# Balancing a sustained pursuit of nutrition, health, affordability and climate goals: exploring the case of Indonesia

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**ABSTRACT**

**Background:** To guide the transformation of food systems to provide for healthy and sustainable diets, countries need to assess their current diet and food supply in comparison to nutrition, health, affordability, and environmental goals.

**Objectives:** We sought to compare Indonesia's food utilization to diets optimized for nutritional value and cost and to diets that are increasingly plant-based in order to meet further health and environmental goals, including the EAT-Lancet planetary health diet, to explore whether multiple goals could be achieved simultaneously.

**Methods:** We compared 13 dietary scenarios (2 current, 7 optimized, 3 increasingly plant-based, 1 EAT-Lancet) for nutrient content, cost, greenhouse gas emissions (GHGe), and water footprints, using the FAO food balance sheet, Indonesia Household Income and Expenditure Survey household food expenditure, food composition, life cycle assessment, food losses, and trade data.

**Results:** The diversity of modeled scenarios was higher than that of current consumption, reflecting nutritional deficiencies underlying Indonesia's burden of different forms of malnutrition. Nutrient intake targets were met best by nutrient- and cost-optimized diets, followed by the EAT-Lancet diet. Those diets also had high GHGe, although less than 40% of a scenario in which Indonesia would adopt a typical high-income country's diet. Only the low food chain diet had a GHGe below the 2050 target set by the EAT-Lancet commission. Its nutrient content was comparable to that of a no-dairy diet, slightly above those of fish-and-poultry and current diets, and somewhat below those of the EAT-Lancet diets. To meet nutrient needs, some animal-source foods had to be included. Costs of all except the optimized diets were above the current national average food expenditure. No scenario met all goals simultaneously.

**Conclusions:** Indonesia's consumption of rice and unhealthy foods should decrease; food production, trade, and processing should prioritize diversification, (bio)fortification, and limiting environmental impacts; and consumer and institutional demands for healthy, nutritious, and sustainable foods should be stimulated. More granular data and tools are required to develop and assess more detailed scenarios to achieve multiple goals simultaneously. *Am J Clin Nutr* 2021;114:1686–1697.

**Keywords:** Indonesia, diet and climate, sustainable healthy diets, greenhouse gas emissions, climate change, nutritional value, food expenditure, affordability, water footprint, EAT-Lancet diet

## Introduction

Healthy diets produced by sustainable food systems are required for better human and planetary health. The FAO and WHO recently defined sustainable healthy diets as "dietary patterns that promote all dimensions of individuals' health and wellbeing; have low environmental pressure and impact; are accessible, affordable, safe and equitable; and are culturally acceptable" (1). Identifying and realizing dietary patterns that

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Abbreviations used: EAA, essential amino acids; en%, percent of energy; FBS, food balance sheets; GHGe, greenhouse gas emissions; NCD, noncommunicable disease; SUSENAS, Indonesia Household Income and Expenditure Survey.

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could meet all these goals is the challenge that is upon all of us for this decade and is a major theme for the UN Food Systems Summit 2021.

It is clear that massive change is required of food systems, including people's diets (2, 3). Food systems are localized but very much influenced by factors such as climate change, population growth, urbanization, and global trade (4). Improving diets to eliminate malnutrition in all its forms, while mitigating climate change, freshwater depletion, and other environmental impacts, requires a critical examination of current and possible future diets and of factors affecting food production to inform research, development, and planning. The EAT-Lancet commission proposed a planetary health diet that would promote health, in particular by lowering the noncommunicable disease (NCD) burden, and would reduce greenhouse gas emissions (GHGe) from food production and consumption worldwide by up to 80% (5). That diet, however, exceeded the income of at least 1.6 billion people (6). Furthermore, a recent analysis has shown that adopting the EAT-Lancet planetary health diet today, using current food production methods, would reduce GHGe in 101 countries, increase them in 36, and leave them virtually unchanged in 14 (7).

Indonesia, with 264 million people (8), is the largest country with a severe triple burden of malnutrition (9). The high prevalence of undernutrition early in life (30.8% stunted) (10) holds back development and increases morbidity and mortality throughout life. Meanwhile, the burden of overweight and NCDs is increasing and micronutrient deficiencies persist (11) as consequences of a high prevalence of undernutrition early in life; the nutrition transition with a continued high intake of rice; increasing intake of foods high in sugar, unhealthy fats, and/or salt (12); changing food consumption patterns that are trending toward several consumption moments throughout the day (13); and lower physical activity associated with urbanization. Improving the nutritional value of the diet early in life is key to breaking the vicious cycle of the triple burden of malnutrition. Meanwhile, Indonesia is experiencing the impacts of climate change and environmental degradation, and reducing its contribution to these problems is also a high priority (14).

The goals of our study were to assess *1*) to what extent current food utilization in Indonesia (2 patterns) provides for meeting health and nutrition targets and how its GHGe and water footprints compare to global targets; and *2*) how alternative dietary scenarios, optimized to meet nutrient needs at the lowest possible cost (7 scenarios) or designed to be more healthy and environmentally friendly (4 scenarios), compare to current food patterns for nutrient content, agricultural contributions to climate change, and freshwater conservation, as well as cost.

## Methods

We measured the costs, nutrient content, GHGe, and water footprints associated with 13 dietary patterns or scenarios, henceforth referred to as "diets."

### Diets

The diets included in this analysis are summarized in **Table 1**.

The current Indonesian diet was modeled using loss-adjusted food availability from FAO food balance sheets (FBS) (15) as a

**TABLE 1** Summary of diets[1]

| Diet(s) name (*n*) | Food items used in modeling | Method | Guidelines or parameters used |
|---|---|---|---|
| Current diet (*n* = 1) | FBS items; adapted to SUSENAS items for cost and nutrient content | Based on food availability as reported in FBS, adjusted for food losses using method from Kim et al. (16) | None |
| Current adjusted diet (*n* = 1) | FBS items; adapted to SUSENAS items for cost and nutrient content | Adapted from FBS food availability to meet macronutrient guidelines | 2300 kcal, minimum 69 g protein |
| Increasingly plant-based diets (*n* = 3) | FBS items; adapted to SUSENAS items for cost and nutrient content | Modeled using method from Kim et al. (16) | 2300 kcal, minimum 69 g protein, cap on sugars, at least 5 servings of fruits and vegetables |
| EAT-Lancet planetary health diet (*n* = 1) | FBS items; adapted to SUSENAS items for cost and nutrient content | Adapted from Willett et al. (5) using method from Semba et al. (7) | Scientific targets for human health and food system planetary boundaries |
| Diets optimized for household members (*n* = 5) | FBS items; adapted to SUSENAS items for cost and nutrient content | Modeled using Cost of the Diet software (19) | Optimized to meet nutrient targets for each household member at lowest cost |
| Average of household members' diets (*n* = 1) | FBS items; adapted to SUSENAS items for cost and nutrient content | Average of Cost of the Diet results for 5 household members | Mathematical average of the optimized diets of the 5 household members (see above) |
| Diet optimized for an average individual (*n* = 1) | FBS items; adapted to SUSENAS items for cost and nutrient content | Modeled using Cost of the Diet software | Optimized to meet Codex Alimentarius nutrient reference values and 2300 kcal and 69 g protein at lowest cost |

[1] FBS, food balance sheets; SUSENAS, Indonesia Household Income and Expenditure Survey.

proxy for current intake. We also included an adjusted variant of the current diet that was modified to provide 2300 kcal and a minimum of 12% of energy (en%) from protein, or 69 g/capita/day, for the purpose of comparison to the increasingly plant-based diets and the optimized diets.

