food labels. The database and methodology created in this study – linking retail food items to prices, environmental impacts, and nutritional profiles – can be used to inform comprehensive labeling schemes, as well as the selection of low-cost, healthy, environmentally sustainable foods for inclusion in nutrition programs or interventions.

These results can also highlight specific areas where innovations to improve the efficiency of food supply chains and reduce food prices. For example, we find that less expensive vegetables have lower GHG emissions and water footprint but are also less nutritious. In particular, less expensive vegetables tend to have lower vitamin and mineral content. Thus, innovations to reduce the price and environmental impacts of expensive vegetables such as tomatoes, spinach, and broccoli could have benefits for both nutrition and the environment.

Strengths and limitations

This is the first global analysis connecting retail food prices to estimates of the environmental impacts and healthfulness of foods available at retail around the world. We utilize average country-level retail food prices from 181 countries from the ICP, an established initiative managed by the World Bank to monitor and compare retail prices between countries. We leverage a comprehensive, recently created database of GHG emissions and water footprint associated with specific food items, created through a standardized methodology that accounted for the quality and uncertainty of existing evidence (Petersson et al. 2021). We estimate nutrient profile using FCS, a multidimensional nutrient profiling system that allows us to assess both the overall healthfulness of each food item and components that contribute to these scores. By starting with retail food availability and prices, we focus on the cost and impacts of the foods available in retail food environmental worldwide rather than foods consumed as part of theoretical dietary patterns. By converting prices and environmental impacts to units per kilocalorie, we are able to meaningfully compare between different options within the same food group that have different mass, water content, and inedible portion.

This study has a few important limitations. First, we use estimates of GHG emissions and water footprint compiled by Petersson et al. (2021) based on a review of available evidence. Most studies estimating the GHG emissions and water footprint of foods are from higher-income countries, yet we utilize ICP food prices from 181 countries. Thus, we use global estimates of GHG emissions and water footprint for each food item rather than country-specific estimates. In addition, estimates of GHG emissions and water footprint were not available for all ICP food items. We matched GHG emissions estimates to 78% of ICP food items and water footprint estimates to 76% of ICP food items. We exclude foods for which no appropriate match was available, including some processed foods for which available GHG emissions and water footprint estimates did not account for important post farm gate impacts. (See Appendix 1c for details on matching between ICP food items and environmental impact estimates.)

Water footprint is a consolidated indicator that includes both green and blue water use and pollution. The estimates used do not differentiate between green and blue water use, nor do they account for local water scarcity. Still, the water footprint estimates from Petersson et al. (2021) provide a starting point for understanding the relationship between retail food prices and water use. In addition, food systems have important environmental impact beyond GHG emissions and water use, such as contributions to land use and land use conversion, biodiversity loss, and pollution of land, air, and waterways. Reliable estimates of the magnitude of how specific foods contribute to these impacts are scarce. Future studies of the environmental impacts of food items that focus on a wider variety of countries, foods, and types of environmental impacts could lead to useful insights on the relationship between food prices and environmental impacts for specific foods, agricultural production systems and value chains, geographies, and contexts.

Conclusions

As climate change and other environmental crises intensify and diets continue to transition towards less healthy diets in many countries, we increasingly need to identify strategies to reduce the health and environmental impacts of diets while simultaneously addressing the affordability of healthy diets. When we look at retail food environments globally, less expensive food items tend to have lower environmental impacts but also lower nutritional profiles. Still, there are inexpensive, low-impact options within each food group. Accounting for these differences in environmental harm, health impacts, and cost by type of food could help guide policy interventions towards healthier and more environmentally sustainable options for all.

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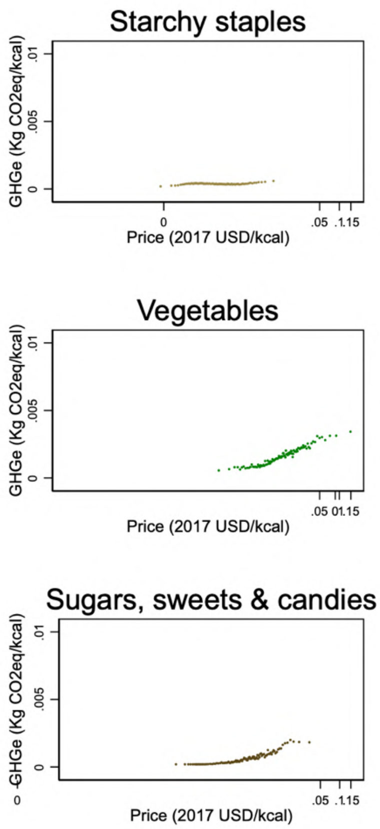
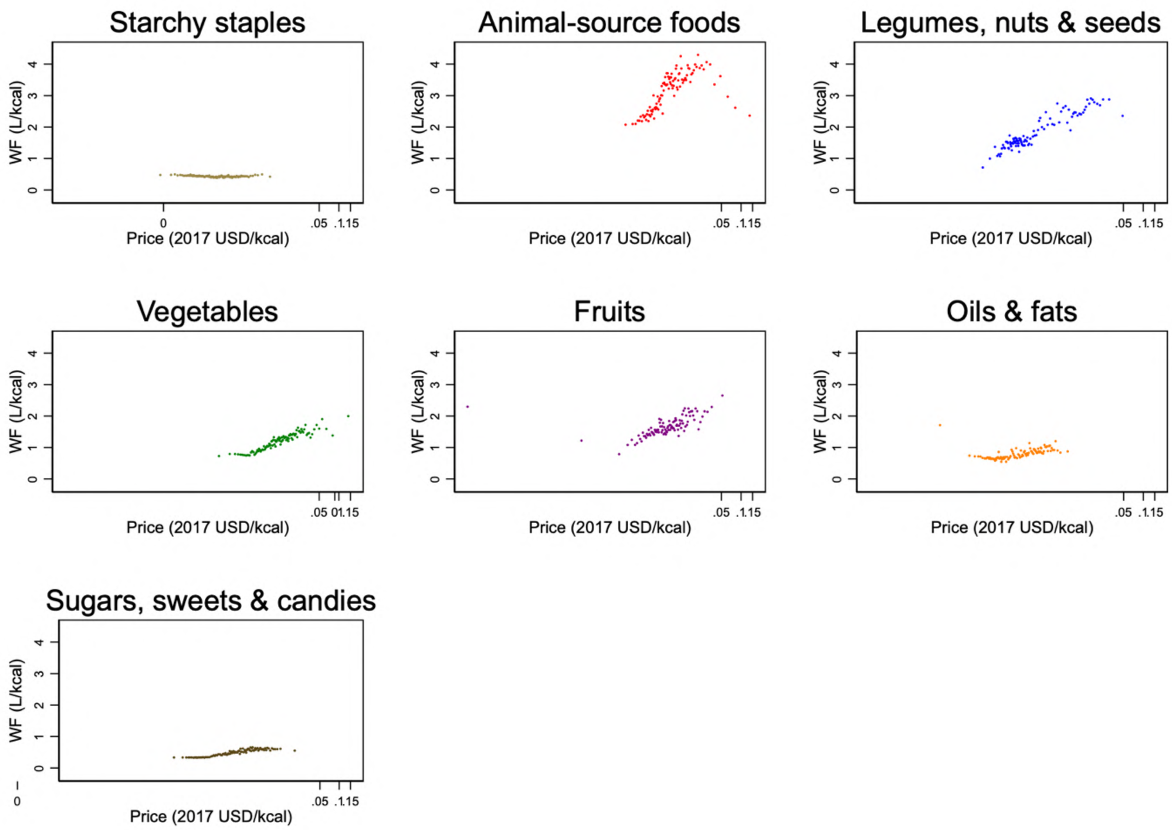
Tables and figures

Figure 1a. Estimated mean GHG emissions conditional on price per kilocalorie, by food group



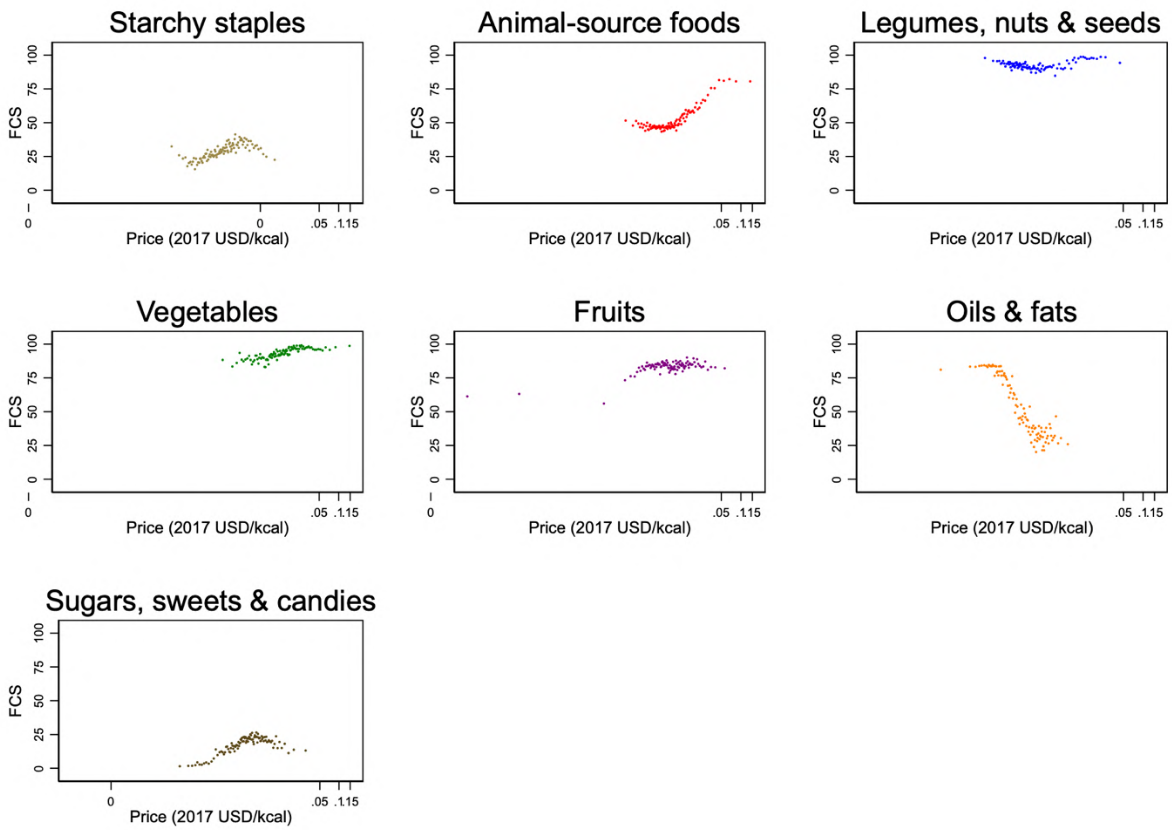
Note: GHG emissions estimates from Petersson et al. (2021) matched to average retail food prices from the World Bank International Comparison Program in 2011 and 2017 for 699 food items in 181 countries. Price in 2017 USD per kilocalorie is shown in natural-log scale.

Figure 1b. Estimated mean water footprint conditional on price per kilocalorie, by food group



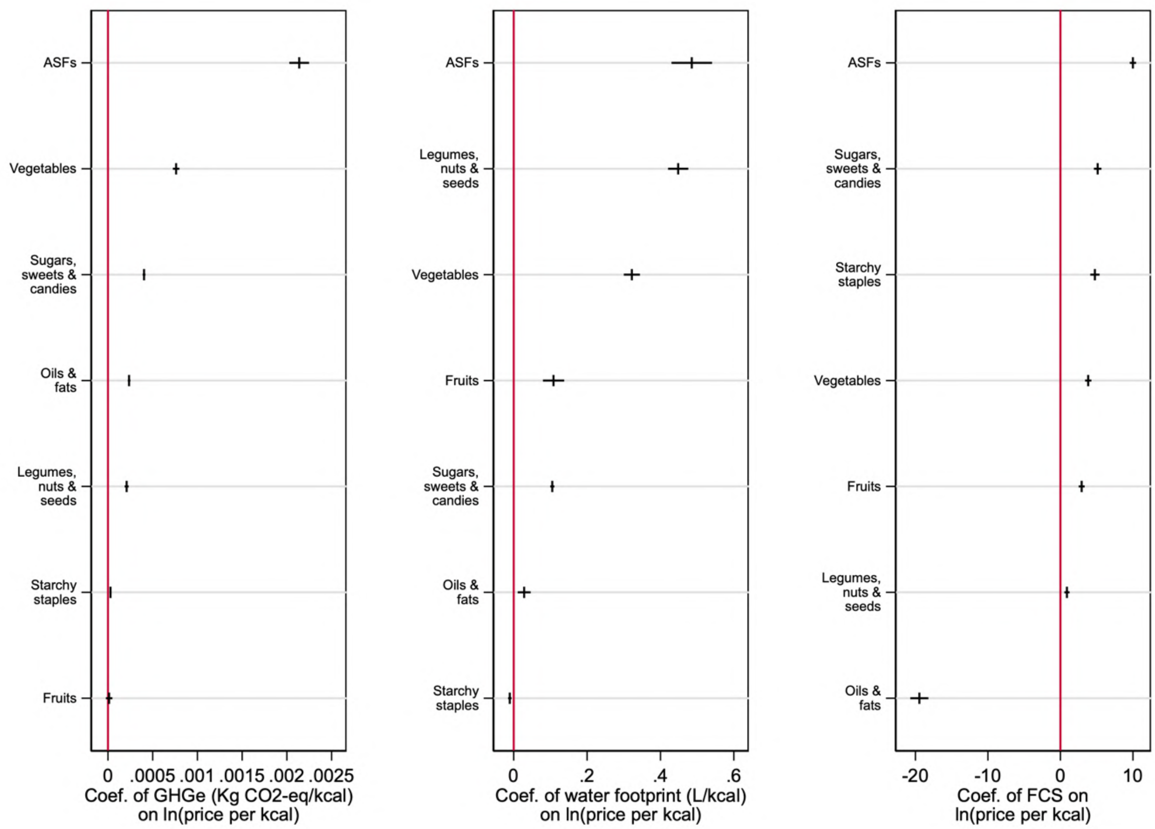
Note: Water footprint estimates from Petersson et al. (2021) matched to average retail food prices from the World Bank International Comparison Program in 2011 and 2017 for 681 food items in 181 countries. Price in 2017 USD per kilocalorie is shown in natural-log scale.

