

What do people really eat? Consolidating datasets to account for intake from composite foods, misreporting and outdated survey data.

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Research Article

Keywords: Diets, Food intake survey, Sustainability, Bayesian statistics, Modeling, Optimization, Agriculture

Posted Date: October 2nd, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-8206894/v2>

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Additional Declarations: The authors declare no competing interests.

What do people really eat? Consolidating datasets to account for intake from composite foods, misreporting and outdated survey data.

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Abstract

For diets to become environmentally sustainable and healthier, a clear understanding of status quo diets is essential, but often difficult given the complexity of composite foods, misreporting by intake survey participants and infrequently conducted surveys. We create a consistent quantity flow along the food value chain in Germany by consolidating datasets on market-level quantities, survey-based food intake, recipes, processing, food waste, energy intake, and meat partitioning. The method developed links per capita food intake and market demand for agricultural commodities, allowing for a more integrated assessment of the health, environmental, and economic impacts of diets. It allows quantification of intake of ingredients in composite foods and reduces biases in the original datasets. Using recent market-level quantities, we update the quantity flow from the year of the last German intake survey, 2006, to 2025, thus generating up-to-date food intake quantities. We thus contribute an improved reference of status quo diets for developing dietary recommendations and enhancing the simulation of demand changes in sectoral models widely used in policy advice.

Keywords

Diets, Food intake survey, Sustainability, Bayesian statistics, Modelling, Optimisation, Agriculture.

1 Introduction

The potential of dietary changes to improve environmental sustainability and human health is broadly recognised (Adolph & Tilg, 2024; Chepeliev & Aguiar, 2019; Gerten et al., 2020; Grummon et al., 2023; Himics et al., 2022; Rockström et al., 2025; Stylianou et al., 2021; Willett et al., 2019). Inadequate diets are core contributors to the triple burden of malnutrition, non-communicable diseases and premature mortality (Adolph & Tilg, 2024; GBD 2017 Diet Collaborators, 2019). Western diets, high in calories and animal products, drive type II diabetes, cardiovascular diseases and certain cancers (Adolph & Tilg, 2024; Springmann et al., 2016). These diets are also resource-intensive, impacting biodiversity and climate (Campbell et al., 2017; Crippa et al., 2021; Kehoe et al., 2017; OECD, 2025; Poore & Nemecek, 2018). Because agricultural systems are globally integrated, assessing the environmental consequences of diets requires tools that capture these linkages, such as sectoral models like CAPRI, used, for example, to simulate

the Planetary Health Diet (PHD) (CAPRI Consortium, 2022a; Gibson et al., 2026; Rieger et al., 2023; Rockström et al., 2025; Sundiang et al., 2025). While environmental assessment builds on quantities of agricultural commodities produced, assessing health impacts and consumer behaviour requires per-capita intake of foods. This mismatch hinders an integrated assessment of diets, for which three problems need to be overcome: First, composite foods combining several commodities as ingredients make intake of these commodities hard to quantify. Second, survey-based intake quantities are often biased by misreporting. Third, representative intake surveys are expensive and infrequent, leaving data outdated. Below, we define each problem, describe our solution for the example of Germany, and situate our contribution relative to existing work.

First, sectoral models typically report market-balance products, not foods (e.g., commodities like wheat and sugar, not cake and lasagna). Some approaches derive the shares of grains or meat consumed as refined grains or processed meats (Springmann, 2026). Some models, e.g., CAPRI, represent first processing steps for dairy and oils (CAPRI Consortium, 2022b); others do not include processed foods (Tallard et al., 2022). However, as consumers choose between foods, referring to commodities restricts diet analysis to stylised scenarios. For instance, reduced sugar intake is typically simulated by lowering sugar demand alone, holding all other commodities constant (Tallard et al., 2022). In reality, consumers would cut sugary foods, e.g., cake or ice cream, reducing also wheat, egg and cream intake. We address this first problem by linking market-balance products to foods reported in a German intake survey via recipes, quantifying the intake of, e.g., plant oils or eggs, including ingredients in composite foods.