We included 3 increasingly plant-based diets that reflect global trends of ways in which people change their dietary pattern for better health and/or a reduced environmental impact by excluding specific animal-source foods, which are also compatible with dietary patterns in Indonesia that may be driven less by environmental concerns but more by health and cost reasons: *1*) a no-dairy diet (because of lactose intolerance, milk is mainly consumed by children); *2*) a fish and poultry diet (some animal-source foods are consumed, but red meat is too expensive); and *3*) a low food chain diet (plant-based apart from mollusks, pelagic fish, and insects: i.e., animal-source foods that can be gathered, such as from rice fields and at the coast). These were derived from the current diet by removing relevant foods (e.g., red meat from the fish and poultry diet) and adjusting staples and protein-rich foods to meet the same energy and protein criteria as the adjusted current diet, with additional adjustments in line with typical recommendations for a healthy diet that were also used by Kim et al. (16) and had been partly derived from Springmann (17): that is, to cap sugar intake at no more than 10 en% and provide at least 5 servings of fruits and vegetables (see **Supplemental Figure 1** for further information). The proportional distribution of the remaining FBS items, within and between food groups, was preserved as per Indonesia's current food availability to the degree possible while still meeting these criteria. It is important to note that those diets were not optimized for nutrient content or cost.

The current, current adjusted, and increasingly plant-based diets were adapted from Kim et al. (16), with 2 notable differences for this study: food availability and countries of origin (used for calculating GHGe and water footprints) were updated to use more recent food balance and trade data from 2014–2017 (15), and protein and caloric content were based on the nutrient composition data used in this study (see "Nutrient composition" below), for consistency, rather than deriving them from FBS.

We also included the EAT-Lancet recommended "planetary health diet" (5), adapted to FBS items using the method described in Semba et al. (7).

Seven optimized diets were modeled using the March 2018 Indonesia Household Income and Expenditure Survey (SUSENAS) report data, Indonesia's national socioeconomic survey of household food consumption and expenditures (18). We used the Cost of the Diet linear optimization software (19) to generate diets for 5 members of a household that met FAO/WHO average calorie and fat requirements [estimated average requirement (EAR)] and recommended nutrient intakes (RNI) for protein and micronutrients for each specified individual at the lowest possible cost. The household individuals were a breastfed child aged 12–23 months, a child aged 6–7 years, a female aged 14–15 years, a lactating female aged 30–59 years, and a male aged 30–59 years. The software accounted for 4 minerals and 9 vitamins (see "Nutrient composition" below). The sections that follow describe data sources for cost, nutrient composition, and nutrient intake targets. We also included the results averaged across all 5 household members to arrive at an average that is based on different needs throughout the lifecycle ("optimized household"). Finally, we included a diet that was optimized for an average individual using the caloric target (2300 kcal) and protein minimum (69 g) from Kim et al. (16), in addition to the nutrient targets described below ("optimized individual"). This diet was included so it could be compared against the current adjusted and increasingly plant-based diets, which were also modeled using the same energy and protein targets.

## Representation of food items in diets

Food items in the diets were generally expressed in 1 of 2 ways: as items from FBS (15) or as items from SUSENAS (18). A data flow diagram depicting detailed methods is provided in **Supplemental Figure 2**. While FBS items are for the most part generic raw commodities such as soybeans and pelagic fish, SUSENAS provides greater specificity and reflects foods in the form as consumed in Indonesia: for example, tofu, tempeh, and preserved anchovies.

For measuring GHGe and water footprints, we used the study model developed for Kim et al. (16), which uses FBS items as the unit of analysis. For measuring cost and nutrient content, we required a finer level of detail than broad commodity groups from FBS could provide, so we used SUSENAS items. For diets originally modeled using FBS items, these needed to be converted to SUSENAS items for measuring cost and nutrient contents. Conversely, for diets originally modeled using SUSENAS items, these needed to be converted to FBS items for modeling GHGe and water footprints. The details of these conversions are described below.

## GHGe and water footprints

For measuring GHGe and water footprints, we used the study model developed for Kim et al. (16), which uses FBS items as the unit of analysis. We distinguish between blue water (fresh surface and ground water or, in the context of agriculture, water used for irrigation) and green water (rainfall available for use by plants). The study model accounted for country-specific import patterns (in the case of this analysis, specific to Indonesia) and the GHGe and water intensities of foods by country of origin (where sufficient data were available). Refer to Kim et al. (16) for details.

## Cost of the diets

The weekly per capita quantities of food items purchased as reported by SUSENAS were expressed in different units depending on the food: for example, kilograms, liters, pieces of bread, and whole eggs. We standardized quantities of SUSENAS items to kilograms using conversion factors and specific sources (available upon request), mostly based on data from the USDA Food Composition Databases (20) or the Indonesian dietary guidelines (21).

To estimate the costs of all 16 diets, we used food expenditure data provided in SUSENAS. The cost per kg $C$ for each SUSENAS item $i$ was calculated as follows, where $R$ is the spending (in Rupiahs) per capita per week and $Q$ is the quantity purchased per capita per week:

$$C_i = R_i \div Q_i \tag{1}$$

For the current, increasingly plant-based, and EAT-Lancet diets, after converting FBS items to SUSENAS items, multiplying the cost per kilogram by the kilograms of each SUSENAS item in the respective diet yielded the associated cost. The optimized diets used the same cost data from SUSENAS and accounted for cost as part of the optimization algorithm for meeting all specified nutrients at the lowest possible cost.

### Nutrient composition

For the current, increasingly plant-based, and EAT-Lancet diets, after converting FBS items to SUSENAS items, nutrient composition was determined by matching each SUSENAS item in the diet (or FBS item, in the few cases where FBS items were more granular) to an item from the following sources. Micronutrient composition was from the USDA nutrient database (20), Indonesian food composition tables (22), and other sources compiled in the data set provided by the Cost of the Diet software. This data set covered 4 minerals (absorbed iron, calcium, magnesium, and zinc) and 11 vitamins [A, C, D, K, B1 (thiamin), B2 (riboflavin), B3 (niacin), B5 (pantothenic acid), B6 (pyridoxine), B9 (folate), and B12 (cyanocobalamin)]. Iron content was expressed in terms of the estimated amounts absorbed, in order to take bioavailability differences between iron from different food sources into account, and the iron requirement was also expressed in terms of absorbed iron. Choline and essential amino acid (EAA) compositions were primarily obtained from the USDA nutrient database (20) and supplemented with other sources (23–27).

The optimized diets were modeled to account for the 4 minerals and 9 of the 11 aforementioned vitamins as part of the optimization algorithm. Vitamins D and K, choline, and EAAs were measured using the method above but were not considered in the optimization algorithm of the Cost of the Diet software.