Figure 1c. Estimated mean Food Compass Score conditional on price per kilocalorie, by food group



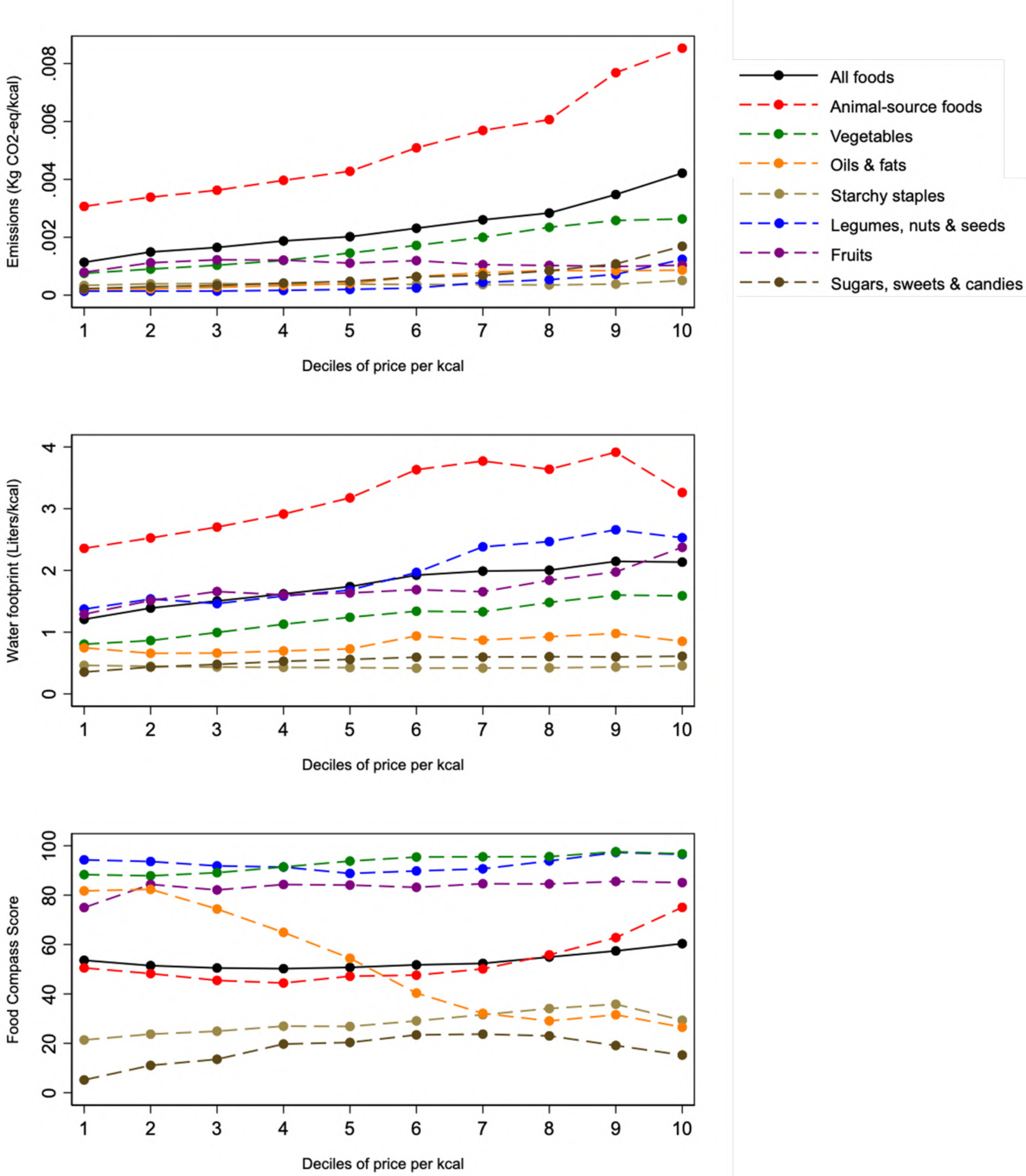
Note: Food Compass Score calculations from Mozaffarian et al. (2021) matched to average retail food prices from the World Bank International Comparison Program in 2011 and 2017 for 824 food items in 181 countries. Price in 2017 USD per kilocalorie is shown in natural-log scale.

Figure 2. Associations between price per kilocalorie and GHG emissions, water footprint, and Food Compass Score by food group



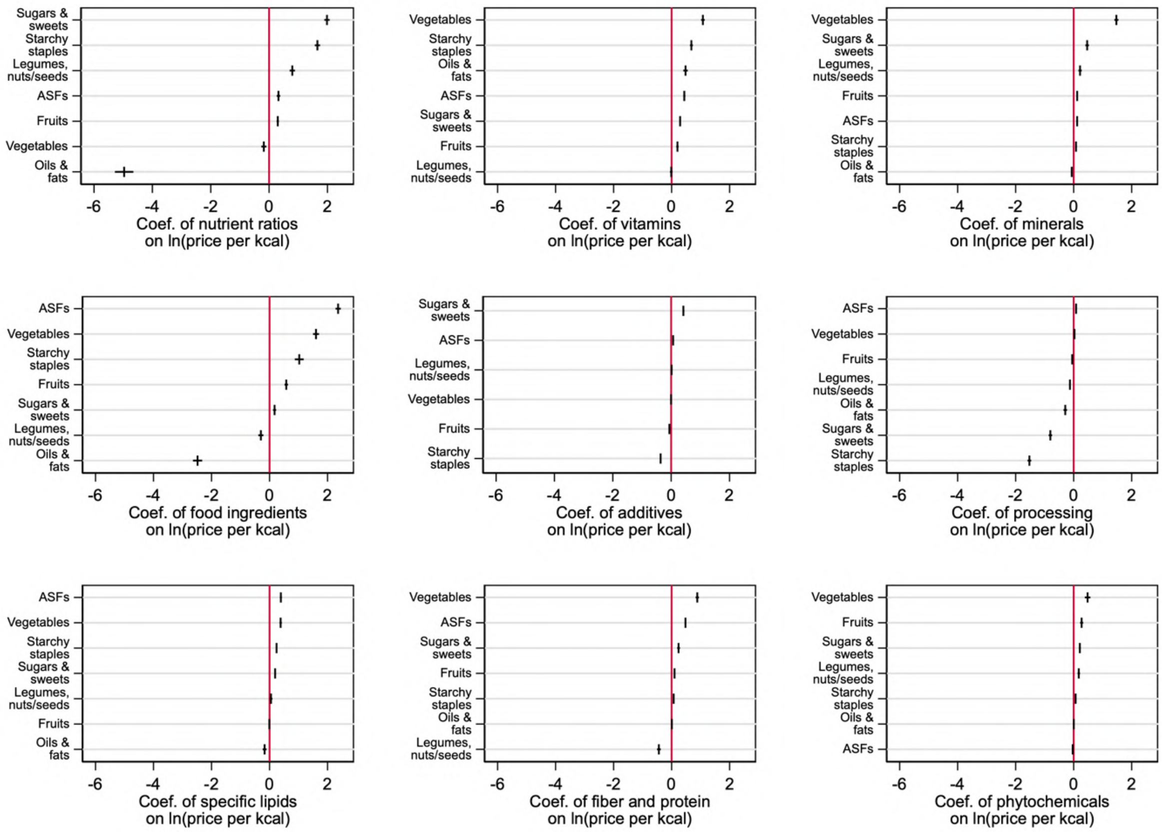
Note: Tick marks represent coefficients and 95% confidence intervals of linear regressions of GHG emissions, water footprint, and Food Compass Score (FCS) on log(price) with country fixed effects, stratified by food group. ASF stands for "animal-source foods."

Figure 3. GHG emissions, water footprint, and Food Compass Score by deciles of price per kilocalorie for each food group



Note: GHG emissions and water footprint estimates from Petersson et al. (2021) and Food Compass Score calculations from Mozaffarian et al. (2021) matched to average retail food prices from the World Bank International Comparison Program in 2011 and 2017 for 824 food items in 181 countries.

Figure 4. Associations between the 9 domains of Food Compass Score and price per kilocalorie by food group



Note: Tick marks represent coefficients and 95% confidence intervals of linear regressions of each domain of Food Compass Score (FCS) on log(price) with country fixed effects, stratified by food group. Estimate for coefficient on "additives" omit the "oils & fats" food group because all food items scored zero in this dimension. ASF stands for "animal-source foods."

Supplementary Materials

Appendix 1a. Equations for calculating price per kilogram (kg), kilocalorie (kcal), and recommended daily intake

Appendix 2: Comparing retail food prices per kilogram and per recommended daily intake to GHG emissions, water footprint, and nutritional profile

Appendix 3: Comparing retail food prices to nutritional profile using Health Star Rating and Nutri-Score

Appendix 1. Supplementary methodological details

Appendix 1a. Equations for calculating price per kilogram (kg), kilocalorie (kcal), and recommended daily intake of each food item

$$Price\ per\ kg\ of\ edible\ matter = \frac{Price\ per\ kg}{Edible\ portion}$$

$$Price\ per\ kcal\ of\ edible\ matter = \frac{Price\ per\ kg\ of\ edible\ matter}{Kcal\ per\ kg\ of\ food}$$

$$Price\ per\ recommended\ daily\ intake = (Price\ per\ kcal\ of\ edible\ matter) \times (Recommended\ intake\ in\ kcal\ of\ food\ group)$$

Appendix 1b. Healthy diet basket daily recommended intakes by food group

Food group	Minimum number of food items selected for cost of healthy diet	Total energy content (kcal)	Equivalent gram content, by reference food (edible portion)
Starchy staples	2	1160	322g dry rice
Animal-source foods	2	300	210g egg
Legumes, nuts, and seeds	1	300	85g dry bean
Vegetables	3	110	270-400g vegetable
Fruits	2	160	230-300g fruit
Oils and fats	1	300	34g oil

Source: Herforth et al., 2023

Appendix 1c: Environmental impact data sources and matching

ICP food items were matched to food item names in Petersson et al. (2021). Where possible, ICP names were matched directly to names used by Petersson. If a direct match to the food item was not available, we matched to estimates of GHG emissions and water footprint for a group of foods (e.g., berries, seafood), referred to as typology or sub-typology by Petersson et al. (For example, a food item “raspberries” might fit in the typology “fruits” and the subtypology “berries.”) For example, shrimp and prawns were matched directly to an estimate of GHG emissions for shrimp and prawns, while crab was matched to an estimate of GHG emission for seafood on average. ICP food items were excluded from the analysis if there was no relevant food item, typology, or subtypology in Petersson et al. (e.g., camel meat) or if the relevant typology or subtypology did not account for important ingredients or value chain stages. For example, dried fish, smoked fish, and canned fish other than tuna were excluded because the Petersson et al. estimate of GHG emissions for processed fish included only estimates for canned tuna and fish sticks.

Petersson et al. included estimates of the certainty of each GHG emissions and water footprint estimate, along with suggestions for whether to use the estimate at the item, typology, or subtypology level. We followed the following rules to match food item, typology, and subtypology estimates to each food item.

Recommendation in Petersson et al. (2021) database	**Estimate used**
“Ok item”	Food item
“Item matched typology” OR “Better typology”	Typology
“Better subtypology” or “Better typology or subtypology”	Subtypology
“Item or typology” or “Item or typology or subtypology”	Food item, if item estimate had low uncertainty; Typology or subtypology, if item estimate had high uncertainty

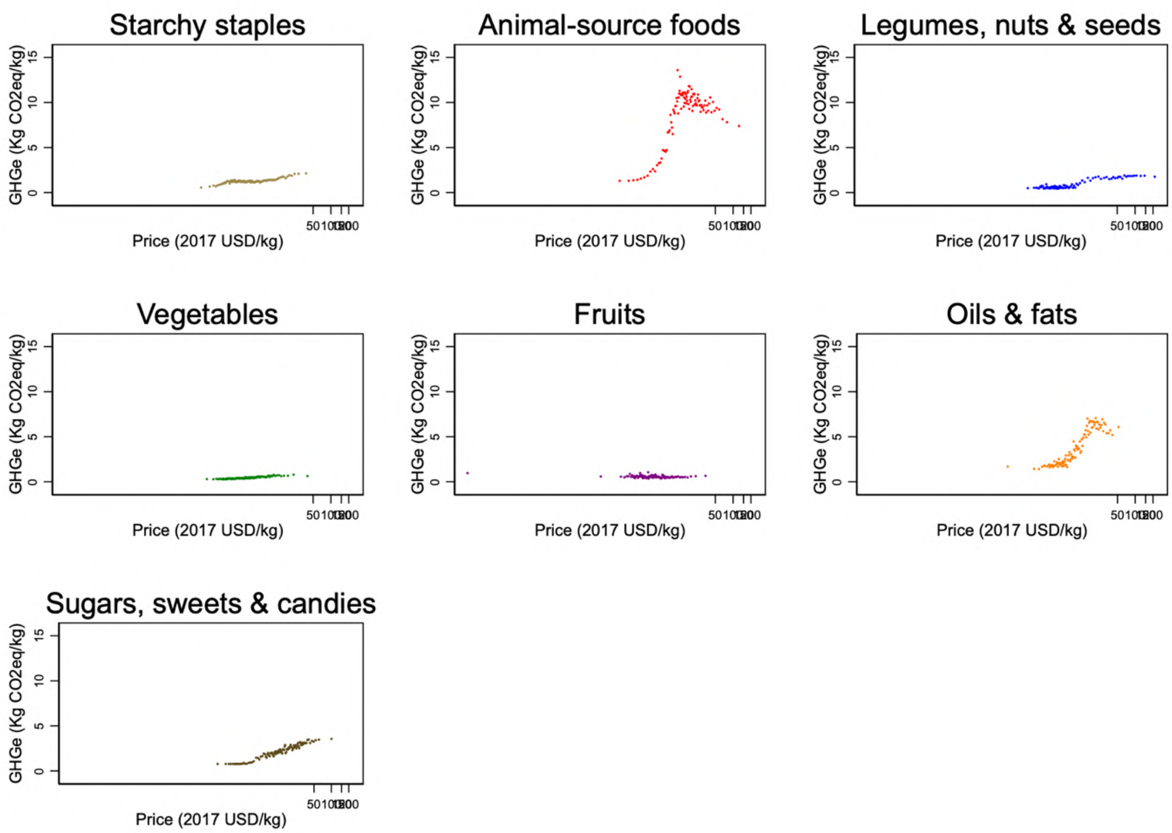
Appendix 1d. Description of the 9 Food Compass Score domains