Second, sectoral models often capture supply quantities available at market level, which differ from actual intake: they also include waste in retail and households, inedible parts and processing losses, and exceed plausible intake by a substantial margin (Giner & Brooks, 2019). Deriving intake from them, therefore, requires additional data or assumptions, e.g., on waste shares and energy intake (Springmann, 2026; Tallard et al., 2022). In intake surveys, responses are frequently biased, e.g., through underreporting of socially stigmatised foods (Bailey, 2021; Burrows et al., 2019; Hebert et al., 1995; Heuer et al., 2015; Krems et al., 2012; Micha et al., 2018; Springmann, 2026; Subar et al., 2003; Toozee et al., 2004). Consequently, survey quantities can misrepresent the dietary status quo, i.e., the quantities of foods, nutrients and energy a population eats, and, hence, the changes needed to meet recommendations.

We address this second problem by building a consistent quantity flow that links market-balance quantities to intake quantities, accounting for data on waste, meat partitioning, processing and recipes. To enforce data consistency, we apply Bayesian estimation: for each data point in each dataset, we determine a consolidated value that satisfies the quantity flow's links while deviating as little as possible from its prior value. Through the deviations, we quantify bias and misreporting and produce a consistent dataset that accounts for it.

Linking food consumption datasets is not new, but previous work covers only parts of the value chain (Grünberger, 2014; Iost et al., 2020), treats unaccounted quantities as residuals without verifying internal consistency (Caldeira et al., 2019; De Laurentiis et al., 2021), or links datasets without enforcing the links between them (Arnoult et al., 2010). Bayesian estimation against priors is likewise established, e.g., for regional disaggregation of agricultural production (Gocht & Röder, 2014), but has not been applied to a complete quantity flow from market balance to food intake.

Third, the consolidated data's relevance is limited by the intake survey's vintage. High-quality, representative intake surveys are costly and therefore infrequent. The most recent German survey, the

National Nutrition Survey II (NVS II), dates from 2006 (Brombach et al., 2006). Using 20-year-old data as a status quo reference misses changes at market level. Outdated or incomplete data constitute a common challenge for research, and approaches to fill such gaps are likely to gain importance amid a broader trend toward reduced public data collection (Casselman, 2025; O'Donnell, 2020; Sachverständigenrat für Wirtschaft, 2026; Stilling, 2025). We address this by using the consolidated quantity flow, together with updated market-balance quantities, to generate synthetic food intake estimates for 2025.

In sum, we make three contributions. First, we quantify per-capita intake per agricultural commodity, including intake as ingredients in composite foods, which matters especially for plant oils, eggs and butter. Second, we build a consistent quantity flow linking market and intake quantities and use it to quantify misreporting in the NVS II for 945 foods: the average adult underreported energy intake by around 620 kcal per day, with underreporting concentrated in sugar and dairy products, and overreporting in fruit and juices. Third, we generate synthetic 2025 food intake quantities that reflect recent changes in food supply. Together, these results provide a more accurate reference for dietary recommendations than either market-balance quantities or unadjusted survey data.

Beyond this standalone application for Germany, the quantity flow is designed as a module compatible with agricultural sector models, translating market-level scenario outputs into implied changes in food intake, making raw-product recommendations like the PHD more concrete and enabling more realistic demand-side inputs to sectoral simulations. This linkage is the subject of ongoing work.

The paper is structured as follows: Section 2 describes terminology, method and data; Section 3 presents results with a sub-section per problem addressed; Section 4 discusses implications, limitations and conclusions.

2 Method

We explain the terminology, specify the logical framework of the quantity flow, describe the initialisation datasets, present the consolidation producing a consistent dataset and explain how we generate updated intake estimates for 2025.

2.1 Terminology and classification

Along the agrifood value chain, commodities are processed and combined with each other. To capture this, we differentiate three stages: market-balance products, ingredients, and foods. This terminology describes roles within the quantity flow rather than mutually exclusive physical product classes.