### Cost, nutrient, GHGe, and blue water footprint targets

The cost of each diet was compared to average per capita national, rural, and urban food expenditures as reported in SUSENAS, including alcohol and spices but excluding tobacco products.

The micronutrient composition of each diet was compared to nutrient reference values for an average individual from the Codex Alimentarius (28). These values were also used as targets in generating the optimized diet for the average individual. For the optimized diets, the micronutrient composition was compared to FAO/WHO nutrient targets for the respective individuals (29). Choline targets were from the Institute of Medicine (30). Targets for the digestible share of EAAs, based on body weight, were from the FAO/WHO (31). We assumed 65% of protein intake was digestible (31).

In addition to calculating the percentage of each nutrient target met by each diet, we calculated 2 aggregate nutrient scores. Both aggregate scores accounted for 18 nutrients: the aforementioned 4 minerals, 11 vitamins, choline, total protein, and a single averaged score for EAAs. We calculated the mean adequacy ratio (32) as the average of these 18 percentages, with percentages over 100% capped at 100%. We also calculated an aggregate nutrient score as follows:

$$\begin{aligned}&(Number\ of\ nutrient\ targets\ met \times 2)\\&\quad + (Number\ of\ nutrient\ targets\ between\ 75\% - 100\%)\\&\quad - (Number\ of\ nutrient\ targets\ below\ 50\%) \qquad (2)\end{aligned}$$

The GHGe and blue water footprint of each diet were compared to scientific targets for sustainable food production determined by Willett et al. (5). The targets are for 2050 and are based on the concept of planetary boundaries and aim to "ensure that the UN Sustainable Development Goals (SDGs) and Paris Agreement are achieved" (5). The GHGe target represents an estimate of unavoidable methane and nitrous oxide emissions from food production, and is based on the ambitious assumptions that 0 carbon dioxide emissions will come from land use change or food supply chains; the 0 carbon dioxide emission assumption will require a global transition to renewable energy (5). Since the targets are global, we adapted the targets and their associated uncertainty ranges to per capita targets by dividing them by the projected global population of 9.7 billion in 2050 (33), resulting in per capita targets of 514 kg $CO_2$e/capita/year (uncertainty range, 483–555) and 256,804 L/capita/year (uncertainty range, 102,722–410,887).

### Conversion from FBS items to SUSENAS items

FBS items generally do not capture the level of detail needed for estimating food prices and expenditures and nutrient content. To obtain this information, quantities of FBS items were converted to food items from SUSENAS (18). The details of this conversion are as follows.

Each FBS item reported for Indonesia was matched to 1 or more food items in SUSENAS. For FBS items without an exact match in SUSENAS, we identified proxies. For the few cases where FBS items were more granular than their SUSENAS counterparts, each SUSENAS item was matched to multiple FBS items, preserving the finer level of granularity. While all FBS items had a match in SUSENAS, some SUSENAS items were comprised of multiple ingredients (e.g., prepared meals) and thus did not have a suitable match among FBS items.

Many SUSENAS items are processed goods (e.g., wheat flour, tempeh, dried fish), whereas most FBS items are expressed in terms of raw, unprocessed commodities or "primary equivalents" (e.g., raw wheat, soybeans, whole fresh fish). Before FBS items could be converted to SUSENAS items, to make FBS and SUSENAS items compatible, we used extraction rates to convert quantities of processed SUSENAS items back to their primary equivalents. For example, 160 g/capita/week of Indonesian tofu reported in SUSENAS was converted to 70 g/capita/week of unprocessed soy (in this example, the primary equivalent has less mass because making tofu adds water weight). Wherever data were available, we used extraction rates specific to Indonesia provided by the FAO Statistics Division. If for a given item there were no extraction rate data for Indonesia, we used the global average extraction rate for that item, weighted by the mass of production of that item in each producing country. Extraction rates for dried aquatic animals (e.g., dried shrimp) were not included in the data set provided by FAO, so we derived them using moisture content data from Indonesian food composition tables (22).

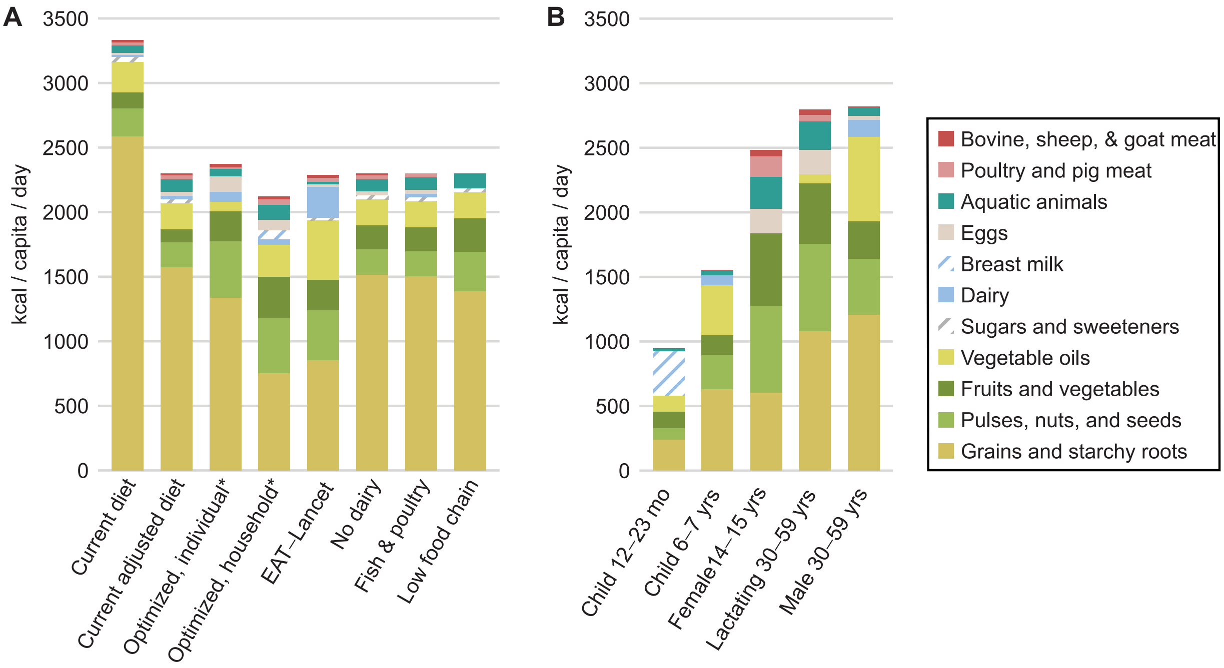


**FIGURE 1** Energy content and contributions from different food groups for the current and modeled diets (kcal/cap/d), (A) for an average individual and modeled household average and (B) optimized for specific individuals. *Optimized to meet nutrient requirements at the lowest cost.

The mass of each FBS item in each diet was then allocated over the corresponding SUSENAS item(s). Allocation was based on the relative quantities, by mass, consumed of each SUSENAS item. For example, 137 g/capita/day of the FBS item "fruits, other" in the low food chain diet was allocated over 9 matched fruit items in SUSENAS. Of those 9 items, rambutan represented 25% of the share of consumption reported in SUSENAS. Accordingly, 25%, or 34 of the 137 g of "fruits, other," was allocated to rambutan. If an FBS item was matched to only 1 SUSENAS item, 100% of the quantity of the FBS item was allocated to the SUSENAS item.