Domain	**Description**
Nutrient ratios	Ratios of the quality of fats (unsaturated:saturated fats), carbohydrates (carbohydrate:fibre), and/or minerals (potassium:sodium)
Vitamins	Vitamins related to undernutrition and chronic diseases (e.g., Vitamin A, thiamin)
Minerals	Minerals related to undernutrition and chronic diseases (e.g., calcium, iron)
Food-based ingredients	Food groups with impacts on chronic diseases (e.g., fruits, whole grains)
Additives	Food additives with evidence of heath harms (e.g., nitrates, artificial sweeteners)
Processing	NOVA classification and other processing characteristics (e.g., fermentation, frying) with health implications
Specific lipids	Lipids with evidence of health associations (e.g., trans fats, cholesterol)
Fiber and protein	Total fiber and total protein
Phytochemicals	Total flavonoids and total carotenoids

Source: Mozaffarian et al. (2021), Supplementary Table 3

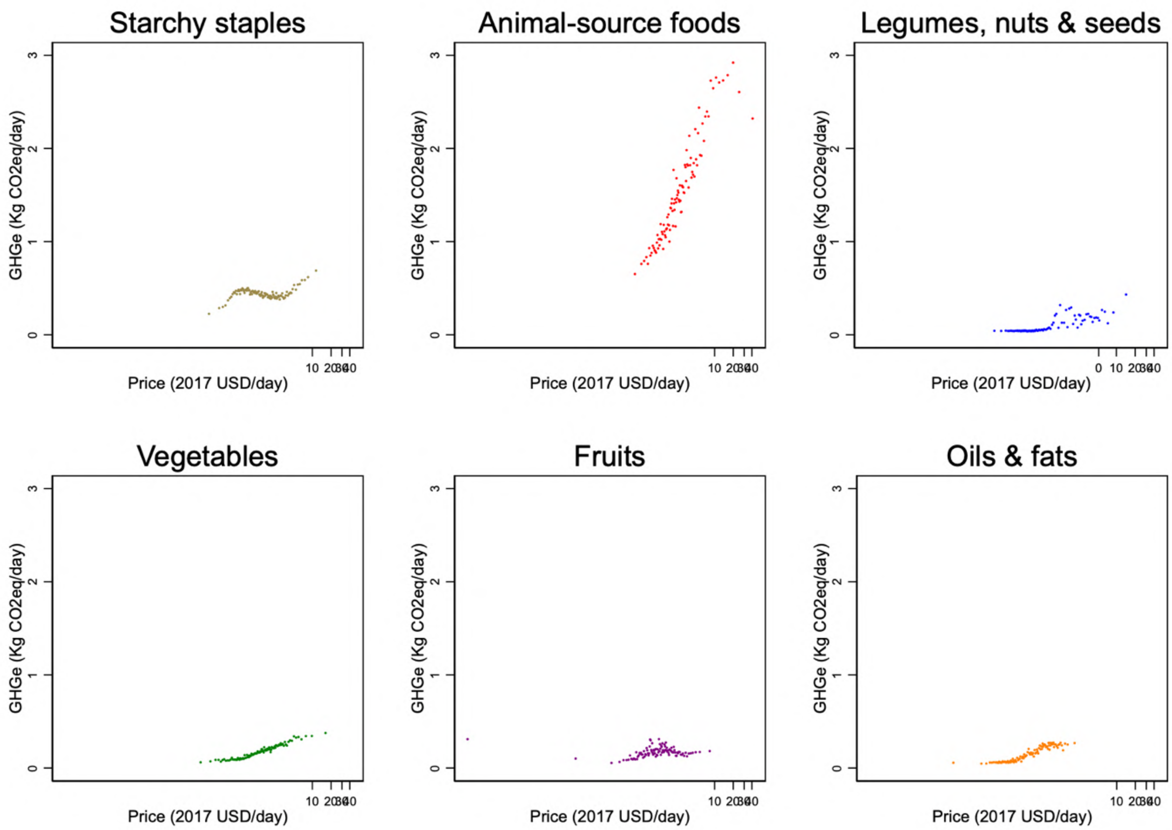
Appendix 2: Comparing retail food prices per kilogram and per recommended daily intake to GHG emissions, water footprint, and nutritional profile

Supplementary Figure 2a. Estimated mean GHG emissions conditional price per kilogram, by food group



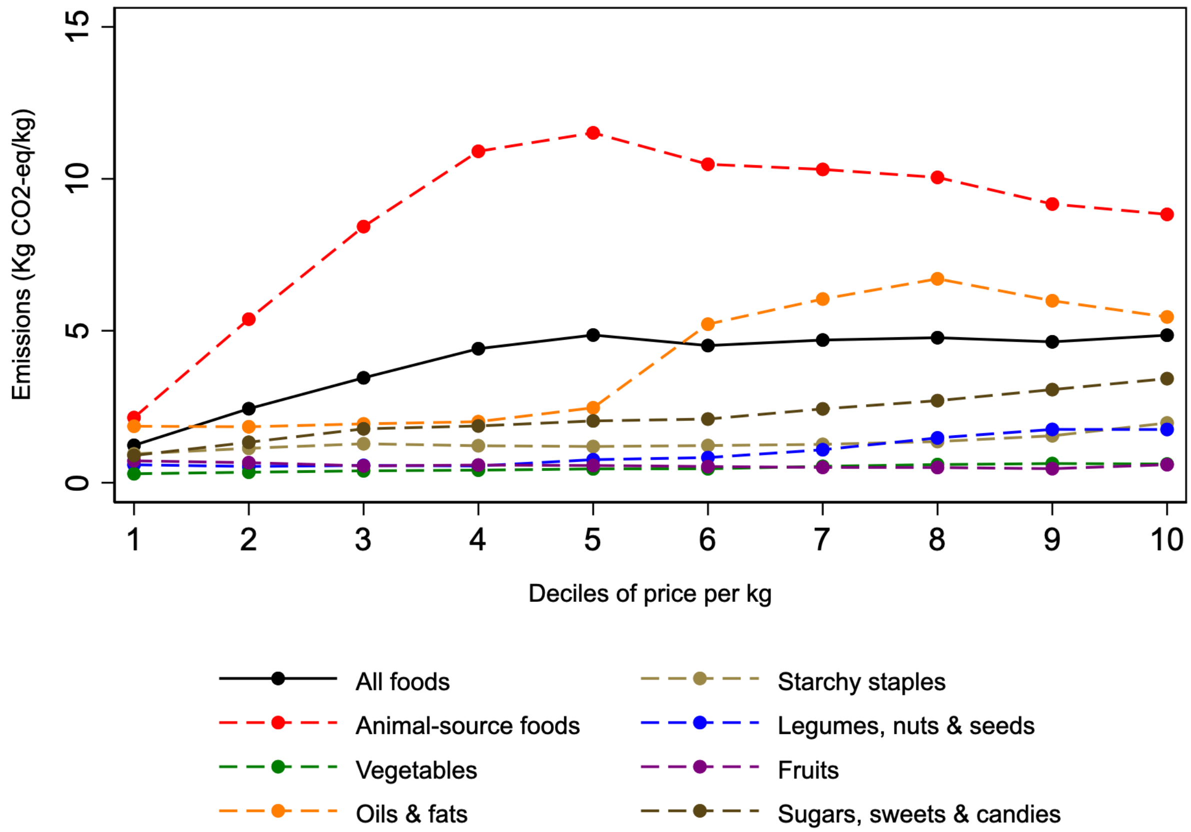
Note: GHG emissions estimates from Petersson et al. (2021) matched to average retail food prices from the World Bank International Comparison Program in 2011 and 2017 for 700 food items in 181 countries. Price in 2017 USD per kilogram is shown in natural-log scale.

Supplementary Figure 2b. Estimated mean GHG emissions conditional on price per recommended daily intake, by food group



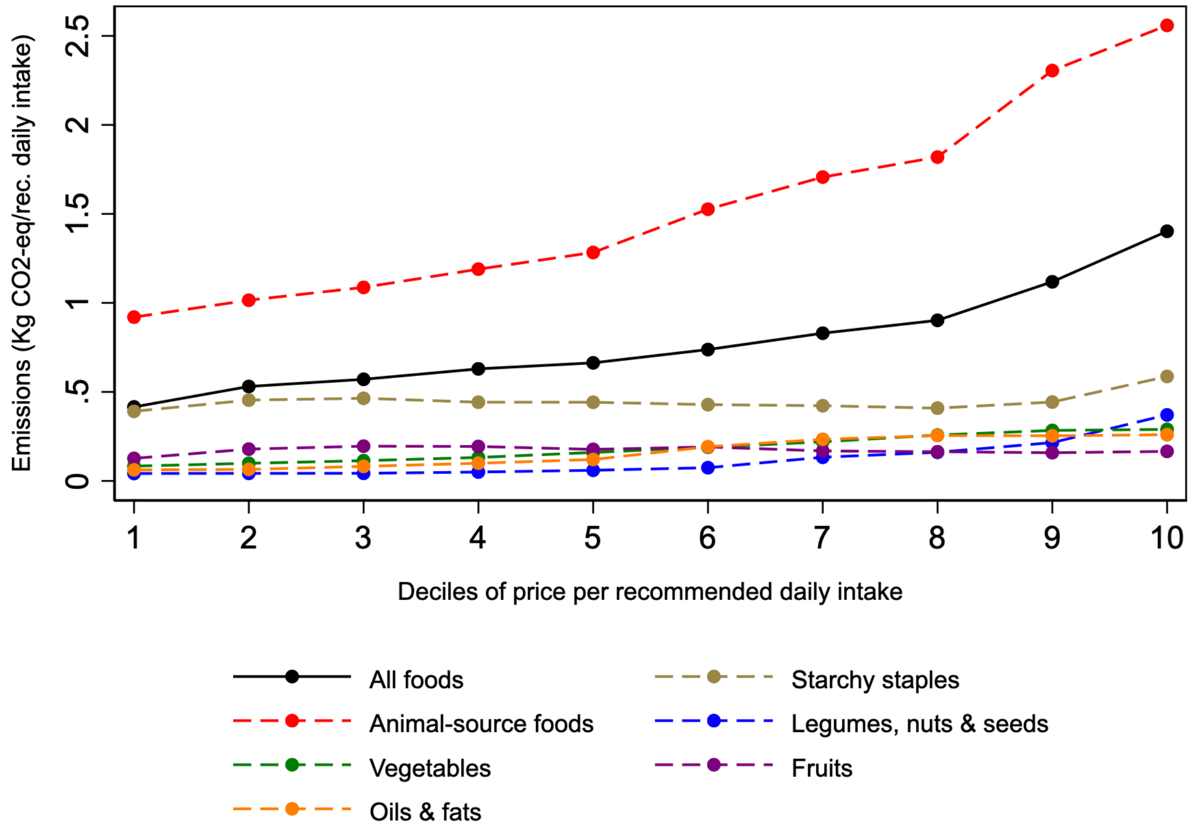
Note: GHG emissions estimates from Petersson et al. (2021) matched to average retail food prices from the World Bank International Comparison Program in 2011 and 2017 for 637 food items in 181 countries. Price in 2017 USD per recommended daily intake is shown in natural-log scale.

