



## Nutrient Requirements and Optimal Nutrition

## Replacement of Milk and Dairy Products with Soy-Based Alternatives—How to Avoid Nutrient Deficiencies in a Milk-Free Diet?

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### ABSTRACT

**Background:** In Germany, milk and dairy products are increasingly replaced by their plant-based alternatives. Although they can be used as substitutes, they differ significantly in their nutrient composition; thus, substitution could lead to nutrient deficiencies. So far, there are no food-based dietary recommendations that show which foods can replace milk and dairy products in a healthy way when switching to a plant-based substitute.

**Objectives:** Against this background, the question arises as to how to ensure adequate intake of critical nutrients when plant-based alternatives are consumed instead of milk and dairy products. To answer this question, this study aims to analyze what dietary changes would be required to avoid possible nutrient deficiencies and what types of foods can be consumed instead.

**Methods:** To answer the research question, 3 different models are compared using the linear programming method: healthy diets with 1) milk and dairy products, 2) nonfortified plant-based alternatives, and 3) fortified plant-based alternatives. The models are applied to omnivorous, pescatarian, and vegetarian diet types.

**Results:** The results show that when consuming nonfortified soy alternatives, an adequate supply of calcium and, in the case of a vegetarian diet, vitamin B<sub>12</sub> can only be achieved if significant dietary changes are made compared to the average diet. This includes a significantly higher consumption of fruit and vegetables, whereby within the groups, calcium-rich varieties should be chosen (e.g., green leafy vegetables). When consuming fortified soy-based alternatives instead, the absence of milk and dairy products can be well compensated by the nutrients currently added to commercially available products.

**Conclusions:** Given the trend to consume less milk and dairy products or to abstain from them altogether, public health measures should point out possible nutrient deficiencies as well as necessary dietary changes, especially because in Germany, many plant-based alternatives are not fortified.

**Keywords:** healthy diet, plant-based dairy alternatives, plant-based milk alternatives, nutrient deficiencies, linear programming, soy drinks

## Introduction

Cow milk consumption in Germany has been declining for years and, with a per capita consumption of 47.8 kg in 2021, is at its lowest level since 1991 [1]. One of the reasons for the declining milk consumption could be the increasing popularity of plant-based milk alternatives. In 2022, sales of plant-based milk alternatives in the food retail sector in Germany amounted to 331 million L, which corresponds to about one-tenth of drinking milk sales [2].

Although plant-based milk alternatives can be used as a substitute for milk, they differ significantly in their nutrient

composition, for example, providing less calcium and vitamin B<sub>12</sub> than milk [3–6]. Such nutrient differences can also be seen in plant-based substitutes for cheese and yogurt [7]. For instance, many plant-based cheese substitutes are low in protein but high in saturated fat and, therefore, do not have a healthy nutrient profile [8,9]. Therefore, when replacing milk and dairy products with plant-based alternatives without other dietary adaptations, nutrient deficiencies can be risked, e.g., the amount of calcium and vitamin B<sub>2</sub> correlates with the amount of milk and dairy products in a diet [10]. Because of these differences, it is recommended to adjust the diet accordingly to compensate for nutrient losses when switching to plant-based alternatives [3].

**Abbreviations:** EVS, German income and consumption survey; LP, linear programming.

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However, there is a lack of consistent and culturally appropriate dietary recommendations that show which foods can replace animal-sourced foods in a healthy way when switching to a plant-based diet [11].

Against this background, the question arises as to how to ensure adequate intake of critical nutrients when plant-based alternatives are consumed instead of milk and dairy products. To answer this question, this study aims to analyze what dietary changes would be required to avoid possible nutrient deficiencies and which kind of food can be consumed instead.

To identify possible nutrient deficiencies and the dietary changes needed to achieve nutrient recommendations, this study uses the linear programming (LP) method. With LP, it is possible to create healthy food baskets that meet all nutrient requirements while deviating as little as possible from observed consumption habits. Based on the LP method, 3 different healthy food baskets are created and compared in this study: the first includes milk and dairy products, the second nonfortified soy-based alternatives, and the third fortified soy-based alternatives. Soy products are used as an example here: Although soy milk accounts for only 20% of the plant-based milk alternatives [12], they are the closest nutritional substitute for milk [13,14] and the only plant-based alternative for which nutrient data with a high level of detail are available.

## Methods

The LP is used in this study to transform a usually observed diet into a healthy one so that it deviates as little as possible from the observed diet while adhering to nutrient and food-related recommendations. This is done by including or excluding milk and dairy products and replacing them with soy-based alternatives. LP has already been used in international nutritional studies (e.g., [15–20]) and also for developing food-based dietary guidelines (e.g., [21–24]).

As a basis for the calculations, different data sets are required, which are described below.

## Data

### Consumption data

To determine typical consumption habits, data from the 2013 German Income and Consumption Survey (EVS) were used. The EVS is part of official statistics and is conducted every 5 y as a representative household survey. Part of the overall survey is the documentation of purchases of food, beverages, and tobacco products, in which households record all expenditures and quantities over a 1-mo period. The dataset includes 11,416 households of different sizes and compositions. However, in this study, only the data of single households with 1315 males and 2380 females were used, as in multi-person households' consumption cannot be clearly allocated to the individuals. Of the single households, only data from households that consume all foods, including meat and fish, were used so that data from 1230 males and 2220 females were available for the calculations. The data set contains 199 food and beverage groups, which were aggregated into 117 groups, including 109 foods and 8 beverages. Aggregation was performed when identical food groups with different processing stages were involved (e.g., fresh pies/cakes and frozen pies/cakes).

**Nutrient data.** To obtain information on nutrient contents of the 117 food groups of the EVS, the data were linked to the national German food composition database (Bundeslebensmittelschlüssel version 3.02). This dataset contains information on the nutritional values of 14,814 foods available on the German market. The allocation of nutrients to the food groups of the EVS was done at the disaggregated level of the 199 groups. If a clear allocation to a single EVS food group was not possible, the average nutrient values of 2 or more food groups were used. After the 199 food groups were combined into the 117 food groups, the nutrients were averaged. Only nutrients naturally present in foods were considered in the nutrient allocation to foods, as the focus of this study is to analyze how a healthy diet can be achieved through nonfortified foods. Only in the case of soy products we made an exception and considered once nonfortified and once fortified products in the soy and soy+ model (see Section Model types).