After the allocation step, quantities of SUSENAS items were converted from primary equivalents back to their processed weight for compatibility with cost and nutrient content data, and to present quantities of food items in terms of how they will be purchased and consumed.

### Conversion from SUSENAS items to FBS items

To calculate the GHGe and water footprints of optimized diets, we converted SUSENAS items to FBS items. For this, we reversed the steps described above.

## Results

### Compositions of the diets

**Figures 1** and **2** show the energy and protein intake, respectively, as contributed by different food groups for the different diets. The current diet, which is based on loss-adjusted food availability data from FBS, contained 3331 kcal/cap/d and 78 g protein/cap/d after converting the generic commodities reported by FBS (e.g., soybeans and products) to the specific items consumed in Indonesia (e.g., tofu and tempeh). Without this conversion, based on FBS nutrient data for each commodity, the diet provided only 2721 kcal/cap/d and 61 g protein/cap/d. Most of this difference is explained by the fact that the caloric content of rice in FBS is equated to 240 kcal/100 g, whereas it is 360 kcal/100 g in food composition tables, a difference that we were not able to reconcile. In the current diet, grains and starchy roots, which largely consisted of rice and some wheat-based products, provided 77 en% and 64% of protein. In going to the adjusted current diet, the absolute and relative contributions to total energy from rice were decreased, while the contributions from other food groups, especially those contributing protein, such as animal-source foods and pulses, were increased (see Figure 2).

The diet for an average individual that was optimized to meet nutrient intake recommendations at the lowest possible cost (Figures 1A and 2A: "optimized, individual") contained more than 700 kcal from pulses, nuts, and seeds; vegetables and fruits; and eggs, and less than 1400 kcal from rice, aquatic animals, and poultry, while the current adjusted diet had less than 300 kcal from the former and more than 1600 kcal from the latter. The average individual's diet also contained a high amount of protein (113 g/cap/d). Among the animal-source foods that were selected for this diet by the linear optimization software were eggs, aquatic animals, dairy, and ruminants (beef, buffalo, sheep, and goat), as well as some poultry and a very small amount of pig meat. The diet optimized for different household members and averaged per capita (Figures 1A and 2A: "optimized, household") included less rice and more oil than the diet that was optimized for an average individual and also more fruits, vegetables, and several animal-source foods. Figures 1B

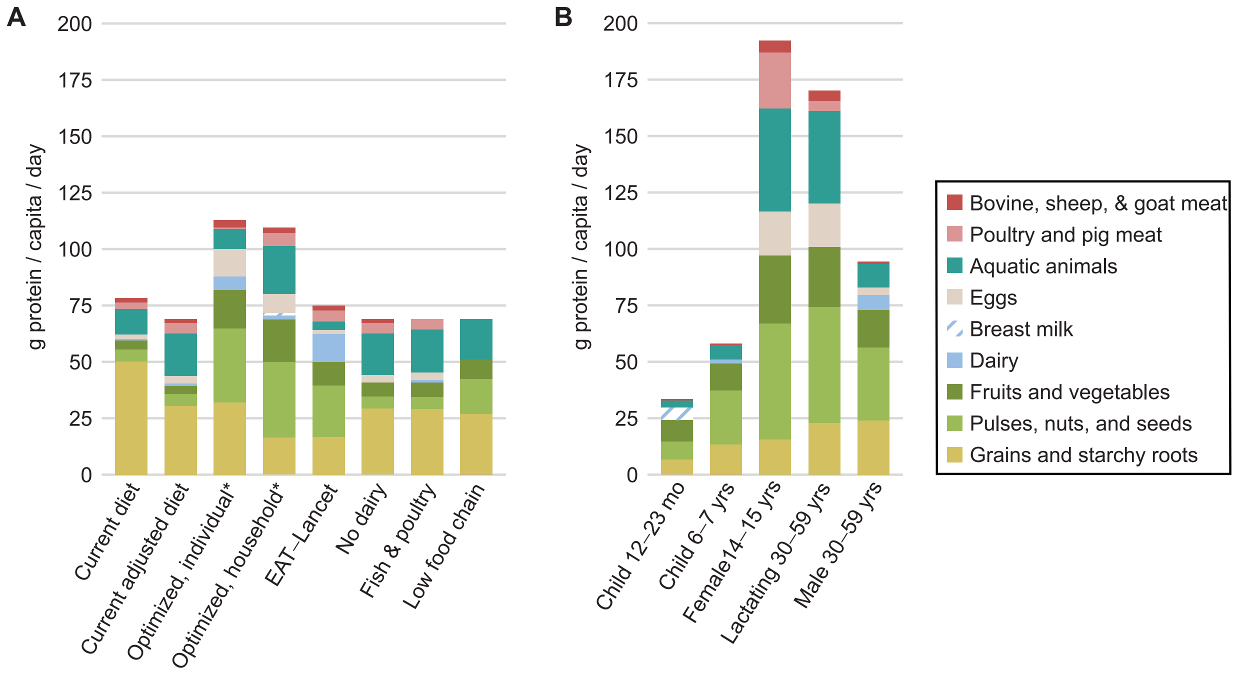


**FIGURE 2** Protein content and contributions from different food groups for the current and modeled diets (g/cap/d), (A) for an average individual and modeled household average and (B) optimized for specific individuals. *Optimized to meet nutrient requirements at the lowest cost.

and 2B show what the diets for the 5 different members of the household looked like. The adolescent girl and lactating woman had the most diverse diets in the household and more than 150 g of protein per day (other diets had less than 100 g/d). Compared to the adult male and the school-age child, their diets had high quantities of almost all foods and no and very little vegetable oil, respectively. In comparison to the school-age child, the adolescent girl's amount of rice was the same, although her energy intake was approximately 40% higher. As the optimized diets of the individual household members were comprised of different foods in different relative quantities, they could not be derived from the optimized household average by just scaling the amounts of the same foods in accordance with individuals' energy needs.

The EAT-Lancet planetary health diet had a much smaller amount of rice and much more diversity than the current diet. It included only slightly more rice than the optimized household diet, and large amounts of dairy, vegetable oil, and pulses, nuts, and seeds.

The increasingly plant-based diets differed in protein sources and the relative contributions of each source to total protein intake. The no-dairy and the fish and poultry diets had comparable amounts of protein from rice; pulses, nuts, and seeds; and fruits and vegetables, while the low food chain diet had a relatively low amount of rice, a large share of protein from plant foods, and large amounts of pulses, nuts, and seeds.

## Costs of the diets

The costs of the different diets, broken down by food group, are shown in **Figure 3**. The average expenditure on food (Figure 3A) was 18,288 Rp/cap/d in urban areas and 13,583 Rp/cap/d in rural areas. All diets, including the optimized ones, cost more than 15,000 Rp/cap/d. The EAT-Lancet diet cost almost as much as food expenditure in urban areas. The costs of the other increasingly plant-based diets were close to the cost of the current diet and approximately 10% more than the adjusted current diet. The optimized diet costs were close to those of the current adjusted diet. In comparison to the proportional share of energy, the proportional share of the cost was particularly high for animal-source foods, followed by fruits and vegetables. Rice and pulses, nuts, and seeds were relatively inexpensive.