Supplementary Figure 2c. GHG emissions by decile of price per kilogram for each food group



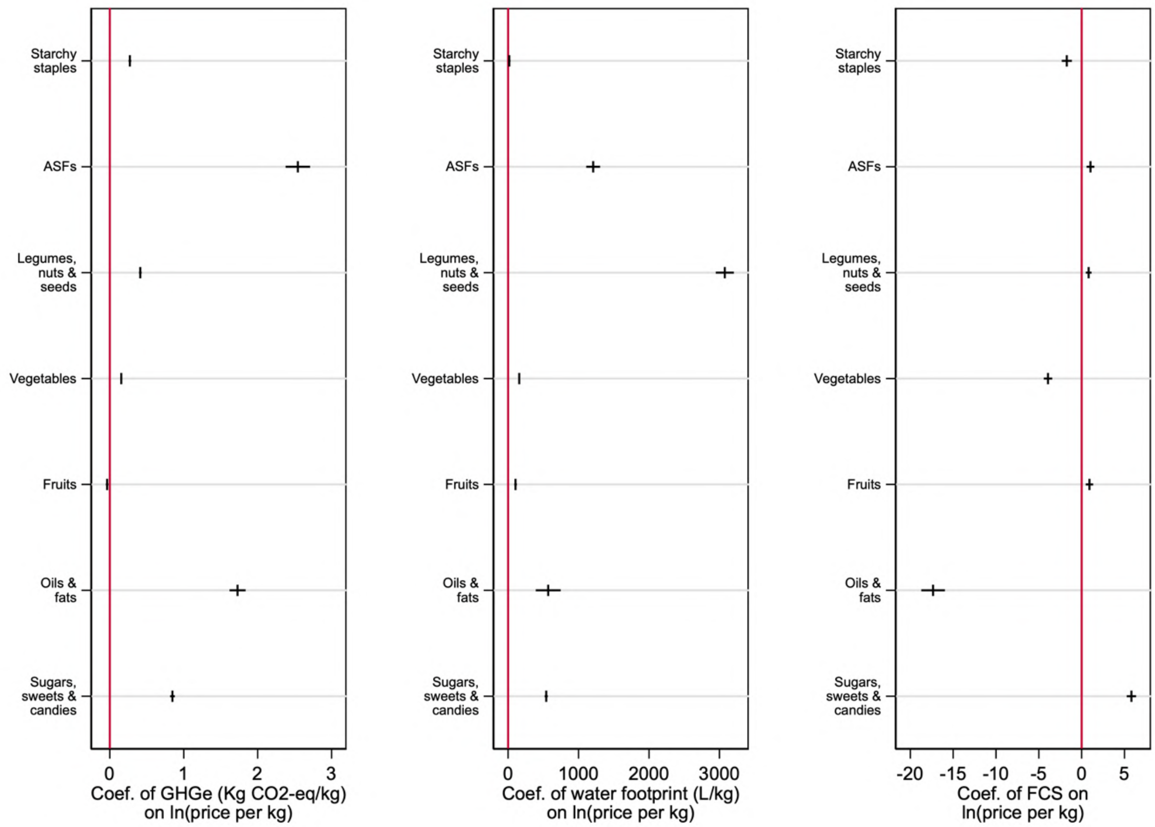
Note: GHG emissions estimates from Petersson et al. (2021) matched to average retail food prices from the World Bank International Comparison Program in 2011 and 2017 for 700 food items in 181 countries.

Supplementary Figure 2d. GHG emissions by decile of price per recommended daily intake for each food group



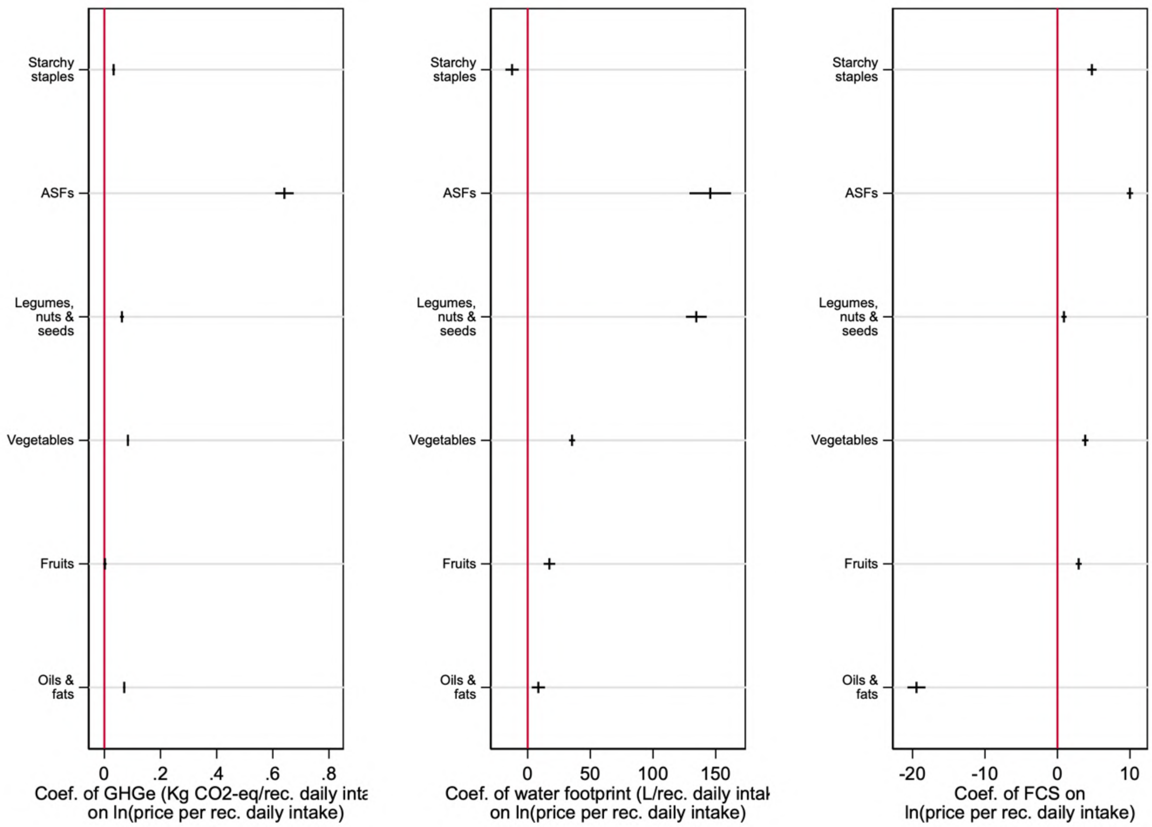
Note: GHG emissions estimates from Petersson et al. (2021) matched to average retail food prices from the World Bank International Comparison Program in 2011 and 2017 for 637 food items in 181 countries.

Supplementary Figure 2e. Associations between price per kilogram and GHG emissions, water footprint, and Food Compass Score by food group



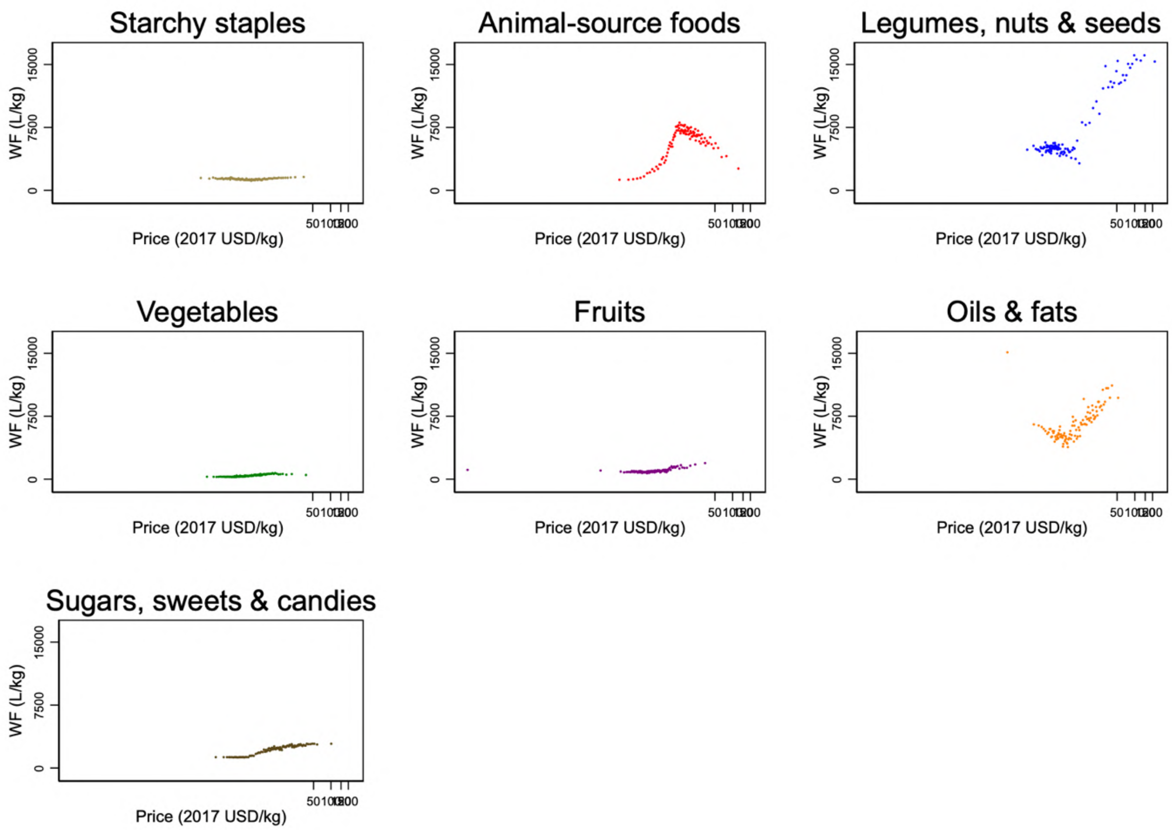
Note: Tick marks represent coefficients and 95% confidence intervals of linear regressions of GHG emissions, water footprint, and Food Compass Score (FCS) on log(price) with country fixed effects, stratified by food group. Estimates per recommended daily intake omit “sugars, sweets & candies” because there is no recommended intake of this food group. ASF stands for “animal-source foods.”

Supplementary Figure 2f. Associations between price per recommended daily intake and GHG emissions, water footprint, and Food Compass Score by food group



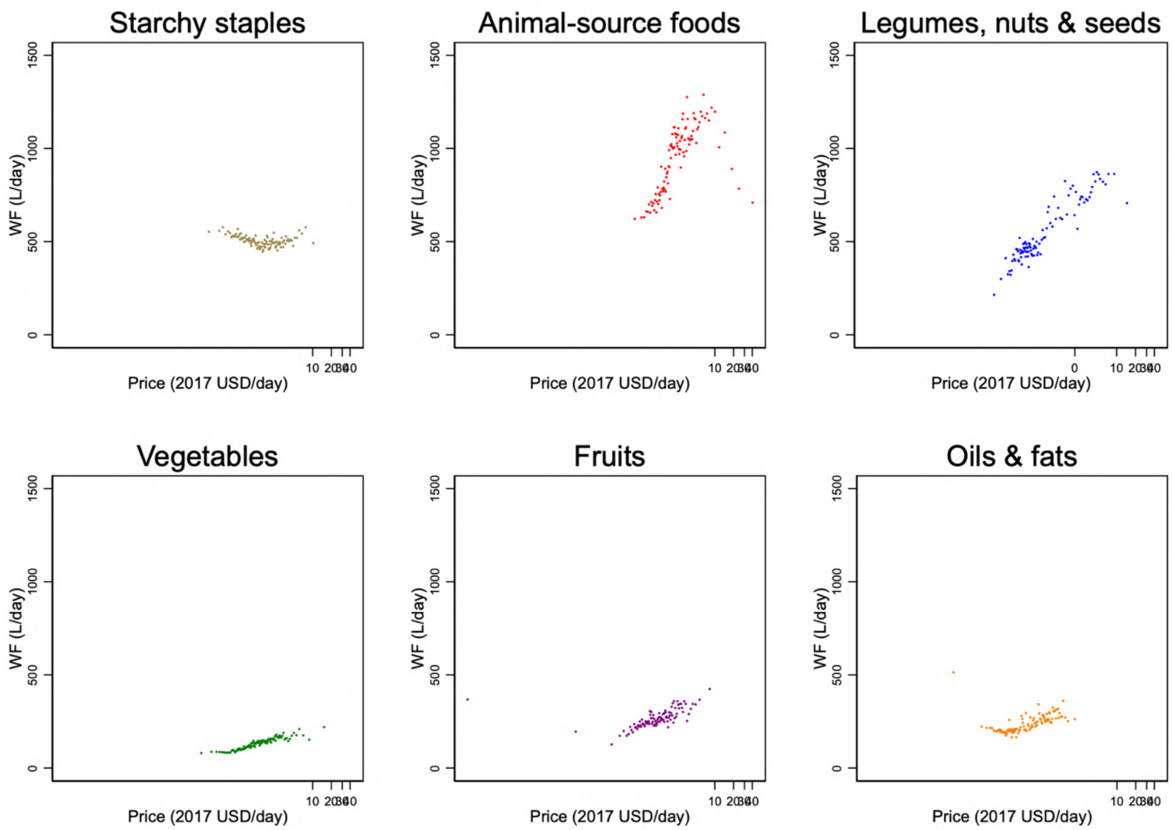
Note: Tick marks represent coefficients and 95% confidence intervals of linear regressions of GHG emissions, water footprint, and Food Compass Score (FCS) on log(price) with country fixed effects, stratified by food group. Estimates per recommended daily intake omit "sugars, sweets & candies" because there is no recommended intake of this food group. ASF stands for "animal-source foods."