## The LP model

The LP model includes an objective function, decision variables, and constraints. The structure of these models to answer the research question is described below.

### Objective function

The LP objective function includes decision variables whose values are the outcomes of the models. In this study, the outcomes are optimal food quantities that result from minimizing the deviation from an observed diet (objective function) while adhering to constraints such as nutrient recommendations. The linear objective function  $Y$  has the form  $Y = a_0 + a_1 \cdot X_1 + a_2 \cdot X_2 + \dots + a_n \cdot X_n$ , where  $X_1, \dots, X_n$ , are the decision variables and  $a_0, \dots, a_n$  are constants.

This study aims to design the objective function in such a way that it minimizes the deviation between an observed diet and the healthy diet calculated with the LP. As a starting point for the optimization, the observed mean consumption  $C_i$  (with  $i = 1$  to  $n$ , where  $n$  is the number of food groups) was first calculated based on the EVS.

The total deviation is defined as the difference between the quantities of each food  $X_i$  calculated by the LP (with  $i = 1 \dots n$ , where  $n$  is the number of food groups) and the observed mean diet consumption  $C_i$ , divided by  $C_i$ . Dividing by the amount,  $C_i$  aims to standardize the differences between food groups. The approach follows Darmon et al., 2002 [16] and is based on the principle of goal programming approach [25]. The function of the “Total Deviation from the Observed Mean Diet” is thus as follows:

$$TDMD = \frac{ABS(C_1 - X_1)}{C_1} + \frac{ABS(C_2 - X_2)}{C_2} + \dots + \frac{ABS(C_n - X_n)}{C_n}$$

By introducing further decision variables and constraints, this nonlinear objective function can be transformed into a linear objective function of  $X_n$  (described in detail in [16]). Using this transformation, the function can be solved as a linear optimization problem using OpenSolver in Excel.

### Constraints

The restrictions used in this study are divided into 2 parts. On the one hand, health-related constraints for nutrient and food recommendations were considered in order to model a healthy

diet. On the contrary, consumption-related constraints were included to ensure that food and beverage quantities were within consumable ranges.

**Health-related-constraints.** The food baskets in this study were calculated for adult males and females with moderate activity levels. To consider nutrient-related constraints, the European Food Safety Authority reference values for adequate nutrient intakes were chosen [26] based on a physical activity level of 1.4. This corresponds to a sedentary lifestyle with little or no strenuous leisure activities. To ensure age-appropriate nutrient intakes for adults, reference values for 25–49-y-olds were taken. Recommendations based on body weight or energy intake were converted using the following assumptions: Body weight: 82 kg (male), 66 kg (female) [27]; energy content of energy-providing nutrients according to Regulation (EU) No 1169/2011 of the European Parliament and of the Council. Only vitamin D was not included at the full concentration of 15 µg/d. Because of the German consumption habits, which are the basis of this study, it is considered to be difficult to reach the vitamin D recommendation only through food intake. This is the reason why the German Society for Nutrition recommends taking supplements in case of insufficient sun exposure [28]. Because of the problem of reaching vitamin D recommendations through food intake, it is common in many studies that use the LP method to lower the vitamin D limits [29]. In this study, a lower limit of 5 µg/d was used. Besides lower limits, the European Food Safety Authority also sets upper limits for some nutrients that should be consumed in limited amounts (vitamins A, B<sub>6</sub>, D, E, copper, iodine, zinc, and fluoride) [30]. These have also been considered.

In addition to the reference values for nutrient intake, there are some food-related recommendations that are important for a healthy diet. These relate to fruit, vegetables, water, salt, sugar, and caffeine. The food-related recommendations used in this study, their sources, and more detailed explanations are given in Table 1 [31–36].

**Consumption-related-constraints.** To ensure that the optimized food and drink quantities were within the range of consumption, the total quantity of food and drink was limited to the 90th percentile of observed consumption based on EVS data. In addition, lower and upper limits were set for 25 major food groups. The 10th percentile was used as the lower limit. Since several models were not solvable using the 90th percentile as the upper limit, the 95th percentile was taken instead. This is because the diets observed in the population tend to be unhealthy (e.g., too fatty, too salty) and, therefore, require a greater deviation from existing consumption patterns.

### Model types

In order to compare the diets with and without milk and dairy products, 3 different healthy diet models were developed: The first contains milk and dairy products (milk model), in the second, the milk and dairy products were replaced by their soy-based alternatives (soy model) and in the third by their soy-based alternatives fortified with calcium, vitamins D, B<sub>2</sub>, and B<sub>12</sub> (soy+ model). The fortified nutrients are those that are currently added to commercially available soy products. In

Germany, only 25% of available soy-based drinks (milk) contain the added nutrients calcium, vitamins D, B<sub>2</sub>, and B<sub>12</sub> [37]. Fortification of plant-based dairy alternatives is, therefore, not a widespread standard in Germany.

Since possible nutrient deficiencies and the dietary changes required to reach nutrient recommendations can vary greatly depending on the type of diet people follow, the 3 models were applied to 3 different diet types: omnivorous (all foods are included), pescatarian (meat is excluded) and vegetarian (meat and fish are excluded). The motives for consuming plant-based milk alternatives are very diverse and include, for example, animal welfare, sustainability, switching to a vegetarian/vegan diet, but also reduced tolerance of cow milk [38]. The omnivore models primarily target groups of people who avoid dairy products for health reasons, such as lactose intolerance or allergies but do not focus on reducing animal-sourced foods. In contrast, pescatarian and vegetarian diets are often followed by groups of people who wish to avoid milk and dairy products and other animal-sourced foods. For the pescatarian diet, the option of including plant-based meat alternatives was introduced in the LP models; for the vegetarian diet, the possibility of introducing plant-based meat and fish alternatives was allowed. An overview of the models is shown in Table 2.

In all LP models, the average food quantities determined from the EVS consumption data for a diet of males and females were used as a starting point and then transformed into a healthy diet. The results of the model calculations show how males and females with average food intakes would have to change their diets if they wanted to follow a healthy omnivorous, pescatarian or vegetarian diet with dairy products (milk model), nonfortified soy-based alternatives (soy model) or fortified soy-based alternatives (soy+ model).