While the per capita cost of the optimized household was below that of the optimized individual, reflecting the slightly lower average per capita energy intake of the 5 individuals, there are large differences of the costs among the individual household members (Figure 3B). The cost for the adolescent girl was more than twice that of the adult man, while her energy intake was lower (Figure 1B). The lactating woman's diet was second highest in cost, almost 70% higher than of the adult man, for roughly the same energy content. The main contributors to the costs of the girl's and the lactating woman's diets were animal-source foods. The costs for the 2 children's diets were low, in line with their lower energy intakes.

## Greenhouse gas emissions

**Figure 4** shows the median GHGe in kg of $CO_2$ equivalents/cap/year for the different diets, by food group. We included IQRs to reflect uncertainty in the data for aquatic animals and plant foods [terrestrial animal products used point estimates specific to the countries of origin; see Kim et al. (16) for details]. All diets, except the low food chain diet, had GHGe above the

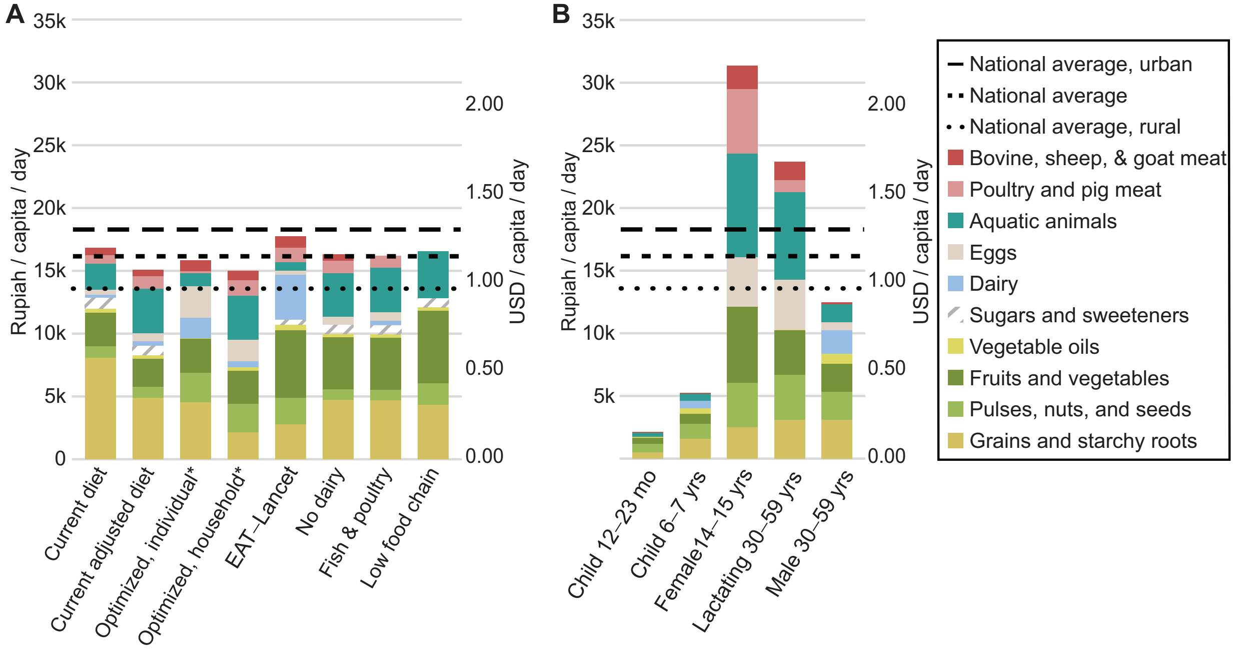


**FIGURE 3** Costs and contributions from different food groups for the current and modeled diets (Rupiah/cap/d), (A) for an average individual and modeled household average and (B) optimized for specific individuals. Dashed lines indicate the current national food expenditure on average and in urban and rural areas (Indonesia Household Income and Expenditure Survey). *Optimized to meet nutrient requirements at the lowest cost.

2050 target as adapted from the EAT-Lancet commission. The GHGe for the optimized individual and EAT-Lancet diets were particularly high (more than a third higher than the current diet). The most GHGe-intensive food groups per kcal were bovine meat (by an order of magnitude), sheep and goat meat, pig meat, eggs, and dairy. Rice content also contributed substantially to the GHGe of the diets, because the consumption levels were high. The optimized diets of the lactating woman and the adolescent

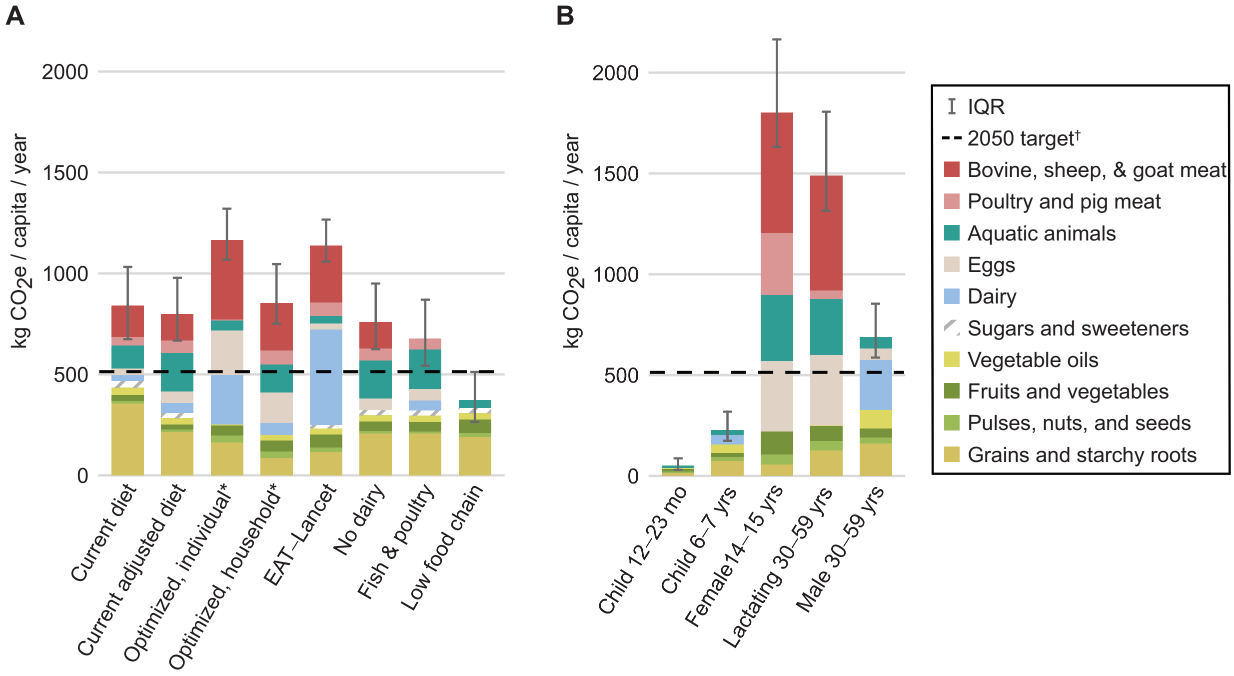
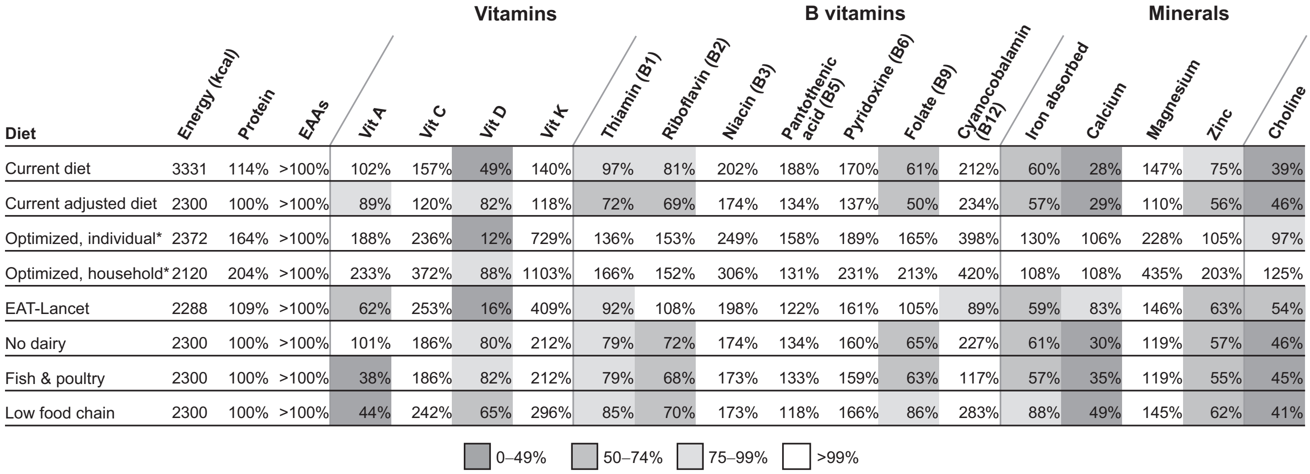