Supplementary Figure 2g. Estimated mean water footprint, conditional on price per kilogram, by food group



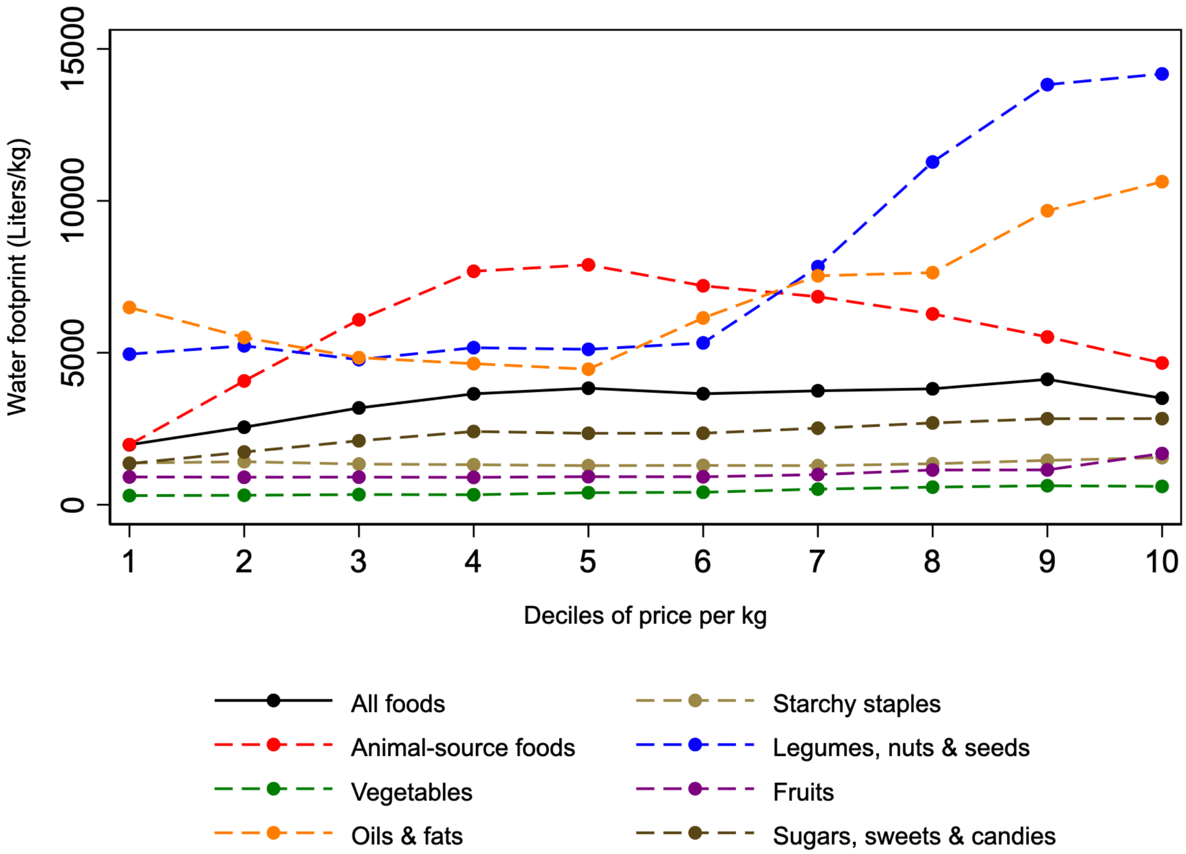
Note: Water footprint estimates from Petersson et al. (2021) matched to average retail food prices from the World Bank International Comparison Program in 2011 and 2017 for 682 food items in 181 countries. Price in 2017 USD per kilogram is shown in natural-log scale.

Supplementary Figure 2h. Estimated mean water footprint conditional on price per recommended daily intake, by food group



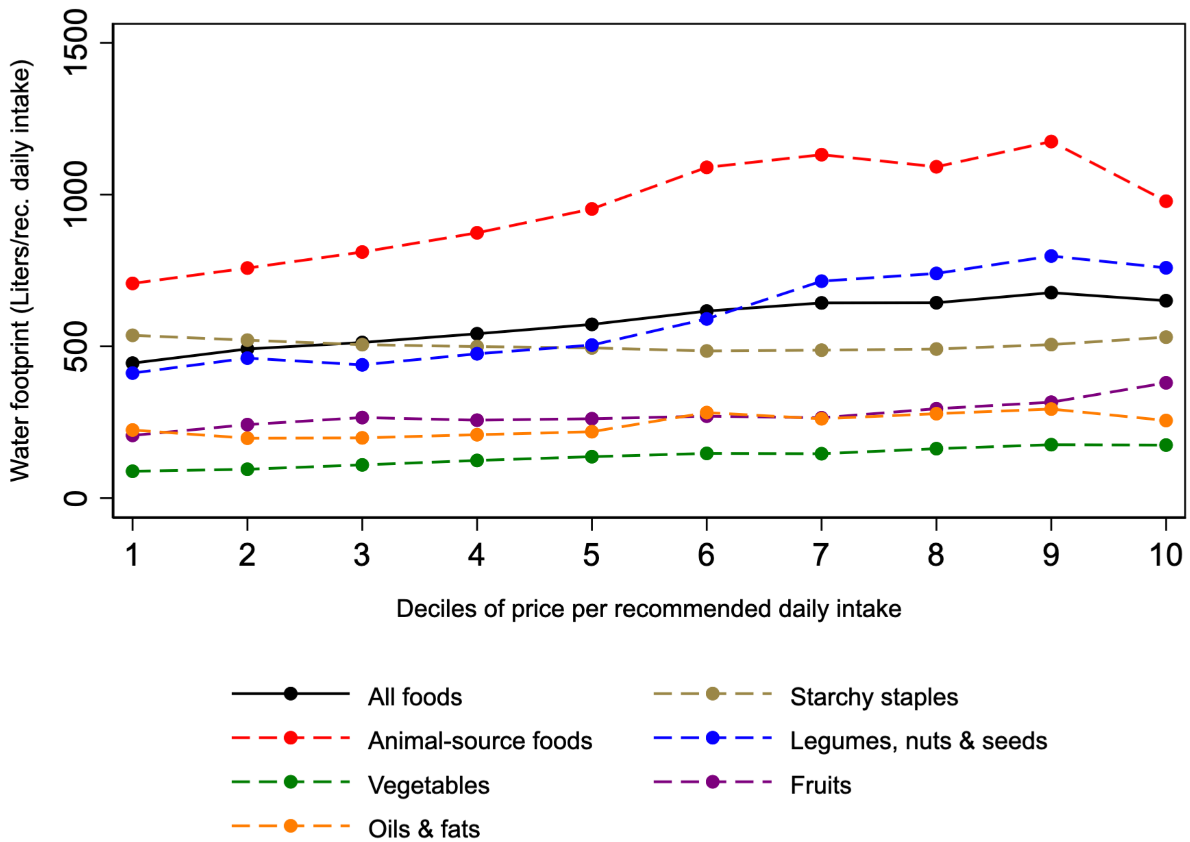
Note: Water footprint estimates from Petersson et al. (2021) matched to average retail food prices from the World Bank International Comparison Program in 2011 and 2017 for 633 food items in 181 countries. Price in 2017 USD per recommended daily intake is shown in natural-log scale.

Supplementary Figure 2i. Water footprint by decile of price per kilogram for each food group



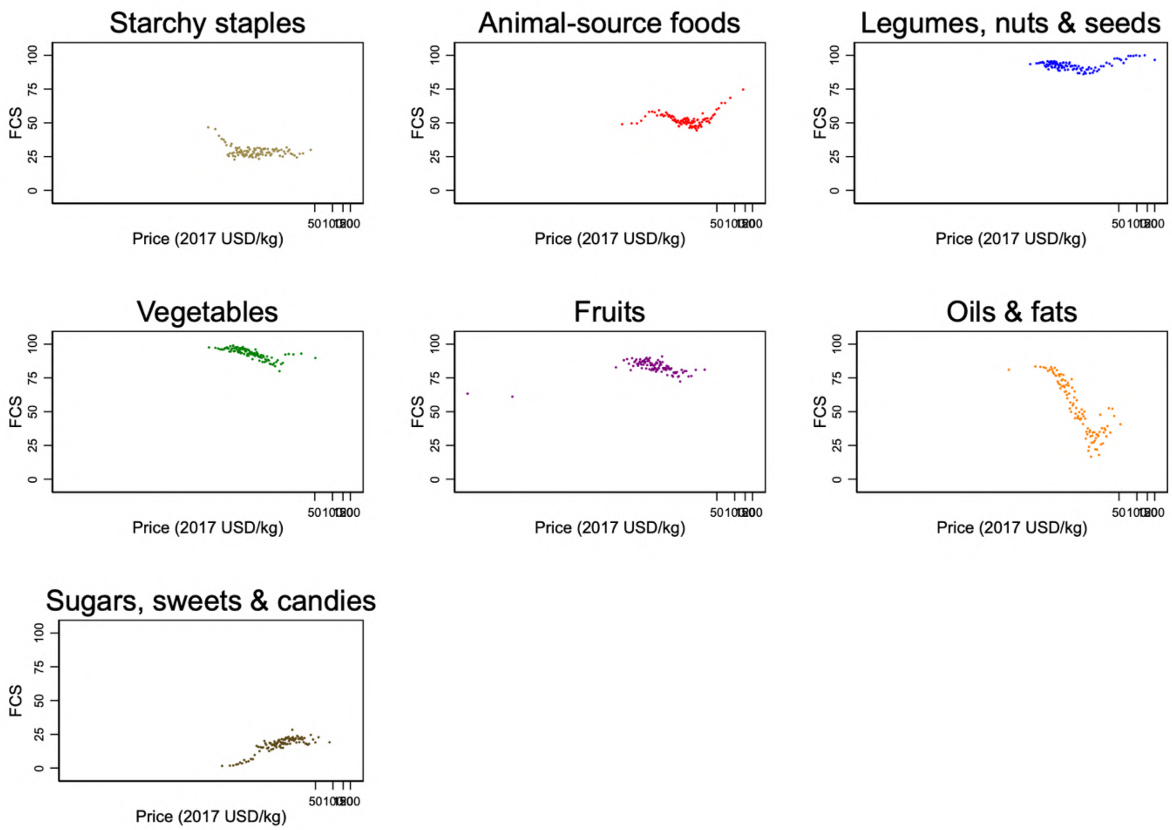
Note: Water footprint estimates from Petersson et al. (2021) matched to average retail food prices from the World Bank International Comparison Program in 2011 and 2017 for 682 food items in 181 countries.

Supplementary Figure 2j. Water footprint by decile of price per recommended daily intake for each food group



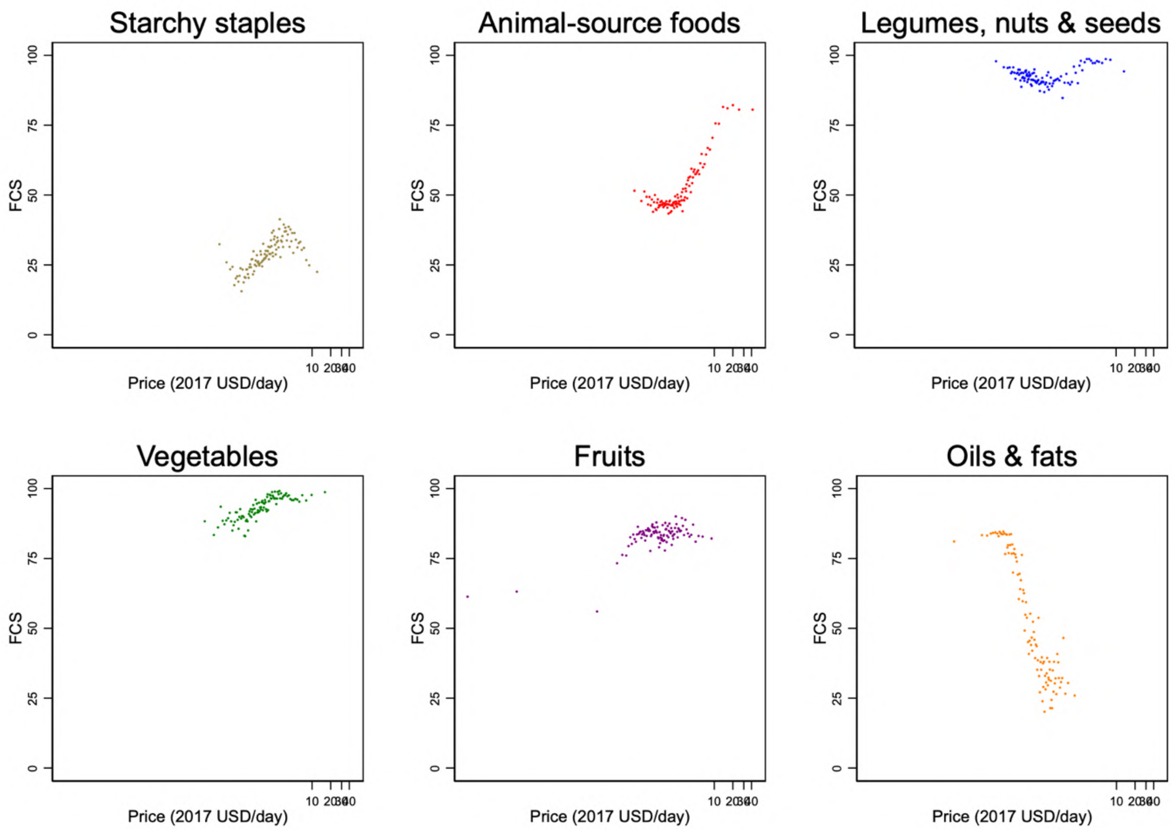
Note: Water footprint estimates from Petersson et al. (2021) matched to average retail food prices from the World Bank International Comparison Program in 2011 and 2017 for 633 food items in 181 countries.