## Results

In the following, the compositions of the healthy food baskets based on 3 different LP models (milk, soy, and soy+) for 3 different diet types (omnivorous, pescatarian, and vegetarian) are presented. Each of the food baskets meets all food- and nutrient-related recommendations for a healthy diet and shows how the intake of milk and dairy products (milk model), soy-based alternatives (soy model), and fortified soy-based alternatives (soy+ model) affects the composition of the food baskets.

The description of the results is subdivided into 3 sections. In the first section, the quantitative differences of food groups between the 3 healthy food baskets of the milk-, soy-, and soy+-model are described (Section Quantitative food group differences between milk-, soy-, and soy+-model). Since the differences between the models (milk, soy, and soy+) can be explained in terms of nutrients to which milk and dairy products make a relevant contribution (namely calcium, vitamin B<sub>2</sub>, zinc, and vitamin B<sub>12</sub>), the coverage of these nutrients in the food baskets is presented for the 3 diet types in a second section (Section Nutrient coverages in the milk-, soy- and soy+-models). In the third section, the percentage deviations of the optimized healthy diets to the usual dietary patterns of the population are presented (Section Deviations from observed dietary habits).

**TABLE 1**  
Food-related recommendations considered in the linear programming model

	Quantities/d	
	Males	Woman
Vegetables <sup>1</sup> (g)	≥294.7	≥236.7
Fruits <sup>1</sup> (g)	≥196.4	≥157.8
Salt <sup>2</sup> (g)	≤6	≤6
Sugar <sup>3</sup> (g)	≤56.1	≤45.1
Beverages <sup>4</sup> (mL)	≥1410	≥1410
Coffee/tea (caffeine) <sup>5</sup> (mL)	≤800	≤643.9

<sup>1</sup> Source: [31]. Recommendation that fruits and vegetables should provide ≥7% of energy intake [31]. Conversion in g/d is based on the following assumptions: 2 portions of fruit and 3 portions of vegetables [32]; average calorie content of fruit/vegetables: 50 kcal/20 kcal [31].

<sup>2</sup> Source: [33].

<sup>3</sup> Source: [34].

<sup>4</sup> Source: [35].

<sup>5</sup> Source: [36]. Limitation of caffeine (400 mg/d) by limiting coffee and tea. Conversion under the following assumptions: Caffeine content per cup of coffee (200 mL) of 100 mg [36]. The 4 cups are thus within the safe intake level. Conversion for females based on body weight.

**TABLE 2**  
Models considered for 3 types of diets

	Milk model	Soy model	Soy+ model
	Milk and dairy products	Soy-based alternatives instead of milk and dairy products	Fortified soy-based alternatives <sup>1</sup> instead of milk and dairy products
Omnivorous	All foods are included		
Pescatarian	Meat is excluded, and meat substitutes are included <sup>2</sup>		
Vegetarian	Meat and fish are excluded, and meat and fish substitutes are included <sup>2</sup>		

<sup>1</sup> Fortification/100 mL: calcium: 120 mg; vitamin B<sub>2</sub>: 0.21 mg; vitamin B<sub>12</sub>: 0.38 µg; vitamin D: 0.75 µg,

<sup>2</sup> Tofu, vegetarian meat substitutes, etc.

The calculation of the models shown in Table 2 revealed that no solution could be found for the vegetarian soy model in which all nutrient requirements are met within the specific intake limits (95th percentile). This was because the vitamin B<sub>12</sub> requirement could not be met. For this reason, the vegetarian soy model is not included in the following descriptions of the results.

**Quantitative food group differences between milk-, soy-, and soy+-model**

Supplementary Annex 1 shows quantitative food group differences in grams per day for 3 models (milk, soy, and soy+) and 3 diet types (omnivorous, pescatarian, and vegetarian). It is evident that in all milk models, milk and dairy products are present in larger quantities (226–526 g/d). The smallest quantities can be found in the omnivorous diets (274 and 226 g/d), whereas milk and dairy products become increasingly important in the pescatarian (310 and 230 g/d) and especially in the vegetarian diets (409 and 473 g/d).

Table 3 shows the percentage quantity changes for the soy and soy+ models compared to the milk model. It is noticeable that, compared to the milk model, larger amounts of fruits (+50 to +154%) and vegetables (+16 to +43%) have to be consumed in the soy model in order to meet the nutrient recommendations. In addition, the composition of the vegetable group changes significantly in the soy model, as it consists almost exclusively of green leafy varieties (e.g., spinach and salads), which are considered to be particularly rich in calcium. In Supplementary Annex 1, it is shown that the proportions of green leafy varieties within the vegetable group range from 82% to 91% in the soy model. A similar effect can be observed within the fruit group. In the soy model, the amounts of oranges, which is a calcium-rich fruit, increase strongly within the fruit group and take up shares between 48% and 74%. It can also be seen that the amount of soy-based alternatives in the soy model is higher than that of milk and dairy products in the milk model (+69% to +119%). Even if the quantities of beverages remain unchanged, the composition of the beverages changes. Supplementary Annex

**TABLE 3**  
Percentage changes in quantities compared to the milk model for 3 diet types – Results of Linear Optimization Models

Food groups	Omnivorous diet (%)				Pescatarian diet (%)				Vegetarian diet (%)	
	Males		Females		Males		Females		Males	Females
	Soy	Soy+	Soy	Soy+	Soy	Soy+	Soy	Soy+	Soy+	Soy+
Carbohydrate-rich foods	–45.5	–1.0	–48.7	–30.4	–45.3	5.1	–52.1	11.7	–33.6	–23.4
Fruits	140.1	0.0	153.7	0.0	54.5	0.0	73.9	0.0	3.3	–18.6
Vegetables	42.5	0.0	26.7	–39.3	17.3	5.5	16.2	9.4	–13.1	7.2
Soy-based alternatives <sup>1</sup>	68.8	101.7	97.9	128.2	83.1	34.6	118.7	23.7	45.3	40.5
Meat or plant-based alternatives <sup>2</sup>	–1.2	99.1	–0.2	62.4	139.8	139.8	252.8	66.1	433.7	476.6
Fish or plant-based alternatives <sup>3</sup>	–52.8	–77.1	21.8	–40.2	–25.5	–63.0	11.7	–38.6	0.0	73.0
Eggs	0.0	–68.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Snacks/sweets	17.3	–3.5	8.4	–2.6	22.7	28.9	7.0	–5.0	18.5	–7.4
Fats/oils	–23.2	59.2	–17.9	33.4	34.3	–53.6	–75.0	–75.0	–70.4	–83.5
Others <sup>4</sup>	15.9	–0.7	–1.0	4.0	–30.7	–1.2	–4.0	0.0	–61.9	–71.7
Beverages	0.0	0.0	0.0	–42.5	0.0	0.0	0.0	–25.1	0.0	–38.8

<sup>1</sup> Soy-based alternatives for milk and dairy products without and with added nutrients, respectively.