Market-balance products are commodities covered in market data, either unprocessed (e.g., oranges) or not processed beyond a first step (e.g., sunflower seed oil, butter, chicken muscle, wheat flour). We differentiate between 426 market-balance products, which we aggregate into 47 market-balance aggregates (e.g., wheat, poultry, citrus fruit) to match the categorisation of the Common Agricultural Policy Regionalised Impact Modelling System (CAPRI), a model used frequently to simulate dietary changes (CAPRI Consortium, 2022a; Gibson et al., 2026; Rieger et al., 2023; Rockström et al., 2025; Sundiang et al., 2025) (Table 1). Water, other meat and other products are depicted in the quantity flow but are not initialised with statistical data, leaving 44 aggregates with priors. For the results description, we further aggregate the market-balance products.

116 **Table 1: 47 market-balance aggregates am and super-aggregates. See Supplementary Table 1 for the 426 market-**
 117 **balance products m belonging to the 47 aggregates.**

Super-aggregates	47 market-balance aggregates am
Cereals	Wheat, Rye, Barley, Oats, Maize, Rice, Other cereals
Starchy roots	Potatoes
Legumes	Pulses, Soybean
Sunflower seed	Sunflower seed
Plant oils	Rapeseed oil, Sunflower seed oil, Soya oil, Olive oil, Palm oil
Fruits	Apples, Table grapes, Citrus fruit, Other fruit, Table olives, Table wine
Vegetables	Tomatoes, Other vegetables
Coffee, cocoa, tea	Coffee, Cocoa, Tea
Red meat	Beef, Sheep and goat meat, Pork
Poultry	Poultry
Eggs	Eggs
Fish	Freshwater fish, Saltwater fish, Other aquatic products
Dairy	Fresh milk products, Cheese, Cream, Concentrated milk, Skimmed milk powder, Whole milk powder, Whey powder
Butter	Butter
Sugar	Sugar
	Other meat
	Water
	Other products

118

119 Ingredients are commodities that have undergone further processing not explicitly differentiated in market
 120 data (e.g., white wheat flour), as well as market-balance products that do not undergo further processing
 121 (e.g., apples). We differentiate between 682 ingredients (Supplementary Table 2).

122 Foods are items that consumers reported in the intake survey, mostly ready-to-eat, but in some cases the
 123 ingredients used for preparing dishes. The term thus captures foods consisting of several ingredients after
 124 various processing steps, like apple strudel, as well as unprocessed raw products like apples (also a market-
 125 balance product and an ingredient) or processed commodities like white wheat flour (also an ingredient).
 126 We use “composite foods” to describe foods consisting of more than one ingredient, e.g., fruit salad or
 127 apple strudel. We differentiate between 945 foods, grouped into 19 aggregates following the structure of
 128 the FoodEx2 exposure hierarchy (EFSA, 2015) (Table 2). FoodEx2 features an aggregate “composite dishes”,
 129 which includes some but not all composite foods (e.g., apple strudel is categorised as a grain product).

130 **Table 2: 19 food aggregates af , following the FoodEx2 exposure hierarchy (level 1). Examples of the 945 foods f .**
 131 **See Supplementary Table 3 for full names and abbreviations.**

19 food aggregates af	Examples of the 945 foods f belonging to the respective aggregate
Fruit products	e.g., apples, dried figs, jam
Vegetable products	e.g., cherry tomatoes, mashed vegetable puree, pickled vegetables
Juice products	e.g., orange juice, multivitamin juice
Legumes, nuts, seeds	e.g., chestnuts, peanut butter, canned chickpeas, lentils (dry), spices
Sugar products	e.g., sorbet, white chocolate, white sugar
Grain products	e.g., multigrain bread, mixed breakfast cereals, cheesecake
Starchy root products	e.g., mashed potato powder, boiled potato, sweet potato
Fats & oils	e.g., rapeseed oil, butter, margarine
Dairy products	e.g., skimmed milk, gouda, ice cream

Egg products	e.g., boiled eggs, fried eggs, egg powder
Fish products	e.g., salmon, shrimps and prawns, canned fish
Meat products	e.g., fresh pig meat, liver cheese, Frankfurter sausage
Alcoholic beverages	e.g., beer, gin, sparkling wine
Coffee, cocoa, tea	e.g., cappuccino, rooibos infusion, cocoa powder
Beverages	e.g., tap water, cola beverage, orange soft drink
Products for non-standard diets	e.g., tofu, soya drink, imitation cream
Composite dishes	e.g., lasagna, potato soup, mixed green salad
Sauces	e.g., mayonnaise sauce, ketchup, bechamel sauce
Isolated ingredients	e.g., corn starch, baking yeast, gelatine