Supplementary Figure 2k. Estimated mean Food Compass Score conditional on price per kilogram, by food group



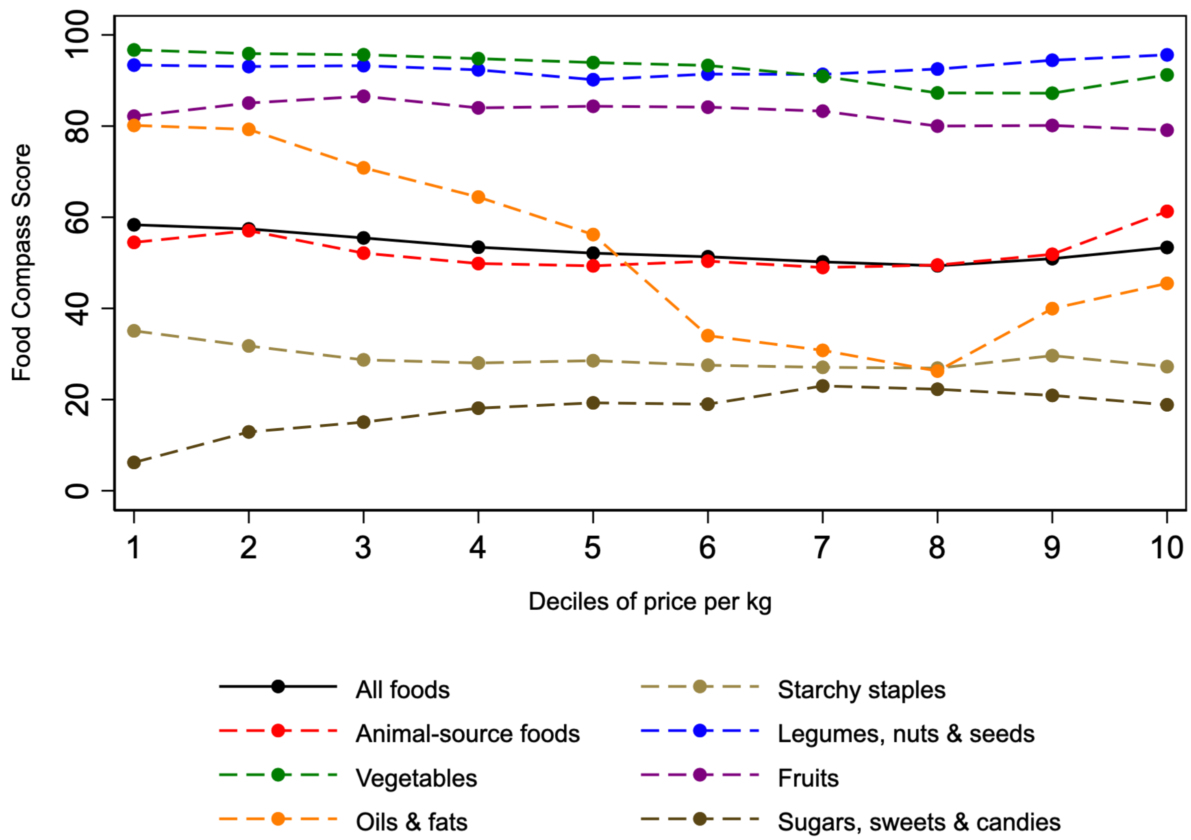
Note: Food Compass Score calculations from Mozaffarian et al. (2021) matched to average retail food prices from the World Bank International Comparison Program in 2011 and 2017 for 827 food items in 181 countries.

Supplementary Figure 2l. Estimated mean Food Compass Score conditional on price per recommended daily intake, by food group



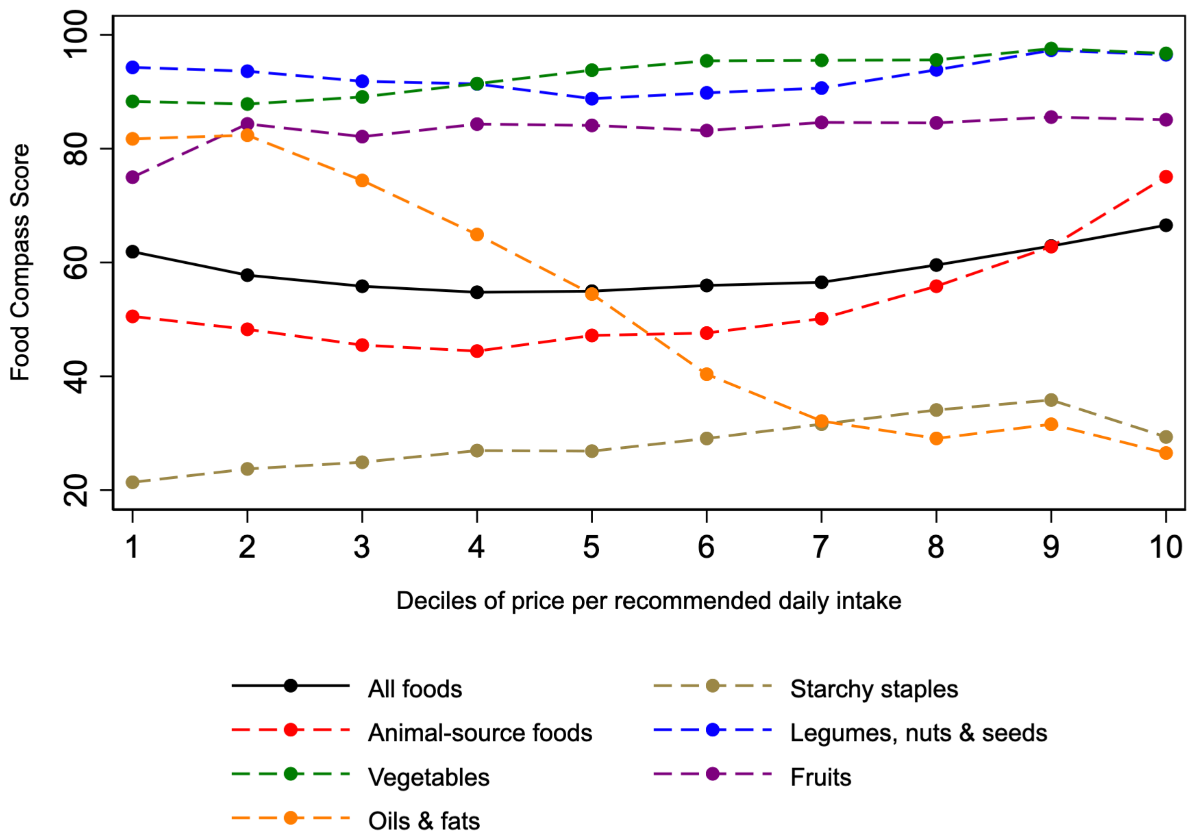
Note: Food Compass Score calculations from Mozaffarian et al. (2021) matched to average retail food prices from the World Bank International Comparison Program in 2011 and 2017 for 720 food items in 181 countries.

Supplementary Figure 2m. Food Compass Score by decile of price per kilogram for each food group



Note: Food Compass Score calculations from Mozaffarian et al. (2021) matched to average retail food prices from the World Bank International Comparison Program in 2011 and 2017 for 827 food items in 181 countries.

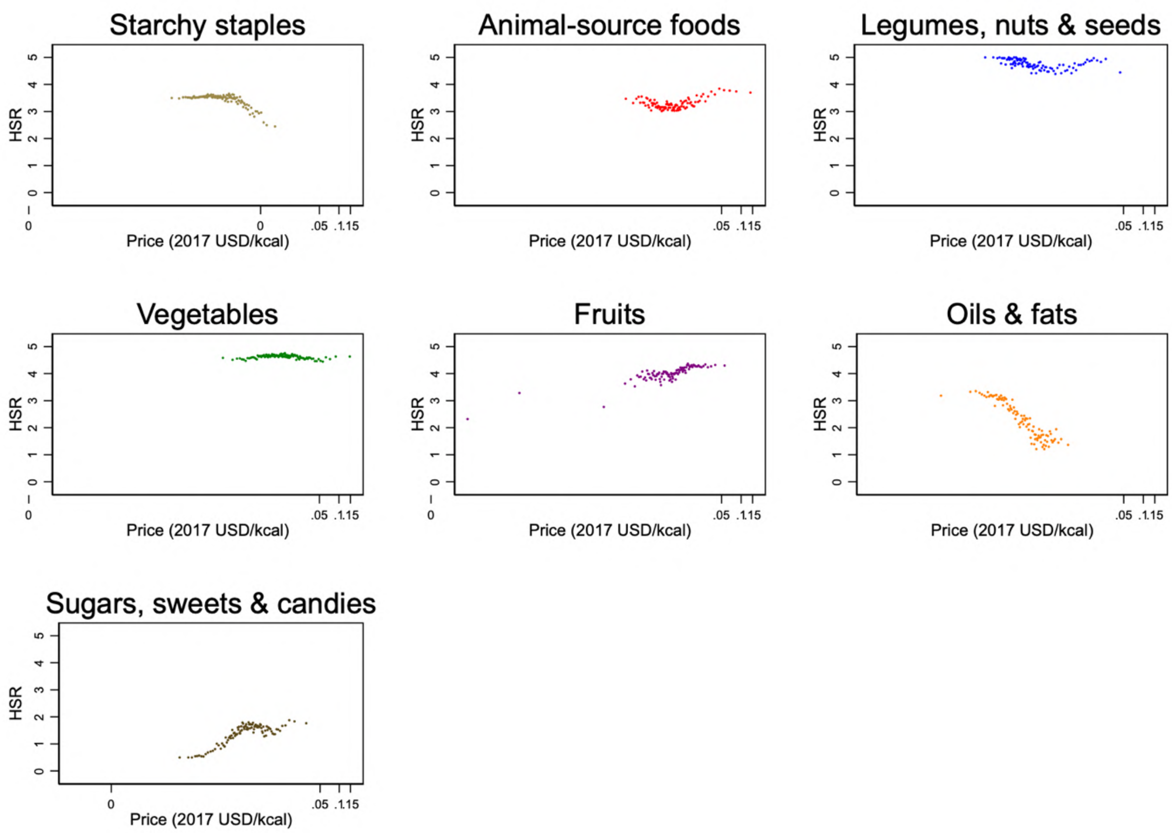
Supplementary Figure 2n. Food Compass Score by decile of price per kilogram for each food group



Note: Food Compass Score calculations from Mozaffarian et al. (2021) matched to average retail food prices from the World Bank International Comparison Program in 2011 and 2017 for 720 food items in 181 countries.

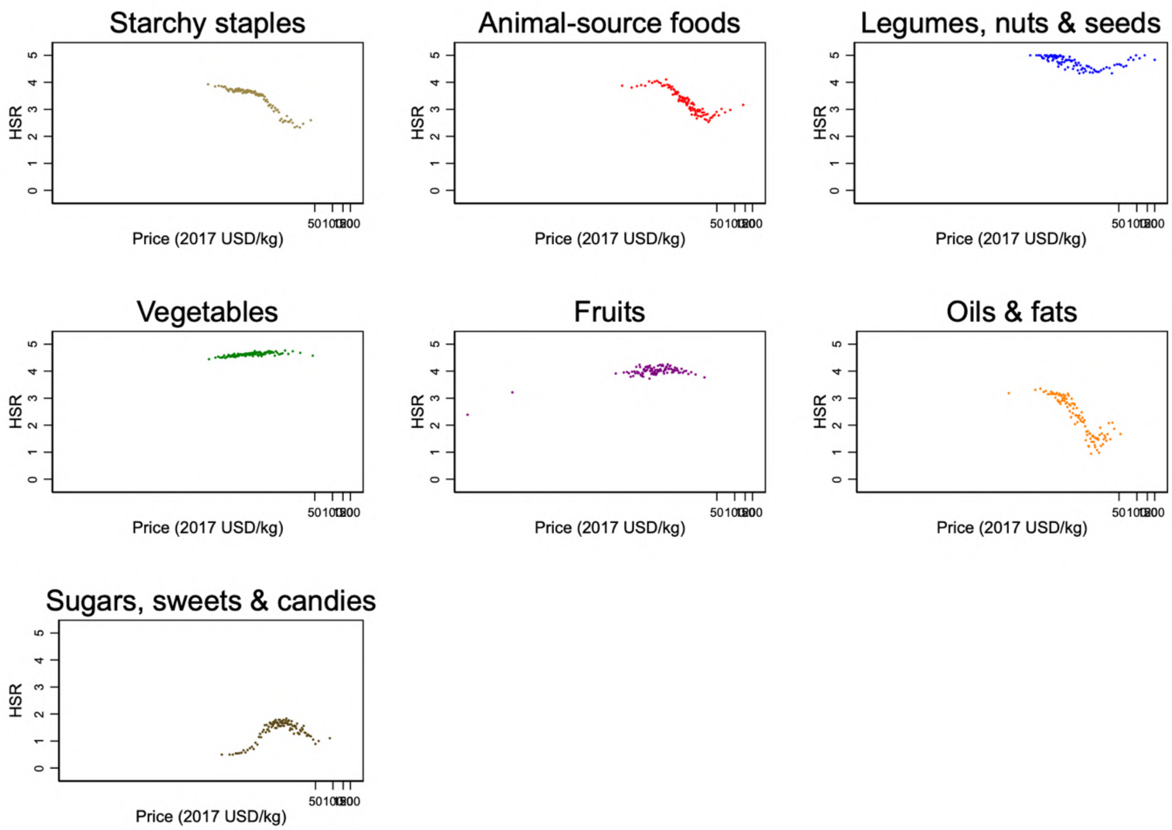
Appendix 3: Comparing retail food prices to nutritional profile using Health Star Rating and Nutri-Score

Supplementary Figure 3a. Estimated mean Health Star Rating conditional on price per kilocalorie, by food group



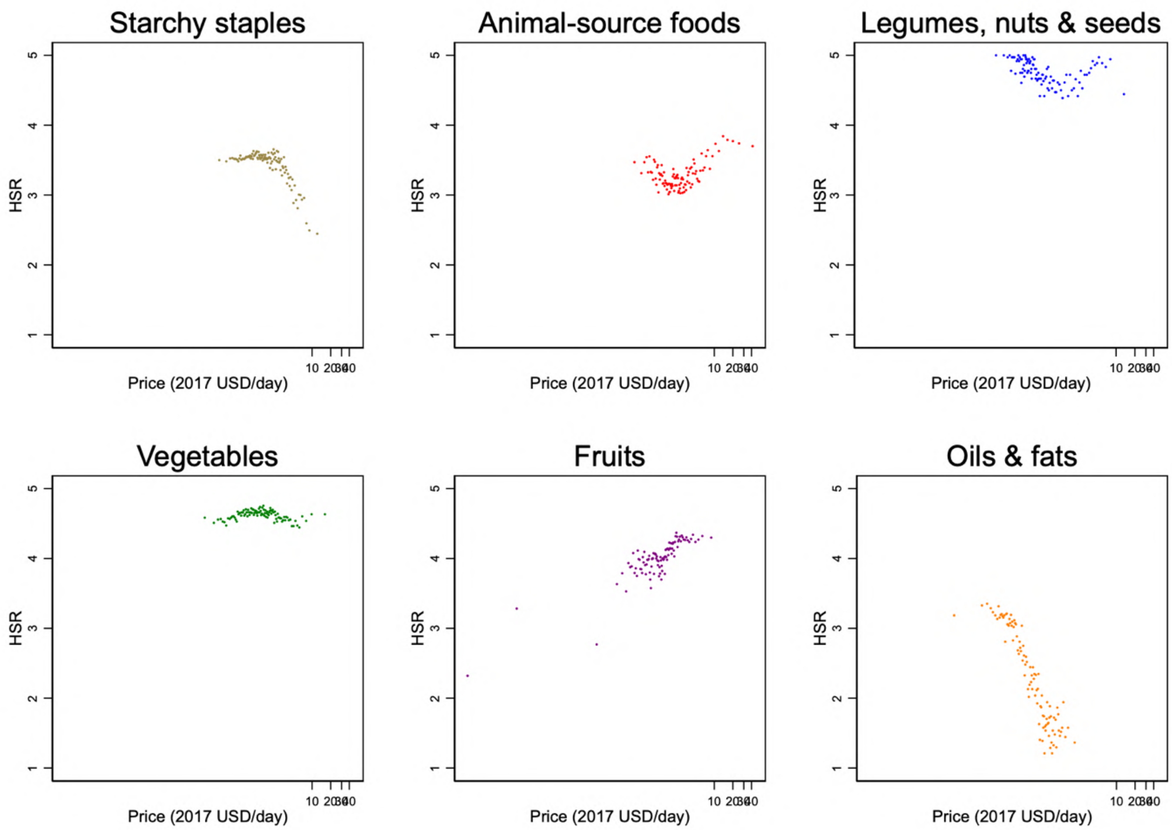
Note: Health Star Rating calculations from Mozaffarian et al. (2021) matched to average retail food prices from the World Bank International Comparison Program in 2011 and 2017 for 817 food items in 181 countries. Price in 2017 USD per kilocalorie is shown in natural-log scale.