<sup>2</sup> In the omnivorous diet: meat and sausages; in the pescatarian and vegetarian diet: plant-based alternatives.

<sup>3</sup> In the omnivorous and pescatarian diet: fish. In the vegetarian diet: plant-based alternatives.

<sup>4</sup> Others include unclassifiable foods such as salt, vinegar, spices, baking agents, etc.

TABLE 4

Contribution of food groups to the achievements of the calcium and vitamin B<sub>2</sub> recommendations – Results of Linear Optimization Models

	Omnivorous						Pescatarian						Vegetarian			
	Milk		Soy		Soy+		Milk		Soy		Soy+		Milk		Soy+	
	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females
Calcium																
Carbohydrate-rich food	7.1	6.8	5.4	5.1	7.5	5.3	7.2	5.8	5.3	3.9	8.3	7.1	6.7	5.3	6.2	5.3
Fruits	3.1	3.7	21.0	19.0	3.0	3.7	3.1	3.7	11.7	10.3	3.1	3.7	2.5	3.1	3.1	3.5
- of which oranges	0.7	0.9	15.2	16.5	0.7	0.9	0.7	0.9	6.7	7.5	0.7	0.9	0.7	0.9	0.7	0.9
Vegetables	12.2	20.6	29.3	34.4	11.8	8.3	15.3	21.0	29.3	33.2	15.8	24.0	13.8	19.8	15.8	30.1
- of which green leafy vegetables	1.5	16.3	27.7	32.4	1.5	2.3	1.5	12.1	27.7	30.3	1.5	15.1	1.5	14.4	1.5	25.7
Milk or soy-based alternatives <sup>1</sup>	40.5	37.8	7.4	8.5	68.0	63.5	55.6	38.4	8.8	7.4	52.0	34.5	67.1	58.0	91.2	93.0
Meat or plant-based alternatives <sup>2</sup>	0.9	0.7	0.9	0.7	1.6	1.0	3.4	4.1	8.0	14.5	8.0	6.8	1.5	1.2	8.0	6.8
Fish or plant-based alternatives <sup>3</sup>	0.7	1.0	1.2	1.1	0.3	0.4	1.1	1.0	2.6	1.1	1.0	0.4	1.2	0.6	1.2	1.0
Eggs	3.6	3.8	3.6	3.8	1.1	3.8	3.6	3.8	3.6	3.8	3.6	3.8	3.6	3.8	3.6	3.8
Snacks/sweets	5.0	2.5	2.7	2.3	2.2	2.2	5.0	2.5	2.6	2.2	3.7	2.4	4.2	4.4	4.8	4.2
Fats/oils	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Others <sup>4</sup>	2.2	1.6	2.3	1.5	2.1	1.8	2.2	1.6	1.7	1.3	2.0	1.5	6.9	4.6	2.6	1.6
Beverages	24.6	21.5	26.2	23.5	24.4	9.9	26.1	21.5	26.4	22.4	26.4	15.8	25.0	19.9	26.4	11.5
- of which mineral water	17.9	16.6	21.1	20.7	17.9	5.7	20.9	16.6	22.0	18.7	22.0	11.6	18.8	15.1	22.0	7.9
Coverage of recommend [%]	100.0	100.0	100.0	100.0	122.1	100.0	122.6	103.4	100.0	100.1	123.9	100.1	132.6	120.7	163.0	160.8
Vitamin B <sub>2</sub>																
Carbohydrate-rich food	8.7	7.7	8.0	7.0	8.5	6.7	9.1	6.4	8.1	5.5	10.4	7.9	7.9	5.7	9.5	7.0
Fruits	5.1	4.8	14.9	14.2	3.9	4.8	5.1	4.8	9.8	8.9	5.1	4.8	3.5	4.3	5.1	4.5
- of which oranges	0.4	0.6	9.5	10.3	0.4	0.6	0.4	0.6	4.2	4.6	0.4	0.6	0.4	0.6	0.4	0.6
Vegetables	22.8	23.4	31.1	36.0	21.6	13.0	29.3	28.8	31.1	35.7	30.1	31.7	48.4	47.7	30.7	33.1
- of which green leafy vegetables	1.5	16.4	27.9	32.6	1.5	2.3	1.5	12.2	27.9	30.5	1.5	15.3	1.5	14.5	1.5	25.8
Milk or soy-based alternatives <sup>1</sup>	31.4	26.2	8.4	7.9	75.2	70.8	36.1	26.8	10.4	9.3	58.5	36.3	56.3	58.9	105.4	106.7
Meat or plant-based alternatives <sup>2</sup>	11.0	9.7	10.9	7.4	20.0	14.6	5.5	6.8	13.3	24.1	13.3	11.3	2.5	2.0	13.3	11.3
Fish or plant-based alternatives <sup>3</sup>	12.3	3.2	3.6	4.2	2.0	2.2	13.0	3.2	4.3	3.5	2.6	2.2	2.0	1.0	2.0	1.7
Eggs	17.1	18.1	17.1	18.1	5.4	18.1	17.1	18.1	17.1	18.1	17.1	18.1	17.1	18.1	17.1	18.1
Snacks/sweets	4.9	2.4	2.3	2.0	1.8	1.8	4.9	2.4	2.4	2.0	3.2	2.0	5.1	5.1	5.6	4.9
Fats/oils	0.0	0.1	0.0	0.0	0.2	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Others <sup>4</sup>	1.9	1.2	1.9	1.0	1.6	1.0	1.9	1.2	1.1	1.0	1.6	1.0	7.2	4.7	2.1	1.0
Beverages	4.3	3.4	4.1	2.3	4.2	2.9	4.2	3.4	3.7	3.1	3.7	3.3	4.3	3.4	3.7	3.0
Coverage of recommend [%]	119.6	100.1	102.3	100.0	144.4	135.9	126.1	101.9	101.4	111.0	145.4	118.7	154.3	150.7	194.6	191.5