**FIGURE 4** Total greenhouse gas emissions and contributions from different food groups for the current and modeled diets (kg carbon dioxide equivalents/cap/y), (A) for an average individual and modeled household average and (B) optimized for specific individuals, including IQRs. †The 2050 target was adapted from Willett et al. (5): 519 kg carbon dioxide equivalents/cap/y; uncertainty range, 483–555. *Optimized to meet nutrient requirements at the lowest cost.



| | | | | Vitamins | | | | B vitamins | | | | | | | Minerals | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Diet | Energy (kcal) | Protein | EAAs | Vit A | Vit C | Vit D | Vit K | Thiamin (B1) | Riboflavin (B2) | Niacin (B3) | Pantothenic acid (B5) | Pyridoxine (B6) | Folate (B9) | Cyanocobalamin (B12) | Iron absorbed | Calcium | Magnesium | Zinc | Choline |
| Current diet | 3331 | 114% | >100% | 102% | 157% | 49% | 140% | 97% | 81% | 202% | 188% | 170% | 61% | 212% | 60% | 28% | 147% | 75% | 39% |
| Current adjusted diet | 2300 | 100% | >100% | 89% | 120% | 82% | 118% | 72% | 69% | 174% | 134% | 137% | 50% | 234% | 57% | 29% | 110% | 56% | 46% |
| Optimized, individual* | 2372 | 164% | >100% | 188% | 236% | 12% | 729% | 136% | 153% | 249% | 158% | 189% | 165% | 398% | 130% | 106% | 228% | 105% | 97% |
| Optimized, household* | 2120 | 204% | >100% | 233% | 372% | 88% | 1103% | 166% | 152% | 306% | 131% | 231% | 213% | 420% | 108% | 108% | 435% | 203% | 125% |
| EAT-Lancet | 2288 | 109% | >100% | 62% | 253% | 16% | 409% | 92% | 108% | 198% | 122% | 161% | 105% | 89% | 59% | 83% | 146% | 63% | 54% |
| No dairy | 2300 | 100% | >100% | 101% | 186% | 80% | 212% | 79% | 72% | 174% | 134% | 160% | 65% | 227% | 61% | 30% | 119% | 57% | 46% |
| Fish & poultry | 2300 | 100% | >100% | 38% | 186% | 82% | 212% | 79% | 68% | 173% | 133% | 159% | 63% | 117% | 57% | 35% | 119% | 55% | 45% |
| Low food chain | 2300 | 100% | >100% | 44% | 242% | 65% | 296% | 85% | 70% | 173% | 118% | 166% | 86% | 283% | 88% | 49% | 145% | 62% | 41% |

**FIGURE 5** Amounts of energy provided and proportions of recommended intakes for different nutrients [nutrient reference values from Codex Alimentarius (28)] met by the different modeled diets. *Optimized to meet nutrient requirements at the lowest cost. EAA, essential amino acid; Vit, vitamin.

girl had GHGe close to 3 times and more than 3 times that of the 2050 target level.

### Nutrient contents of the diets

The nutrient adequacies of the different diets are shown in **Figure 5**. The optimized diets met the requirements for all nutrients included in the optimization. For the average individual, the requirements for the EAAs and vitamin K were also met, those for choline were almost met, but those for vitamin D were not met (12% of needs met). For the individual household members, all needs were met for the adolescent girl and the lactating woman, while vitamin D and choline needs were not met for the breastfed child, school-age child, and adult man, and vitamin K needs were not met for the breastfed child (data not shown). The greatest deficiencies were for vitamin D (data not shown).

Among the other diets, including the current diet, there were many more deficiencies. Vitamin D, calcium, choline, and vitamin A were severely deficient in several diets. Contents of iron, zinc, folate, and riboflavin were approximately 50%–70% of the recommended intakes and contents of thiamin were 80%–100% of the recommended intakes. Vitamin B12 (cyanocobalamin) was somewhat deficient in the EAT-Lancet diet, but otherwise this diet had fewer and less severe deficiencies.

### Water footprint

All diets had blue water (fresh surface and ground water, for irrigation) footprints that were well below the EAT-Lancet target for sustainable food production, including the lower bound of the uncertainty range (see **Figure 6**). Most of the water footprints for the diets (85%–95%) were attributable to green water (rainfall).

### Balancing concurrent achievement of different targets: how did the diets score?

**Figure 7** shows how well the different diets align with GHGe, blue water footprint, affordability, and nutrition targets. For the purpose of comparing scores of different types of diets, the current (unadjusted) diet should be interpreted separately and the optimized household has been left out, because they do not have the same energy and protein intakes as the other diets. All diets easily met the blue water footprint target. None of the diets scored well on all 3 of the other targets simultaneously. The low food chain diet scored best on GHGe but had suboptimal nutrient scores. The optimized diet scored well on nutrient content and cost but poorest on the GHGe target. The EAT-Lancet diet also scored very poorly on the GHGe target, had the highest cost, and had suboptimal nutrient contents, but was somewhat better than the current adjusted and 3 Indonesian increasingly plant-forward diets. Among the current adjusted and 3 increasingly plant-forward Indonesian diets, the nutrient scores were comparable, whereas the current adjusted diet cost the least and the low food chain diet scored best for GHGe.