Supplementary Figure 3b. Estimated mean Health Star Rating conditional on price per kilogram, by food group



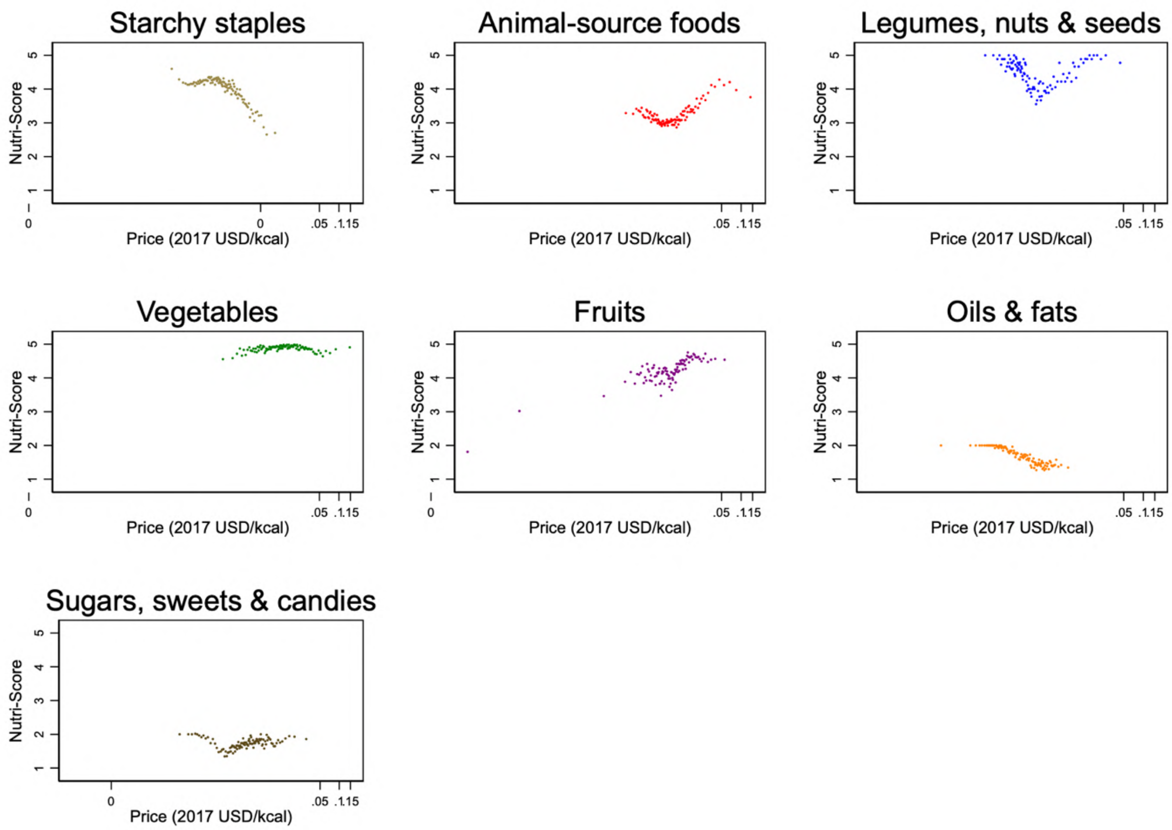
Note: Health Star Rating calculations from Mozaffarian et al. (2021) matched to average retail food prices from the World Bank International Comparison Program in 2011 and 2017 for 818 food items in 181 countries. Price in 2017 USD per kilogram is shown in natural-log scale.

Supplementary Figure 3c. Estimated mean Health Star Rating conditional on price per recommended daily intake, by food group



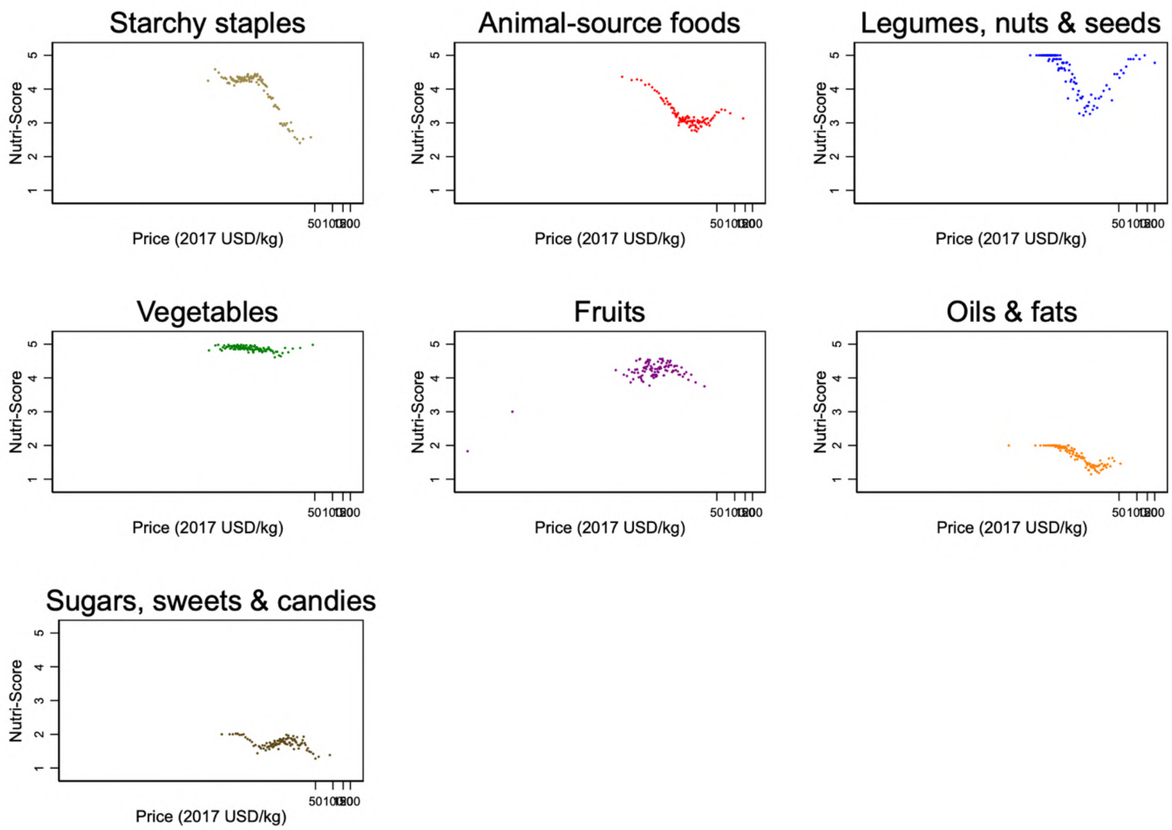
Note: Health Star Rating calculations from Mozaffarian et al. (2021) matched to average retail food prices from the World Bank International Comparison Program in 2011 and 2017 for 715 food items in 181 countries. Price in 2017 USD per recommended daily intake is shown in natural-log scale.

Supplementary Figure 3d. Estimated mean Nutri-Score conditional on price per kilocalorie, by food group



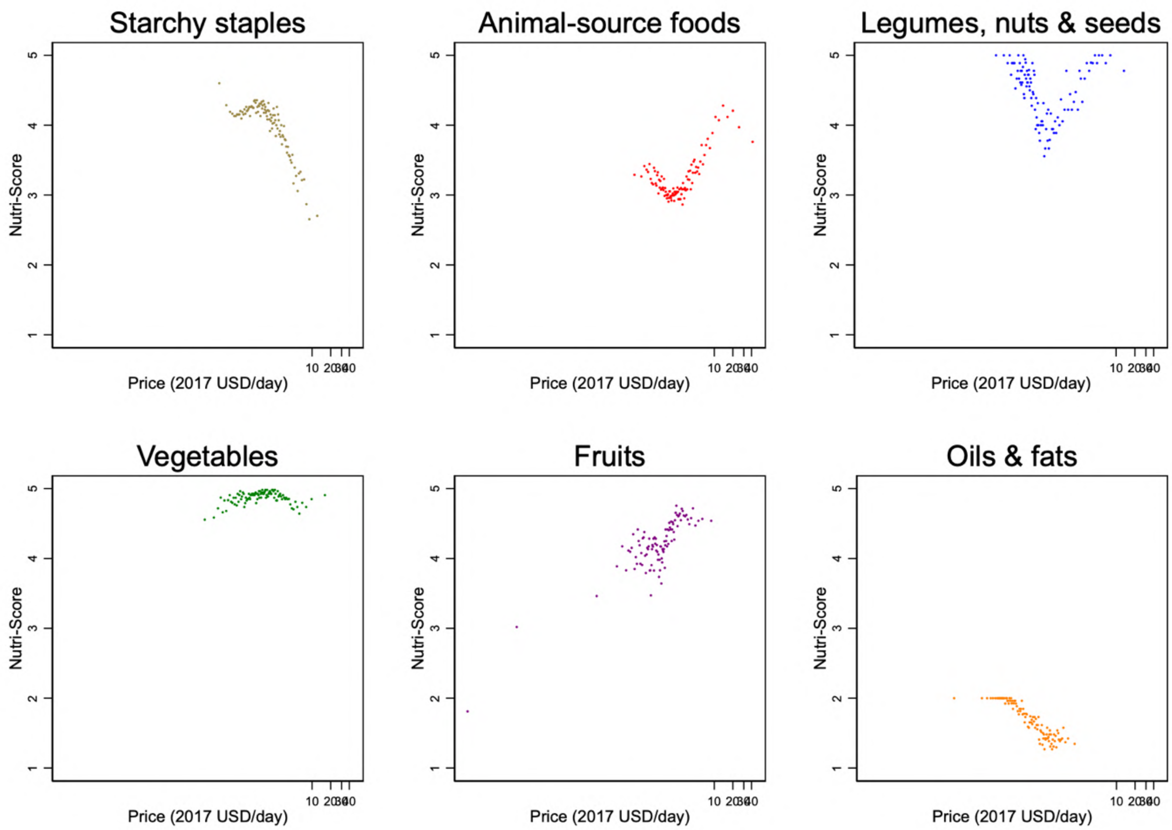
Note: Nutri-Score calculations from Mozaffarian et al. (2021) matched to average retail food prices from the World Bank International Comparison Program in 2011 and 2017 for 817 food items in 181 countries. Price in 2017 USD per kilocalorie is shown in natural-log scale.