<sup>1</sup> In the milk model: milk and dairy products. In the soy and soy+ model, soy-based alternatives for milk and dairy products without and with added nutrients, respectively.<sup>2</sup> In the omnivorous diet: meat and sausages. In the pescatarian and vegetarian diet: plant-based alternatives.<sup>3</sup> In the omnivorous and pescatarian diet: fish. In the vegetarian diet: plant-based alternatives.<sup>4</sup> Others include unclassifiable foods such as salt, vinegar, spices, baking agents, etc.



TABLE 5

Contribution of food groups to the achievements of the Zinc and vitamin B<sub>12</sub> recommendations – Results of Linear Optimization Models

	Omnivorous						Pescatarian						Vegetarian			
	Milk		Soy		Soy+		Milk		Soy		Soy+		Milk		Soy+	
	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females
Zinc																
Carbohydrate-rich food	25.2	27.6	19.2	20.6	24.0	23.1	26.5	24.1	19.7	15.7	30.2	29.7	24.0	23.8	33.8	28.4
Fruits	3.0	3.8	15.8	6.0	2.6	3.8	3.0	3.8	11.9	4.8	3.0	3.8	1.2	1.7	3.0	3.7
Vegetables	14.8	16.6	17.1	25.0	14.1	9.9	19.2	22.0	17.1	24.9	19.8	24.0	19.3	20.4	20.2	23.8
Milk or soy-based alternatives <sup>1</sup>	11.2	13.9	0.7	1.6	1.1	1.0	16.9	14.1	0.6	0.5	0.4	1.0	17.8	20.2	0.3	0.6
Meat or plant-based alternatives <sup>2</sup>	17.4	18.4	17.2	18.2	37.1	35.8	4.1	6.5	9.9	22.8	9.9	10.7	1.9	1.9	9.9	10.7
Fish or plant-based alternatives <sup>3</sup>	1.9	2.3	2.3	2.5	1.6	1.8	4.9	2.3	13.7	2.5	6.2	1.9	1.5	0.9	1.5	1.6
Eggs	7.8	10.4	7.8	10.4	2.4	10.4	7.8	10.4	7.8	10.4	7.8	10.4	7.8	10.4	7.8	10.4
Snacks/sweets	3.9	2.7	5.6	5.4	3.5	4.2	3.9	2.7	6.4	5.1	9.6	5.4	4.5	5.6	9.7	8.1
Fats/oils	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Others <sup>4</sup>	3.1	2.6	3.2	2.4	2.8	2.4	2.6	2.3	1.9	2.4	2.2	2.0	10.6	8.7	3.0	2.0
Beverages	11.7	11.8	11.1	7.9	10.8	7.6	11.1	11.8	10.8	11.3	10.8	11.1	11.5	11.7	10.8	10.6
Coverage of recommend [%]	100.0	110.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.3	100.0	100.0	100.0	105.4	100.0	100.0
Vitamin B <sub>12</sub>																
Carbohydrate-rich food	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1
Fruits	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Vegetables	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Milk or soy-based alternatives <sup>1</sup>	29.2	25.9	0.0	0.0	45.9	42.8	38.6	26.4	0.0	0.0	35.0	21.0	51.1	54.7	61.4	61.7
Meat or plant-based alternatives <sup>2</sup>	60.8	56.7	60.7	41.2	71.7	94.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fish or plant-based alternatives <sup>3</sup>	92.9	65.5	70.3	71.2	49.8	52.0	99.7	65.0	89.2	68.9	61.0	52.2	0.0	0.0	0.0	0.0
Eggs	31.8	33.6	31.8	33.6	10.0	33.6	31.8	33.6	31.8	33.6	31.8	33.6	31.8	33.6	31.8	33.6
Snacks/sweets	3.9	2.0	2.9	2.2	1.8	1.7	3.9	2.0	3.4	2.1	5.1	2.2	3.3	3.3	6.0	4.2
Fats/oils	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Others <sup>4</sup>	4.8	2.6	2.5	1.3	2.4	1.3	2.9	1.7	0.2	1.3	0.6	0.3	13.6	8.3	0.7	0.3
Beverages	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coverage of recommend [%]	223.5	186.3	168.3	149.6	181.8	225.7	176.9	128.7	124.6	106.0	133.6	109.4	100.0	100.0	100.0	100.0

<sup>1</sup> In the milk model: milk and dairy products. In the soy and soy+ model, soy-based alternatives for milk and dairy products without and with added nutrients, respectively.<sup>2</sup> In the omnivorous diet: meat and sausages. In the pescatarian and vegetarian diet: plant-based alternatives.<sup>3</sup> In the omnivorous and pescatarian diet: fish. In the vegetarian diet: plant-based alternatives.<sup>4</sup> Others include unclassifiable foods such as salt, vinegar, spices, baking agents, etc.

1 shows that the already high share of mineral water in the milk model increases further in the soy model, reaching shares between 69% and 80%.

The comparison between the soy+ and milk models in Table 2 shows that there are higher amounts of fortified soy-based alternatives in the soy+ model than milk and dairy products in the milk model (+24% to +128%). In the omnivorous diet, the amount of meat and sausages are also higher in the soy+ model (+99% and 62%), whereas the pescatarian (+140% and 66%) and vegetarian diets (+434% and 476%) contain larger amounts of plant-based meat alternatives. On the contrary, the omnivorous and pescatarian soy+ diets contain less fish (–39 to –77%).