2.2 Logical framework of the quantity flow

The logical framework captures the quantity flow between the stages of the value chain. All quantities available for human consumption at the market level (short: market-balance quantities) are eaten or leave the food value chain as waste or for non-food purposes, as visualised in Figure 1. The grey boxes in Figure 1 indicate which quantities or shares are initialised using external datasets (see section 2.3). Below, we explain the links between the units and quantities constituting the quantity flow, starting from the left-hand side of Figure 1.

From market-balance products to ingredients (blue to orange):

- The market-balance quantity q_{am} of a market-balance aggregate am (blue, left-hand side, e.g., wheat, beef) is the sum of the market-balance quantities of market-balance products m (green, e.g., soft and durum wheat, beef and veal) belonging to it.
- For meat, the market-balance quantities of the market-balance aggregates are given in carcass weight. Therefore, we account for the proportions $c_{m,d,am}$ of the different meat parts, e.g., muscle meat in veal. Not all parts of the animal are eaten, and we account for the meat parts leaving the food value chain.
- The market-balance quantity of a market-balance product m is either processed further, remains unprocessed or leaves the value chain as non-avoidable waste nw_m , e.g., inedible parts like vegetable peel or pits.
- The quantity of a market-balance product m used in a process p determines the quantity of the resulting ingredient i (orange) through the processing yield $y_{m,p,i}$. The yield can reflect quantity loss due to water evaporation, weight gain from water absorption, or coupled processes. For example, fine milling 1 kg of the market-balance product common wheat grain yields 699 g of the ingredient “white wheat flour”, 180 g of “wheat bran” and 20 g of “wheat germ”. Yields account for inefficiencies and losses during processing.
- As for meat partitioning, ingredients from coupled processes (e.g., fine milling) are not eaten in the proportions they are produced (e.g., wheat bran relative to white wheat flour). We capture this by accounting for unused quantities of coupled products leaving the food value chain.

From ingredients to foods (orange to purple):

- Quantities of ingredients are combined in fixed proportions given by recipes $r_{f,i}$, determining the quantities of foods f (purple in Figure 1). Recipes account for further processing of ingredients or foods and associated weight loss through water evaporation (e.g., baking bread) or weight gain through water absorption (e.g., cooking pasta). Therefore, the sum of the ingredient quantities can be higher or lower than that of the resulting food.

From foods to food intake (purple to red):

- The resulting quantities of foods are either eaten (j_f) or leave the value chain as waste aw_f . As the food quantities describe only edible parts, we denominate this waste as avoidable. This includes waste in retail, households and food away from home.
- The intake quantity j_{af} of a food aggregate af (red, right-hand side of Figure 1, e.g., grain products) is the sum of the intake quantities j_f of foods f (e.g., white wheat bread, apple strudel, wholegrain pasta) belonging to this aggregate.

Supplementary Information 1 gives an example and Supplementary Table 4 a complete list of the links within the quantity flow. Table 3 overviews the index sets.