## Discussion

The analyses presented in this paper have shown that the current Indonesian diet does not meet nutrient needs and its GHGe is above the per capita target for 2050 adapted from the EAT-Lancet commission. The dietary patterns that we explored had trade-offs: diets that were optimized to meet nutrient needs at the lowest possible cost had higher GHGe, whereas the low food chain diet that scored better than the GHGe target had suboptimal nutritional scores. Meanwhile, the EAT-Lancet diet had the highest GHGe, more than twice the 2050 target level, and did not meet the nutrient targets either. Clearly, there is no obvious win-win scenario, and identifying priorities and pathways to achieve change requires careful interpretation of the results. The difficulty of identifying a dietary scenario that concurrently meets nutrient, health, affordability, and environmental goals was also reported from Iran by Eini-Zinab et al (34).

The current diet has a high proportion of energy from rice and hence relatively low diversity and a nutrient content that is too low. To benefit nutrition across the entire life cycle, diets should be diverse and even more so for groups with high nutrient-density requirements, such as adolescent girls and women during

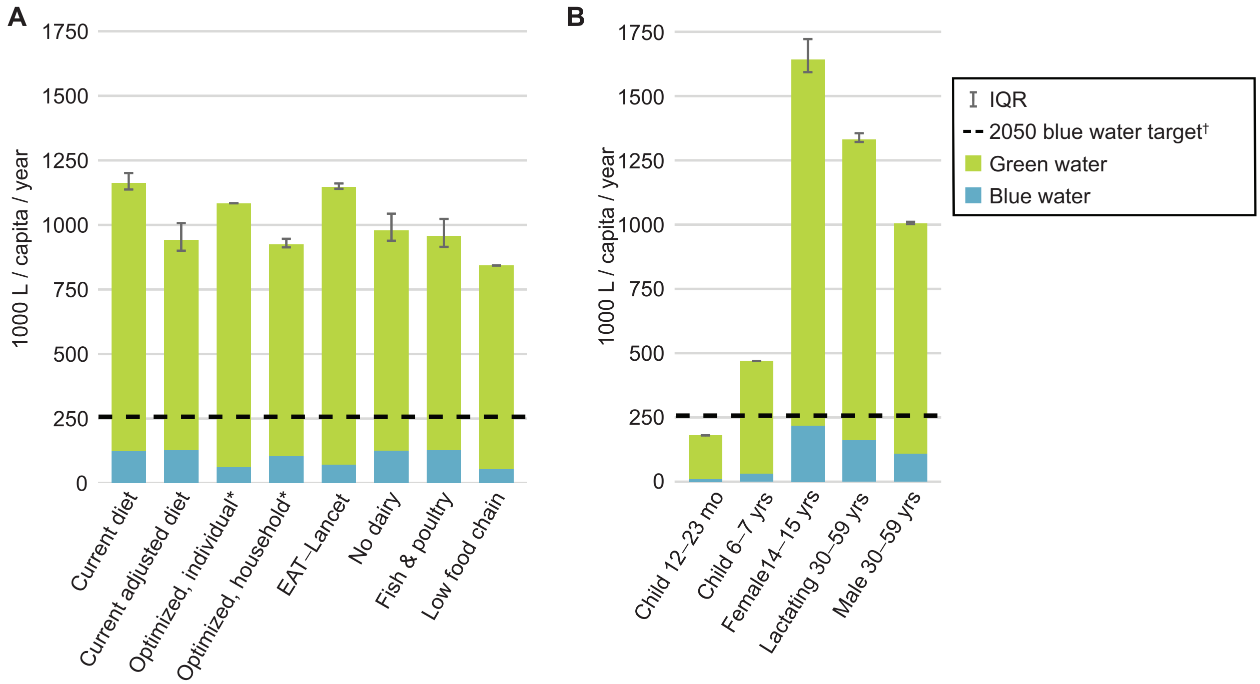


**FIGURE 6** Total per capita blue water (surface and ground water, for irrigation) and green water (from rainfall) footprints for the current and modeled diets (1000 L/cap/y), including IQRs. †The 2050 target was adapted from Willett et al (5): 256,804 L/capita/year; uncertainty range, 102,722–410,887. *Optimized to meet nutrient requirements at the lowest cost.

pregnancy and lactation. Their optimized diets included a larger share of animal-source foods compared to those for the breastfed 1-year old, school-age child, and adult male, as those foods are a more efficient source of protein and many micronutrients and are the only source for vitamin B12 (cyanocobalamin). Increasing the intake of animal-source foods will increase GHGe, unless very specific choices are made in terms of which animal-source foods to consume, how to produce them, and how to prioritize them, in moderation, for phases of high growth and development. Environmental as well as public health and animal welfare harms

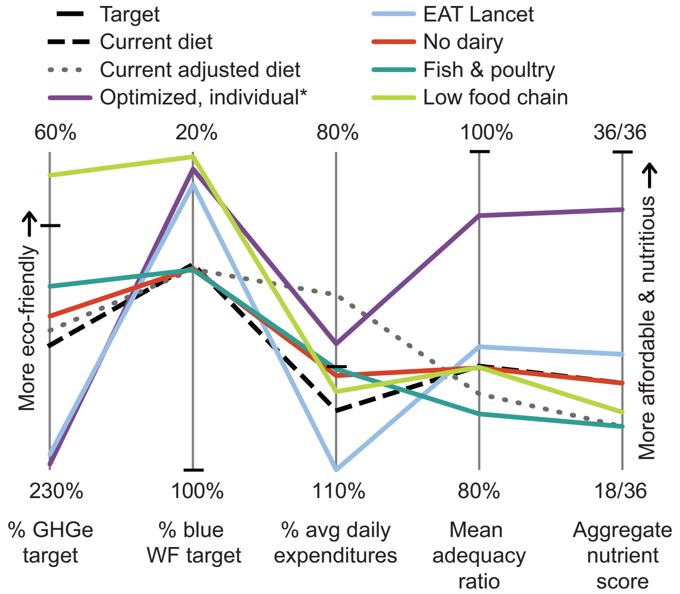


**FIGURE 7** Each diet's score compared to the targets for GHGe, blue WF (surface and ground water, for irrigation), mean nutrient adequacy, and aggregate nutrient score and to the current average food expenditure for cost. A score higher on an axis is better (note that for nutrient scores the target is at the top, with all lower scores being suboptimal, whereas for blue WF all scores are better than the target level). *Optimized to meet nutrient requirements at the lowest cost. GHGe, greenhouse gas emissions; WF, water footprint.

vary by species and by the scale, methods, and context in which they are produced (35). For example, ruminant meat and dairy have much higher GHGe than poultry, fish, and lower food chain animal-source foods, while their nutritional values do not differ very much. Also, industrial food animal production has much more negative impacts on public health risks and animal welfare (36).