Supplementary Figure 3e. Estimated mean Nutri-Score conditional on price per kilogram, by food group



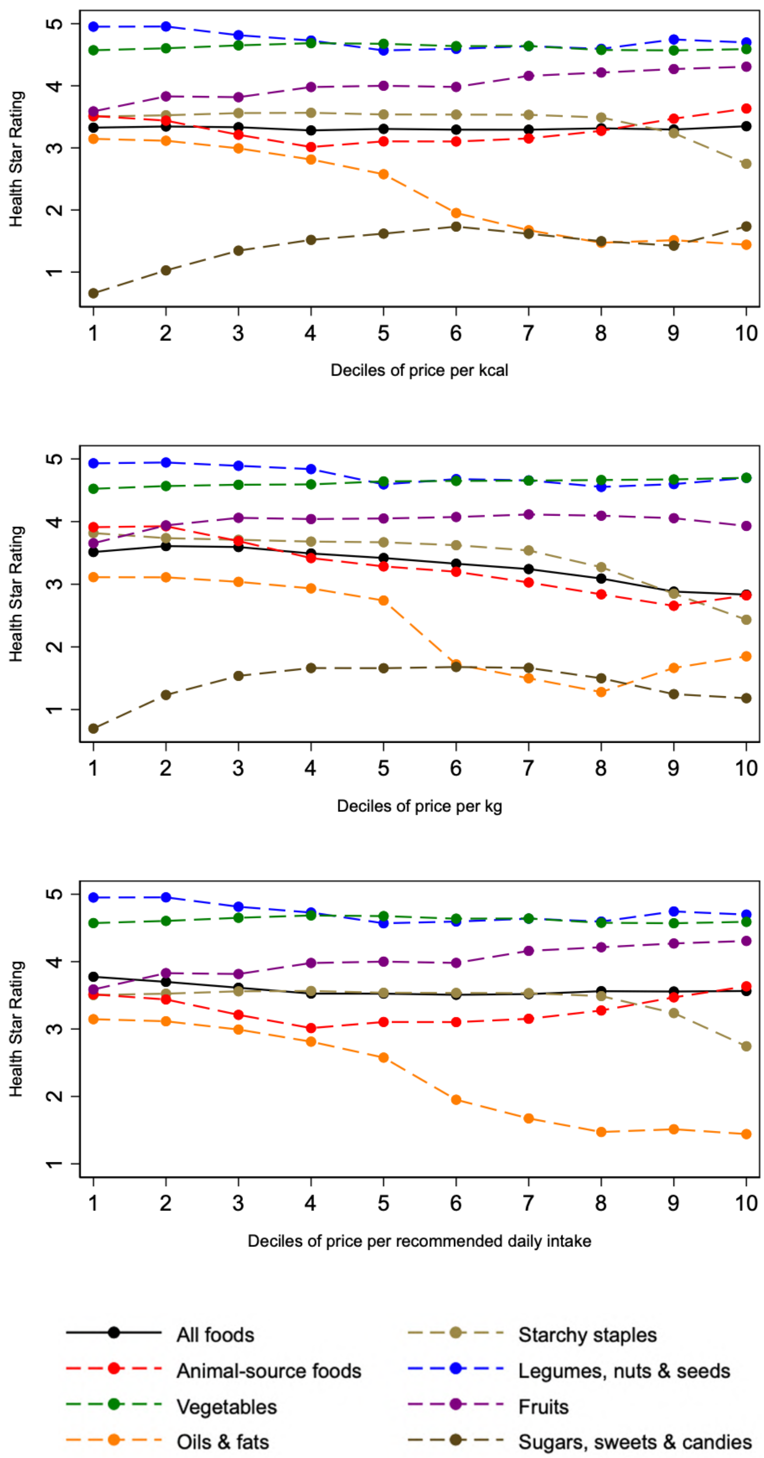
Note: Nutri-Score calculations from Mozaffarian et al. (2021) matched to average retail food prices from the World Bank International Comparison Program in 2011 and 2017 for 818 food items in 181 countries. Price in 2017 USD per kilogram is shown in natural-log scale.

Supplementary Figure 3f. Estimated mean Nutri-Score conditional on price per recommended daily intake, by food group



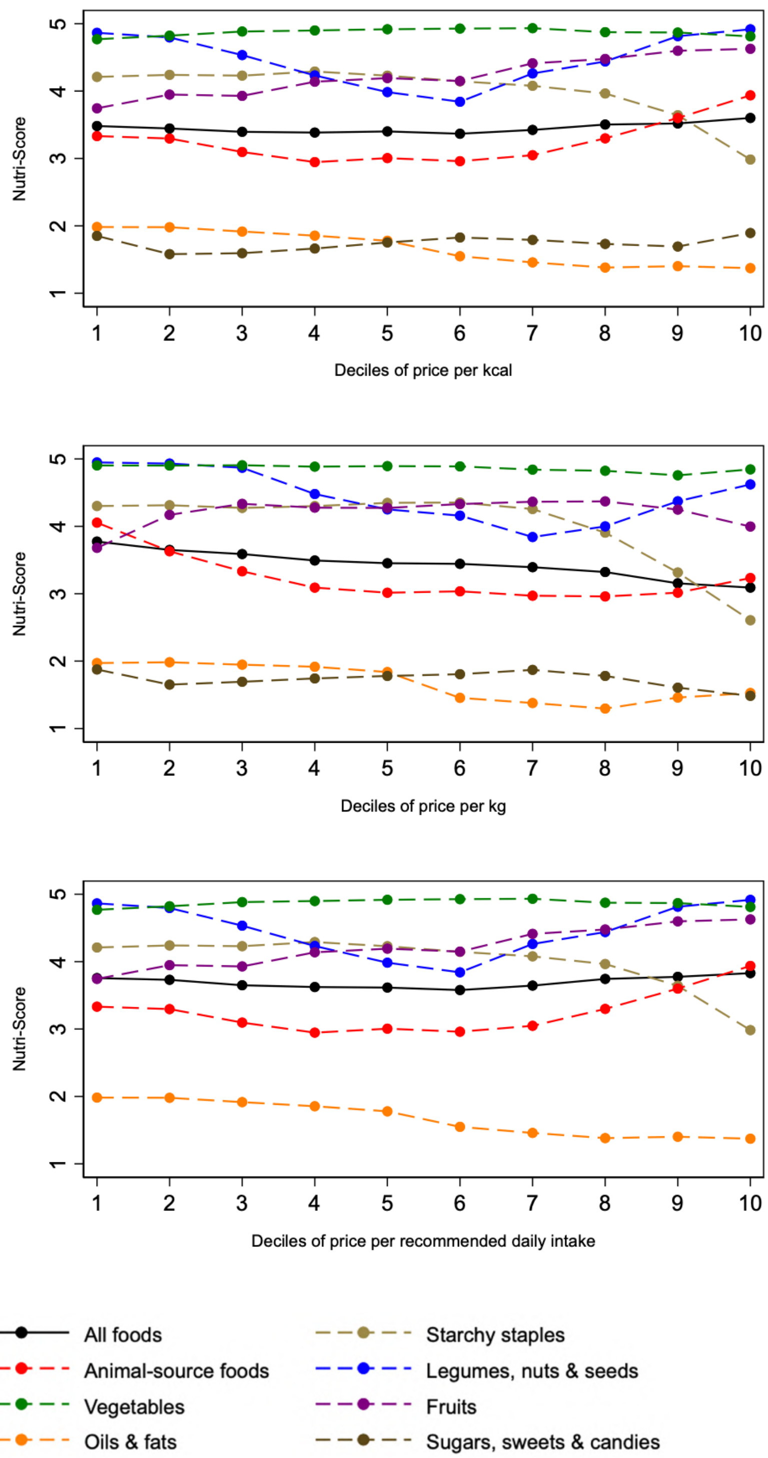
Note: Nutri-Score calculations from Mozaffarian et al. (2021) matched to average retail food prices from the World Bank International Comparison Program in 2011 and 2017 for 818 food items in 715 countries. Price in 2017 USD per recommended daily intake is shown in natural-log scale.

Supplementary Figure 3g. Health Star Rating by deciles of price per kilocalorie, kilogram, and daily recommended intake for each food group



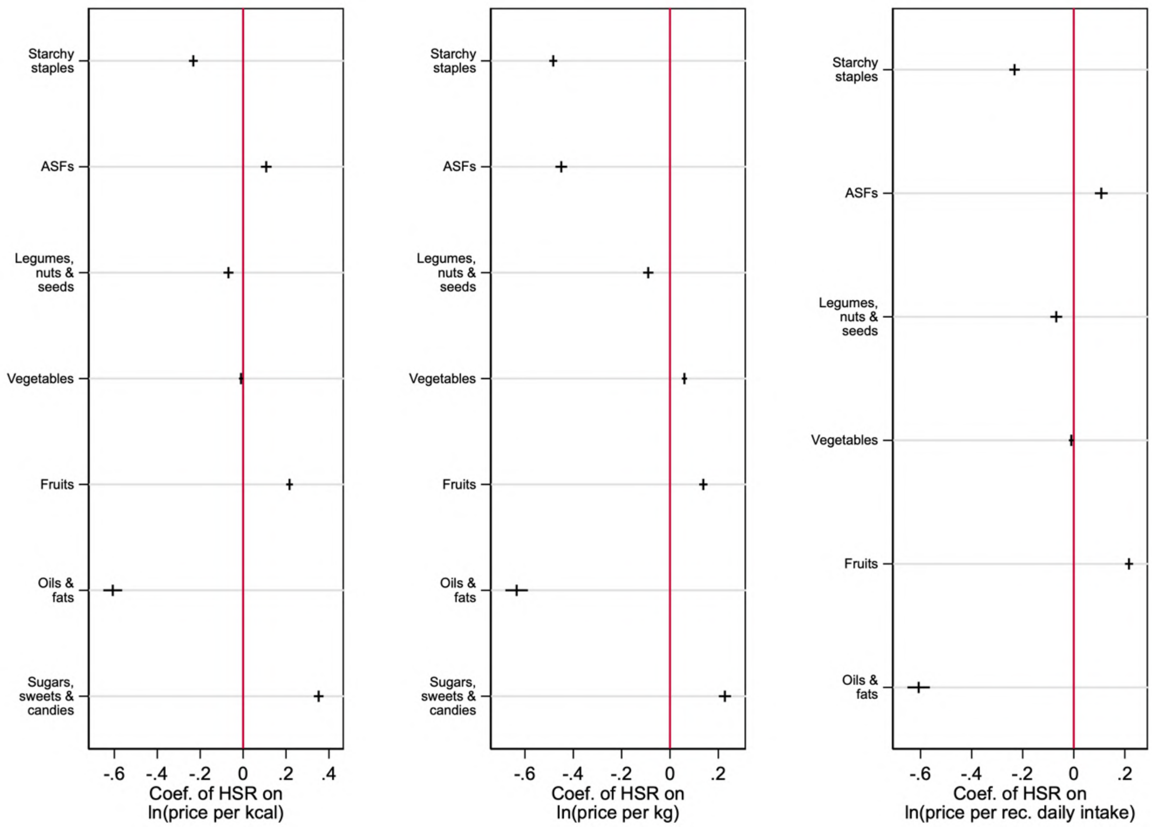
Note: Health Star Rating calculations from Mozaffarian et al. (2021) matched to average retail food prices from the World Bank International Comparison Program in 2011 and 2017 for 818 food items in 181 countries.

Supplementary Figure 3h. Nutri-Score by deciles of price per kilocalorie, kilogram, and daily recommended intake for each food group



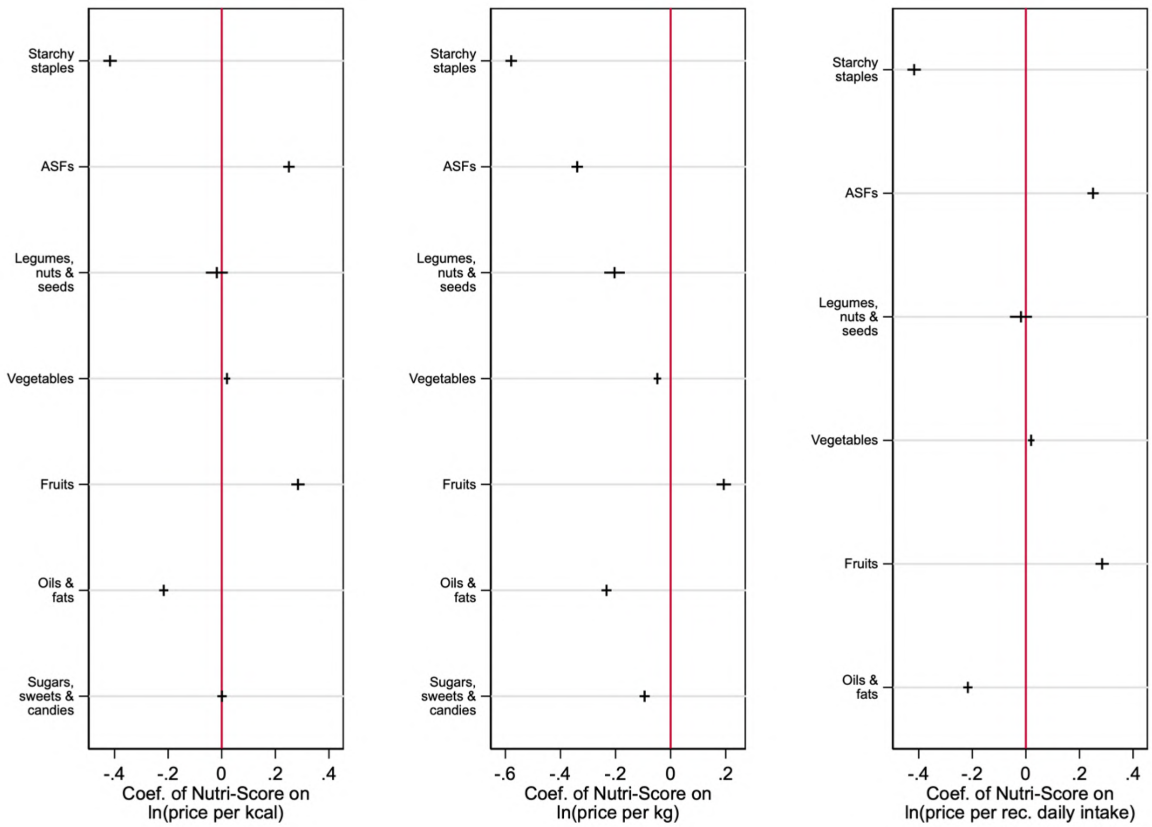
Note: Nutri-Score calculations from Mozaffarian et al. (2021) matched to average retail food prices from the World Bank International Comparison Program in 2011 and 2017 for 818 food items in 181 countries.

Supplementary Figure 3i. Associations between Health Star Rating and price per kilocalorie, kilogram, and recommended daily intake by food group



Note: Tick marks represent coefficients and 95% confidence intervals of linear regressions of Health Star Rating (HSR) on log(price) with country fixed effects, stratified by food group. Estimates per recommended daily intake omit "sugars, sweets & candies" because there is no recommended intake of this food group. ASF stands for "animal-source foods."

Supplementary Figure 3j. Associations between Nutri-Score and price per kilocalorie, kilogram, and recommended daily intake by food group



Note: Tick marks represent coefficients and 95% confidence intervals of linear regressions of Nutri-Score on log(price) with country fixed effects, stratified by food group. Estimates per recommended daily intake omit "sugars, sweets & candies" because there is no recommended intake of this food group. ASF stands for "animal-source foods."