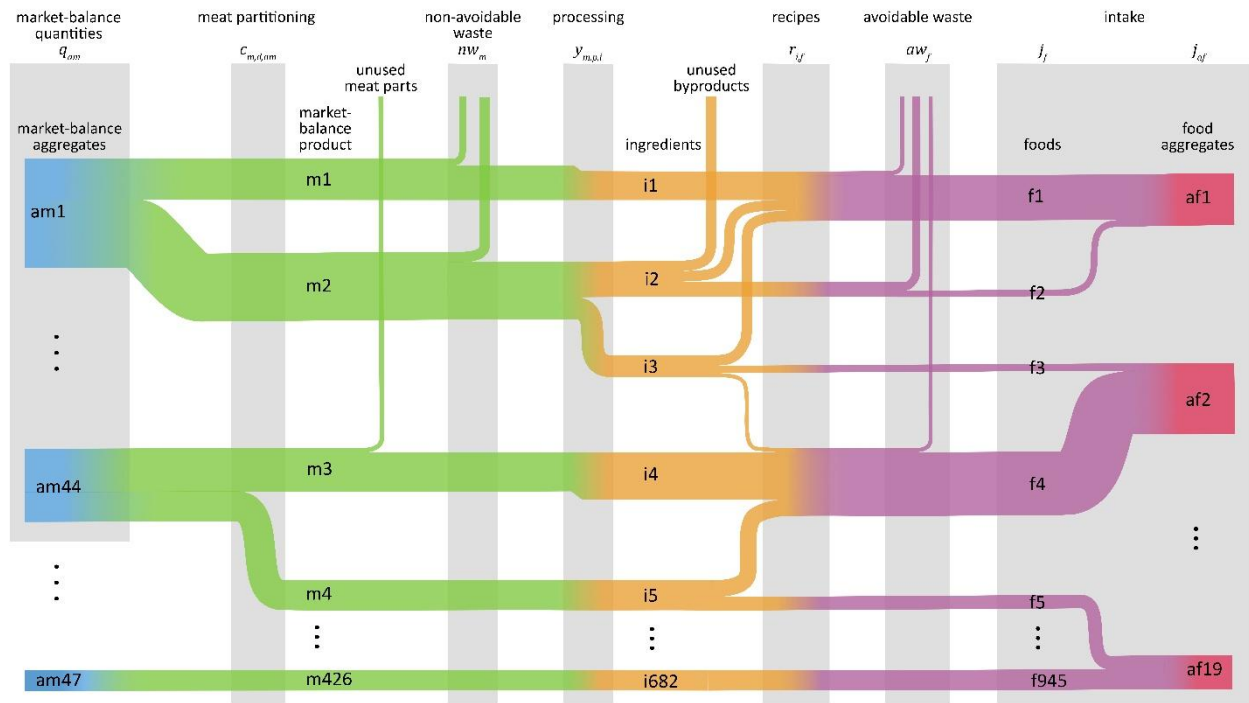


Figure 1: Schematic visualisation of the logical framework of the quantity flow.

Table 3: Index sets of the quantity flow

Set	Description
AM	47 market-balance aggregates.
$AM_{bal} \subseteq AM$	For 44 market-balance aggregates, quantities available for human consumption at market level are taken from market balances (e.g., wheat and sunflower oil). Water, other meat and other are not part of AM_{bal} .
$AM_{meat} \subseteq AM$	Four are meat market-balance aggregates, i.e., beef, pork, poultry, sheep and goat.
M	426 market-balance products (e.g., common wheat grain).
$M_{meat} \subseteq M$	58 are meat market-balance products (e.g., veal muscle meat).
D	8 animal species (e.g., veal).
P	85 processes (e.g., fine milling) that turn a market-balance product m (e.g., common wheat grain) into an ingredient i (e.g., white wheat flour).
I	682 ingredients (e.g., white wheat flour) produced from a market-balance product m by one processing step p .
F	945 foods, for which mean intake quantities are reported in the intake survey (e.g., apple strudel).
AF	19 food aggregates, for which mean intake quantities are reported in the intake survey (e.g., grain products).

2.3 Prior data

We initialise seven sections of the quantity flow with a combination of datasets, represented as grey boxes in Figure 1. Table 4 overviews each dataset, its content, its role in the quantity flow, and the notation used in the equations. See Supplementary Information 2 for a detailed overview and Supplementary Information 3 to 6 for dataset choice and preparation.

Table 4: Overview of the seven datasets used to initialise the quantity flow.