Nutrient coverages in the milk-, soy- and soy+ models

Tables 4 and 5 show which percentage of the daily nutrient recommendations is covered by the individual food groups and shows which foods make a particularly high contribution to covering the recommendation of calcium, vitamin B<sub>2</sub>, zinc, and vitamin B<sub>12</sub>. The daily nutrient recommendations must at least be met, but can also be covered to >100%. This is the case, for example, for calcium in the soy+ model for males, where the recommendation coverage is 122.1% (see Table 4). On the contrary, the nutrients that are just covered 100% are the limiting nutrients, showing that in 87.5% of the models, zinc is a limiting nutrient and, therefore, difficult to achieve. Calcium is a limiting nutrient in 37.5% and vitamin B<sub>12</sub> in 25.0% of the models (Supplementary Annex 2).

In the following, the results for calcium and vitamin B<sub>2</sub> are described together because these 2 nutrients are covered by similar foods. Zinc and vitamin B<sub>12</sub>, on the contrary, influence the model in very different ways and are therefore described separately.

Calcium and vitamin B<sub>2</sub>

Table 4 shows that milk and dairy products make an important contribution to the coverage of calcium and vitamin B<sub>2</sub> in the milk model. For example, between 38% and 67% of the calcium recommendation is covered by milk and dairy products. In contrast, the soy-based alternatives for milk and dairy products in the soy model contain barely any calcium and vitamin B<sub>2</sub>. Here, the requirement is balanced by a higher consumption of fruits and vegetables. In particular, green leafy vegetables contribute significantly to the daily calcium and vitamin B<sub>2</sub> intake, providing between 28–32% (calcium) and 28–33% (vitamin B<sub>2</sub>) of the recommended daily intake. Within fruit, oranges especially contribute between 7–17% (calcium) and 4–10% (vitamin B<sub>2</sub>) of the recommended intake.

In the soy+ model, the soy-based alternatives for milk and dairy products contain added calcium and vitamin B<sub>2</sub>. Therefore, a large part of the daily recommendations can be covered by consuming fortified soy products (calcium: 35–93% of the recommendation; vitamin B<sub>2</sub>: 36–107% of the recommendation). Accordingly, the fortified soy-based alternatives are a good substitute for milk and dairy products to cover these 2 nutrients.

Zinc

In the milk model, milk and dairy products also contribute to the zinc intake, but to a lesser extent than calcium and vitamin B<sub>2</sub> (16%–37% of the recommendation) (Table 5). In contrast, soy-

based alternatives in the soy and soy+ models contain significantly less zinc because soy alternatives are not fortified with zinc and, therefore, make little contribution to the daily zinc requirement (0.3%–1% of the recommendation). As shown in Table 5, it is therefore necessary to switch to other sources of zinc. In the soy model, the zinc requirement is increasingly covered by fruit and vegetables, and in the pescatarian diet, additionally by plant-based meat alternatives and partly by fish. In the soy+ model, zinc requirements in the omnivorous diet are now increasingly met through higher meat consumption (36%–37% of the recommendation). In the pescatarian and vegetarian diets, zinc requirements are met through a higher consumption of plant-based meat alternatives (10%–11% of the recommendation) and the consumption of carbohydrate-rich foods (28%–34% of the recommendation). It can thus be seen that the coverage of zinc requirements is possible via many different sources.

Vitamin B<sub>12</sub>

Vitamin B<sub>12</sub> is a nutrient found in animal-sourced foods. Therefore, there are differences between the omnivorous, pescatarian, and vegetarian diets, especially for this nutrient. In the omnivorous and pescatarian diets, all models (milk, soy, and soy+) contain more than the required amount of vitamin B<sub>12</sub> (Table 5). The main sources are fish and eggs, and in the omnivorous diet additionally, meat and sausages. In addition, dairy products (milk model) and fortified soy-based alternatives (soy+ model) also contribute to vitamin B<sub>12</sub> intakes. Vegetarian diets exclude meat and sausages as well as fish and thus relevant sources of vitamin B<sub>12</sub>. Although milk and dairy products in the milk model and fortified soy products in the soy+ model contain vitamin B<sub>12</sub>, nonfortified soy products in the soy model do not provide any vitamin B<sub>12</sub>. Thus, in the soy model, the only source of vitamin B<sub>12</sub> is eggs. However, since the amount of egg consumption in the models is limited by the upper 95th consumption percentile, which corresponds to 70 g eggs/d, the soy models for vegetarian diets could not be solved. 70 g eggs/d cover ~30% of the vitamin B<sub>12</sub> requirement. If the upper consumption percentile in the model and thus the amount of eggs was increased to 190 g/d (equivalent to ~3 eggs), the models became solvable because the vitamin B<sub>12</sub> requirements could be met. In this case, most of the requirements (>90%) can be covered by eggs. This shows that meeting the vitamin B<sub>12</sub> requirement on a milk-free vegetarian diet is a major challenge if only nonfortified soy-

TABLE 6  
Average percentage deviation per food from observed average consumption

Diet types	Average % deviation per food from observed average consumption <sup>1</sup>					
	Man			Woman		
	Milk	Soy	Soy+	Milk	Soy	Soy+
Omnivorous	38.0	75.5	25.1	27.0	53.9	16.0
Pescatarian	47.7	75.9	43.6	27.9	48.1	24.4
Vegetarian <sup>2</sup>	90.7	-	87.9	109.0	-	61.8

<sup>1</sup> To calculate the values, the sum of the percentage deviations to the average observed omnivorous diet was divided by the number of food groups (n = 117).

<sup>2</sup> The vegetarian soy model was not solvable within the constraints (nutrient and consumption limits) and is therefore not presented in the results.

based alternatives for milk and dairy products are consumed. However, if milk and dairy products or fortified soy-based alternatives are chosen, a large proportion of the vitamin B<sub>12</sub> requirement can be covered by these foods.

### Deviations from observed dietary habits

This section looks at the level of deviations of the optimized healthy diet from the average observed dietary habits of the population. The starting point of all diet types is the average omnivorous diet in Germany, separately for males and females, calculated based on the consumption data described in Section Data. The level of deviations presented in Table 6 results from the sum of the percentage deviations of all food groups divided by the number of food groups ( $n = 117$ ) and thus indicates the average percentage deviation per food group.