Increasing dietary diversity and making choices that are better for the environment is also limited by affordability (37, 38). Considering that 49.5% of total expenditure was spent on food in 2018 (18) and that coronavirus disease 2019 has markedly reduced incomes (39), dietary change should mostly occur without needing to increase food expenditure. Indonesia's emphasis on rice self-sufficiency has not only limited diversification of production, but has also made the price higher than that on the world market, which is in part related to fertilizer subsidies and import restrictions (40). When rice costs more, people spend less on other foods (41, 42). If prices of rice and nutritious foods were lower, and people would lower their consumption of rice and unhealthy foods and beverages, some food expenditure could be reallocated towards more nutritious foods. Furthermore, improving the nutritional value of foods through fortification—for example, of rice, wheat flour, and cooking oil—brings nutrient-adequate diets more within economic reach and is also a way to compensate for dietary micronutrient deficiencies while limiting environmental impacts.

For the current diet and for the diets that were modeled to be healthy, have enough protein, and be increasingly plant-based compared to the adjusted current diet, the contents of several nutrients were well below recommended amounts. The fact that recommended intakes of individual amino acids were met for all diets may be due to the fact that the absolute quantity of protein had been set at 69 g/cap/d, in line with dietary guidance to consume 10–15 en% from protein. Many publications on dietary projections include 50–55 g protein/cap/d, which provides less than 10% of energy for a 2300 kcal diet, which may provide too small amounts of certain EAAs (43).

The analyses presented in this paper have several limitations. First, the data used to characterize the current diet are from FBS, which represent food availability in the food supply rather than dietary intake, as the latter are not available for Indonesia. FBS data are based on estimated production data, minus exports, plus imports; do not capture self-produced and gathered foods; make rough assumptions for food that is fed to animals, food loss along the value chain, and edible portions; set the caloric content of rice and rice products a third lower than for edible rice; group many foods together, and only include processed foods in the form of their primary equivalents. This can lead to substantially different estimates, as was shown by the lower estimates for energy and protein intakes from the FBS items as compared to those obtained after converting FBS into SUSENAS items. Furthermore, we did not account for household-level waste beyond edible portions, because the standardized methodology for optimizing diets at the lowest possible cost sets that at 0. This resulted in only slightly lower GHGe, water footprint, and cost estimates, though, because household waste for Southeast Asia is estimated at 0%–7% (44).

Second, the current, increasingly plant-based, and EAT-Lancet diets were modeled using FBS items, and thus in most cases were expressed in terms of unprocessed whole foods. When these items were matched to SUSENAS items to estimate expenditures, many processed and/or multi-ingredient SUSENAS items, such as prepared foods and certain beverages, were not matched to. To the extent that these SUSENAS items were more (or less) expensive than unprocessed whole foods, the costs of the current, increasingly plant-based, and EAT-Lancet diets would have been underestimated (or overestimated). However, surprisingly, the estimated food expenditure for the current diet was only 1% higher than the actual national food expenditure as reported by SUSENAS.

Third, the Cost of the Diet software that was used to optimize for nutrient contents and the lowest cost did not include all nutrients of interest in its algorithm, such as vitamins D and K, choline, and EAAs, for reasons explained elsewhere (19). Hence, the optimized diets did not meet the requirements for those nutrients, except for EAAs. However, as the SUSENAS data do not include information about fortification of foods, we may have underestimated intakes of specific micronutrients that are, for example, included in fortification of noodles, vegetable oil, and dairy, such as vitamin D. Furthermore, vitamin D requirements were taken from the Institute of Medicine (IOM) and do not take into account specific sun exposure in Indonesia.

Fourth, the nutrient adequacies of the increasingly plant-based diets were lower than those of the more diverse EAT-Lancet diet and the optimized diets, which may be partly due to the fact that the choices of foods for the increasingly plant-based diets were guided by current consumption within food groups as per the FBS data. Nutrient content may improve to some extent with different choices of foods from within the food groups. The optimized diets were selected from SUSENAS foods, but purely based on nutritional value for money, so the selected foods do not necessarily provide for desired variation and appealing dishes, which would cost more.

The EAT-Lancet Commission aimed to develop scenarios for optimal human and planetary health, where they looked primarily at dietary risk factors for NCDs, which are by far the largest global burden of disease and ill health. For Indonesia, however, preventing the triple burden of malnutrition requires a prioritization of preventing undernutrition and meeting nutrient needs, while aiming for diets to become increasingly diversified and healthier. Our results showed that the EAT-Lancet diet did not meet all nutrient requirements; represented a very different dietary pattern from the current diet, with only half the amount of staple food; and, in comparison to the other modeled diets, was the most expensive and had the highest GHGe (more than twice the 2050 target level). However, if Indonesia were to adapt the dietary pattern of high-income countries that are members of the Organisation for Economic Cooperation and Development, the GHGe would be around 2915 $CO_2$ equivalents/cap/y, almost 6 times higher than the target adapted from Willett et al (5). It is important to note that that target was set to be met by both a change of dietary patterns and by changes of food production, including the use of energy from fossil fuels, whereas we only modeled dietary changes. Among the 3 increasingly plant-based dietary patterns that were modeled for Indonesia, the low food chain diet deserves exploring further because it had low GHGe scores: the low food chain animal-source foods in the model were limited to those reported by SUSENAS, but there are more which may improve nutrient content further, and it is a realistic diet for part of the population today.

There are a number of areas that policy-makers in Indonesia should focus on in order to improve food supply and demand towards diets that prevent malnutrition, are affordable, and limit the environmental impact.

First, the consumption of large quantities of rice and increasing consumption of unhealthy foods preclude inclusion of sufficient amounts of diverse, healthy foods. Also, from an affordability perspective, spending on rice and unhealthy foods prevents spending on diverse, healthy foods.

Secondly, food production and trade should prioritize diversification in order to increase supplies of nutritious and healthy foods and lower their prices, as well as the price of rice. Meanwhile, foods should be produced, processed, transported, and stored in the least environmentally taxing way; biofortifiation and postharvest fortification should be prioritized; and GHGe and other environmental impacts from animal-source foods should be limited through a focus on production of specific animal-source foods, including further development of fish and seafood production; increased consumption of low food chain species; optimization and regulation of the ways in which animal-source foods are produced; and development of production targets for moderate consumption.

Thirdly, demand for more diverse diets can be stimulated by lowering the prices of healthy, nutritious foods and increasing those of unhealthy foods high in sugar, fat, and/or salt: for example, through taxes, incentives/disincentives, or other fiscal and regulatory measures. Furthermore, consumers need to be nudged towards healthy choices within their food environment, provided with guidance by nutrition and health professionals, and inspired by influencers. Social and behavior change strategies, as well as food-based dietary guidelines, should include specific messages about higher needs for certain foods, such as animal-source foods, during specific phases of the life cycle. Institutional demand that supports lower-income consumers, such as through school meals and commodity-specific social assistance transfers, should also prioritize contributing to meeting nutrient needs.

Deciding how to manage the trade-offs of transforming Indonesia's food supply and consumption towards nutritious, healthy, affordable, and sustainable diets requires high-level government commitment and also *1*) gathering more granular data on dietary intakes, regional variation of food prices and food expenditures, and food production's environmental burdens beyond GHGe and water footprints; *2*) developing a tool that allows for concurrent review and optimization of dietary scenarios across environmental, nutrition, dietary preference, and affordability targets; and *3*) assessing the feasibility of producing projected quantities of foods in proposed ways.

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## Data Availability

Data described in the manuscript, code book, and analytic code will be made available upon request pending application and approval.

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