Role in quantity flow	Notation in equations	Year, region	Dataset and content used	Number of non-zero data points, range	Source
Market-balance quantities	q_{am}^0 $am \in AM_{bal}$	2006, Germany	Quantities of market-balance aggregates available for human consumption am in 1,000 tonnes.	44 [3; 7,625]	(BMEL, 2023; CAPRI Consortium, 2022b; Eurostat, 2026; FAOSTAT, 2026)
Meat partitioning proportions	$c_{m,d,am}^0$ $m \in M_{meat}$ $d \in D$ $am \in AM_{meat}$	1995–1998, Germany	Quantity of meat parts per carcass weight for 8 animal species d	58 [0.002; 0.71]	(Branscheid, 1998; Ender & Augustini, 1998; Höreth, 1995; Papstein et al., 1995; Pingel et al., 1998; Ristic et al., 1995; von Lengerken et al., 1998)
Non-avoidable waste	nw_m^0 $m \in M$	2015, EU	Shares of inedible parts (peels, pits) for market-balance products m	281 [0.001; 0.12]	(Vanham et al., 2015)
Processing yields	$y_{m,p,i}^0$ $m \in M$ $p \in P$ $i \in I$	2019, global	EFSA Raw Primary Commodity (RPC) model, conversion table: Yield factors for processes p turning market-balance products m into ingredients i	758 [0.29; 100]	(Bergström, 1994; Bognár, 2002; EFSA et al., 2019; FAO, 2000; USDA, 1992)
Recipes	$r_{f,i}^0$ $f \in F$ $i \in I$	2019, USA, Australia and New Zealand	EFSA Raw Primary Commodity (RPC) model, disaggregation table: Quantity of ingredient i per quantity of food f	4,398 [0.000001; 7.71]	(Dotdash Meredith publishing family, 2024; EFSA et al., 2019; FSANZ, 2020; Mintel, 2023)
Avoidable waste	aw_f^0 $f \in F$	2012–2015, Germany and EU	Shares of avoidable food waste (retail, food service, households) per food f	936 [0.03; 0.24]	(Kranert et al., 2012; Vanham et al., 2015)
Intake quantities	$j_{f,i}^0$ $f \in F$ $j_{af,i}^0$ $af \in AF$	2006, Germany	National Nutrition Survey II (NVS II): Mean and standard deviation of per capita intake per food f and food aggregate af per age groups in grams. Official population statistics on share of age groups in total population.	945 [0.09; 21,006,012]	(Brombach et al., 2006; Destatis, 2025; EFSA, 2023; Krems et al., 2006)

2.4 Consolidation

When the values from the seven datasets are inserted into the logical framework of Section 2.2, the resulting quantity flow is not internally consistent: market-balance quantities do not match what the intake quantities imply once waste, processing and recipes are considered. The original datasets in Section 2.3 serve as priors, quantifying what is known before the logical linkages are enforced. The consolidation determines, for each prior data point, a consolidated value that satisfies the links within the quantity flow and stays as close as possible to the prior.

For example, the quantities of apples available on the market are too low to match the apple intake reported in the survey. The consolidation decreases intake of foods containing apples, while also accounting for other potential sources of the inconsistency: The priors may overestimate non-avoidable waste of apples (i.e., stems and pits), the apples needed per litre of apple juice, the apple content in apple strudel, or the waste of foods like apple juice or apple strudel. All these data points are adjusted to achieve consistency. Analysing the differences between prior and consolidated values, we identify biases in the original datasets to improve our understanding of what people eat.

The consolidation is formalised as a nonlinear programming problem with discontinuous derivatives. The links from Section 2.2 provide the framework; an objective function captures the closeness criterion by operationalising adjustments of prior data points.

Equation 1 operationalises the adjustments, $Adj_{k,e}$ for each data point e in each dataset k , penalising large adjustments more than small ones. In the first part, the standard deviation $\sigma_{k,e}^0$, divides the squared difference between the prior ($x_{k,e}^0$) and the consolidated values ($x_{k,e}$). Adjustments exceeding the standard deviation are thus penalised more than those within it, so the consolidation tends to adjust, e.g., the intake of foods with a relatively large standard deviation more than those with a small one. See Supplementary Information 7 for the derivation of standard deviations. In the second part, a Chen-Mangasarian swan-neck function $C_{k,e}$ applies an additional, progressively increasing penalty when a consolidated value passes a threshold close to its bounds (Chen & Mangasarian, 1996). This smoothes the adjustments, keeping them away from the bounds. Supplementary Information 8 and Supplementary Figure 1 visualise the full penalty structure for an example data point. See Table 5 and Supplementary Information 7 for variable bounds.

$$Adj_{k,e}(x_{k,e}) = \left(\frac{x_{k,e} - x_{k,e}^0}{\sigma_{k,e}^0} \right)^2 + C_{k,e}(x_{k,e}), \quad 1$$

$$\text{where: } \underline{\beta}_k x_{k,e}^0 \leq x_{k,e} \leq \overline{\beta}_k x_{k,e}^0$$