Table 6 shows that the lowest deviations from observed consumption are achieved in the omnivorous soy+ models. Thus, a switch from the average observed and rather unhealthy diet to a healthy diet with fortified soy products would require average adjustments per food group of 25% and 16% for males and females, respectively. For the omnivorous milk model, it is 38% and 27%, and for the omnivorous soy model, 76% and 54% for males and females, respectively. People who consume fortified soy-based alternatives (soy+ model) and want to eat healthily can thus stay the closest to the usual dietary patterns, even closer than those who consume milk and dairy products (milk model). Overall, it can be observed that the soy model requires the greatest adjustments within the dietary types or even, as in the case of the vegetarian diet, is not feasible (not solvable) at all. Comparing the different dietary patterns, it can be seen that the largest overall average deviations are found in the vegetarian models (e.g., 91% in the males' vegetarian soy model). This shows how challenging it is to switch from an average, unhealthy, omnivorous diet to a healthy vegetarian diet.

## Discussion

This study investigated the nutrient intakes provided by diets including and excluding milk and dairy products. When milk and dairy products were excluded from the diet, the possibility of replacing them with nonfortified (soy model) or fortified soy alternatives (soy+ model) was allowed. All investigations were made for 3 different diet types (omnivorous, pescatarian, and vegetarian). Overall, the results showed that it is possible for each of the diet types to cover milk-relevant nutrients without consuming milk and dairy products. However, this may involve significant changes in the usual dietary habits, especially if milk and dairy products are replaced by their nonfortified alternatives.

### Consuming nonfortified soy-based alternatives instead of milk and dairy products (soy model)

Milk and dairy products are particularly important for the calcium and vitamin B<sub>2</sub> supply in Germany. In the case of calcium, ~50% of the intake is consumed through these products [39]. Therefore, when avoiding milk and dairy products, calcium intake has to be covered by other foods rich in calcium. This study has shown that in the soy model, where milk and dairy

products were replaced by nonfortified alternatives, significant deviations from normal dietary habits were required to ensure adequate calcium intake. The deviations include significant increases in fruit and vegetables. Among the vegetables, especially the green leafy types (e.g., spinach, lettuce) have a higher calcium content, which is why they account for a share of >80% within the vegetable group. However, in Germany, green leafy vegetables (excluding kale) account for <8% of the total vegetable consumption on average, which corresponds to around 21 g/d [40]. This shows that the preference for green leafy vegetables in Germany is comparatively low. Also, in the fruit group, a concentration of calcium-rich types can be observed. In the soy model, for example, the calcium-rich oranges account for shares between 48% and 74% within the fruit group. Overall, it can be observed that a need not only to increase consumption of fruit and vegetables but also to switch to calcium-rich varieties within the groups, which is accompanied by a significant decrease in diversity. This shows that meeting calcium requirements in a diet where milk and dairy products are replaced by nonfortified alternatives can be a major challenge. This is particularly relevant given that a high percentage of soy products are not fortified. In Germany, only 25% of conventional soy drinks are fortified with calcium [37], compared to 50% of the plant-based drinks in Europe [37]. In the case of organic plant-based beverages, there is even no fortification across Europe, with a few exceptions [37]. The trend toward increasing substitution of milk and dairy products with plant-based alternatives that are not fortified demonstrates the need for increased consumer education about possible nutrient deficiencies.

Not only the changes in dietary habits but also the different bioavailability of calcium in foods could pose a problem for an adequate calcium supply if milk and dairy products are avoided in the diet. The bioavailability of calcium from milk is between 28% and 46% [41–45] and is thus considered good. Although the bioavailability of mineral water is comparable to that of milk [46,47], the bioavailability of green vegetables depends on the level of inhibitors they contain, such as oxalate or phytate [48]. Low-oxalate varieties, such as kale or broccoli, with availabilities between 41%–53% [42,44] and 48% [42], have higher calcium absorption than milk and are good sources of calcium, respectively. In contrast, oxalate-rich varieties such as spinach have a calcium bioavailability of only ~5% [45], i.e., the availability is significantly lower than that of milk. Phytate also reduces the bioavailability of calcium [49,50], but to a lesser extent than oxalate [48]. Therefore, when choosing green vegetables, it is important to select varieties that contain few inhibitors.

Besides calcium, the bioavailability of other nutrients also varies between plant- and animal-sourced foods [51]. This also includes zinc, the availability of which is reduced by phytate contained in plant-sourced foods [52]. To address the problem of bioavailability, these could be directly considered in the model in future studies, as far as this is possible, because of the complexity.

In addition to calcium, vitamin B<sub>12</sub> deficiencies could occur if milk and dairy products are replaced by nonfortified soy alternatives. This applies, in particular, to a vegetarian diet. As the results of this study showed, sufficient vitamin B<sub>12</sub> intake could only be guaranteed with this dietary form, with an egg consumption of ~3 eggs/d. Since the average egg consumption in



Germany is currently <1 egg/d (~40 g), [53] significant changes in the diet will be required here as well. In a vegan diet, all animal-sourced foods and, therefore, eggs as a vitamin B<sub>12</sub> supplier would be omitted, which is why the intake of vitamin B<sub>12</sub> supplements is recommended [54].

### Consuming fortified soy-based alternatives instead of milk and dairy products (soy+ model)

Although switching from milk and dairy products to non-fortified soy alternatives requires significant changes in usual dietary habits to reach nutrient recommendations, the switch to fortified alternatives is much easier. This was shown by the average percentage deviation to observed consumption calculated for the different models. The average percentage deviation indicates how much the diet needs to be changed to cover the nutrient requirements and showed the same or even lower values for the soy+ model than for the milk model. This means that switching from a usual diet to a healthy diet with fortified alternatives requires similar or even smaller dietary changes than switching to a healthy diet with milk and dairy products. This can be explained by the fact that fortified soy products outperform dairy products for some nutrients.

Although the fortification concentration of calcium, vitamin B<sub>2</sub>, and vitamin B<sub>12</sub> in soy-based products is at least equal to that of milk and dairy products, these products also contain more iron [55], and the fortification with vitamin D is even 8 times higher than in milk. The added nutrients contained in fortified soy alternatives can, therefore, cover a large part of the daily nutrient requirements. Zinc, on the contrary, which is not fortified in soy-based alternatives, can be met by switching to other foods such as meat, meat substitutes, and carbohydrate-rich foods (e.g., oatmeal). In summary, those who wish to avoid milk and dairy products can ensure adequate nutrient intake by consuming fortified soy-based alternatives.

However, even though fortified soy alternatives contain many valuable nutrients, the bioavailability of the added nutrients is not necessarily comparable to that of milk. In the case of calcium, for example, the most common forms used for fortification are calcium carbonate and tricalcium phosphate. Although the bioavailability of calcium in the calcium carbonate form is in fortified soy alternatives comparable to that of milk, the bioavailability of the tricalcium phosphate form is ~25% lower [41,56]. Studies on the bioavailability of other supplements added to soy drinks are not available and, therefore, cannot be considered in this context.

### Applicability to other plant-based milk alternatives

In this study, the comparison between milk and plant-based alternatives was made using soy-based alternatives. It can be expected that, even though the nutrient composition differs between the plant-based alternatives [57], similar challenges will arise when avoiding milk and dairy products. For example, plant-based drinks naturally contain significantly lower calcium concentrations than milk as long as they are not fortified with calcium [57,58]. Ensuring calcium intake when avoiding milk and dairy products is therefore also a challenge when switching to other nonfortified plant-based alternatives and also requires the consumption of other calcium-rich foods, such as green leafy vegetables. However, when comparing the plant-based alternatives, soy-based beverages are the most similar to milk in terms

of protein concentration [57]. This makes soy-based alternatives the closest nutritional substitute for milk [13,14]. Against this background, it can be assumed that switching to other plant-based alternatives requires even greater dietary adjustments than those presented in this study.

### Limitations

This study looked at how the diet would have to be changed to cover all the nutrients if milk and dairy products were completely removed from the diet. For this purpose, a certain selection of scenarios was assumed. Scenarios in which, for example, only drinking milk was given up, but other dairy products were still consumed, were not considered. Giving up only drinking milk and the resulting nutrient losses could simply be compensated by an increased consumption of other dairy products and cheese. However, the complete elimination of milk and dairy products is much more complex; this study only focused on these scenarios. Furthermore, the calculations carried out here are based on the consumption habits of adult single households and thus do not reflect the consumption habits of all household types. However, as single households account for 41% of all households in Germany, they represent a large proportion of the German population [59]. In addition, the possible use of supplements was not included in this study. This decision was made against the background that calcium is only supplemented by 11% [60] and is therefore not very widespread in Germany.

To perform the model calculations, some assumptions had to be made (e.g., physical activity level value of 1.4, standard market fortification levels). For this purpose, it was also assumed that all available foods of the respective dietary form (omnivorous, pescatarian, and vegetarian) could be included in the models. This also applies to plant-based meat alternatives, which still differ in sensory perception and acceptance of meat [61]. However, results from Germany show that flexitarians consume plant-based meat alternatives increasingly more frequently [62], and vegetarians and vegans are more open to eating these products than omnivores [63].

An additional limitation relates to the data. The EVS dataset used to calculate average consumption, which serves as a starting point for the LP, is purchasing data documenting both expenditures and purchased quantities of foods from 11,416 households representative of Germany. Although the data that are part of the official German statistics are considered to be meaningful in terms of food consumption, they have the disadvantage that out-of-home consumption, which accounts for 28% of household spending on food in Germany [64], is not included. However, since this part of food consumption is significantly more expensive than consumption at home, it can be assumed that the share in terms of quantities is significantly lower. Whereas the lack of out-of-home consumption leads to an underestimation of food quantities, food waste, which is also not documented in the data, leads to an overestimation of the quantities. An alternative to purchasing data would be consumption data, which also has drawbacks because of the problem of over- and underreporting for some food groups (e.g., vegetables and chocolate). However, the latest German food consumption data are from 2008 and are, therefore, even older than the 2013 data we used. It would have been desirable to perform the calculations with a more recent dataset, but at the time of the calculations, this was the most recent dataset available.

Sensitivity analyses were not conducted in this study because of its scope. Nevertheless, the conduct of sensitivity analyses to evaluate and verify the robustness of the findings would have been worthwhile. Such analyses could be explored in subsequent studies. For instance, it could be investigated how different levels of fortification of soy products or the consumption of additional food supplements, such as vitamin B<sub>12</sub>, may impact dietary composition.

In conclusion, this study confirms that soy-based alternatives are not a 1-to-1 substitute for milk and dairy products because of their different nutrient composition. Especially meeting calcium intakes and, in the case of vegetarians, vitamin B<sub>12</sub> intakes can be challenging in a diet where nonfortified substitutes are used instead of milk and dairy products. In this case, significant changes in dietary habits may be required to avoid nutrient deficiencies. This includes significantly higher consumption of fruit and vegetables, whereby within the groups, calcium-rich varieties should be chosen in particular (e.g., green leafy vegetables and oranges). However, given the low popularity of green leafy vegetables in Germany, this is a challenge and requires a willingness to change one's diet. In contrast, consuming fortified soy-based alternatives can compensate well for the absence of milk and dairy products in the diet. The added nutrients calcium, vitamin B<sub>2</sub>, and B<sub>12</sub> can play an important role in ensuring a healthy diet. However, in Germany, for example, only 25% of soy drinks are fortified with calcium [37], showing that there is a need for action.

In light of the findings of this study, and given the current trend to increasingly replace milk and dairy products with plant-based alternatives, public health interventions should raise awareness of possible nutrient deficiencies and risk of developing related diseases. In addition, they should give advice on how to avoid possible nutrient deficiencies so that individuals who wish to follow a milk and dairy-free diet can make informed choices. Furthermore, it could be helpful if the industry is encouraged to increase the fortification of plant-based milk alternatives.

## Author contributions

The authors' responsibilities were as follows– MT and ST: designed the research; MT: analyzed the data; MT and ST: participated in writing the manuscript. Both authors read and approved the final manuscript.

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The authors reported no funding received for this study.

## Data availability

All data sets used in this study are part of the official statistics and have been used under license, so we are not allowed to distribute them. However, it is possible to request the data from the respective institutions.

## Conflict of interest

The authors report no conflicts of interest.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.tjn.2023.11.003>.

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