Functions	
$Adj_{k,e}(x_{k,e})$	Adjustment for dataset k , data point e .
$C_{k,e}(x_{k,e})$	Chen-Mangasarian swan-neck function. See Supplementary Equation 2.
Variables	
$x_{k,e}$	Consolidated value of data point e in dataset k . Decision variable.
Parameter	
$x_{k,e}^0$	Prior of entry e in dataset k , taken from the dataset (Table 4).
$\sigma_{k,e}^0$	Standard deviation of the prior of entry e in dataset k (Supplementary Information 7).
$\underline{\beta}_k, \overline{\beta}_k$	Lower and upper bound factors for dataset k , expressed as multiples of the prior (Table 5).

Sets	
$k \in K = \{q, c, nw, y, r, aw, j\}$	Set of the seven datasets used to initialise the quantity flow (Table 4).
$e \in E_k$	Set of data entries in dataset k (Table 4).

Equation 2 sums the adjustments over data points e and datasets k , operationalising the total adjustments, $TotalAdj$, which the objective function minimises in the consolidation. To ensure comparability between the datasets, which differ in the number and average level of their data points, the sum of all adjustments from dataset k is scaled by a correction term γ_k . Further, the sums are weighted by a factor ω_k to mirror the direction of inference defining the model: the quantity flow asks what intake pattern is consistent with the market-balance quantities, allowing us to link it with sectoral models in future research. A high ω_q makes adjustments of market-balance quantities costly, so they are held almost fixed. A low ω_j makes adjustments of intake quantities cheap, so survey values move more freely, reflecting the evidence on misreporting in intake surveys (Burrows et al., 2019; Hebert et al., 1995; Subar et al., 2003). See Supplementary Equation 3 for a full and combined formulation of Equations 1 and 2.

$$TotalAdj(x_{k,e}) = \sum_{k \in K} \omega_k \gamma_k \sum_{e \in E_k} Adj_{k,e}(x_{k,e}) \quad 2$$

Functions	
$TotalAdj(x_{k,e})$	Measure of adjustments across all data entries. Objective function minimised in the consolidation.
$Adj_{k,e}(x_{k,e})$	Adjustment for dataset k , data point e .
Variables	
$x_{k,e}$	Consolidated value of data point e in dataset k . Decision variable.
Parameter	
ω_k	Weight of dataset k in the objective function (Table 5).
γ_k	Correction term making datasets comparable despite differing levels and numbers of entries. Calculated as the sum of all entries of dataset k divided by the squared number of entries of dataset k (Table 5).
Sets	
$k \in K = \{q, c, nw, y, r, aw, j\}$	Set of the seven datasets used to initialise the quantity flow (Table 4).
$e \in E_k$	Set of data entries in dataset k (Table 4).

The parameterisation of bounds and weighting reflects plausible prior assumptions about the datasets and keeps model interpretation simple. Although their weights hold market-balance quantities close to their priors, their bounds are wide (Table 5). This ensures feasibility even if adjustments of the other variables are insufficient to achieve consistency.

226 **Table 5: Correction terms, weights, bounds and Chen-Mangasarian thresholds in the consolidation.**

Dataset k		Correction term γ_k	Weight ω_k	Bounds (multiplied with prior)		Thresholds for additional Chen-Mangasarian penalty (multiplied with prior)	
				$\underline{\beta}_k$	$\overline{\beta}_k$	$\underline{\tau}_k$	$\overline{\tau}_k$
q	Market-balance quantities	3.14e+01	10,000	0	10	$\frac{1}{9}$	9
c	Meat partitioning ¹	2.08e-03					
nw	Non-avoidable waste shares ¹	1.04e-04					
y	Processing yields ²	1.04e-03	1	0.8	1.2	0.82	1.18
r	Recipes ³	5.04e-05					
aw	Avoidable waste shares ¹	1.17e-04					
j	Food intake quantities	1.04e+02	0.0001	0.1	10	0.19	9

¹ Shares cannot be larger than 1.

² If a prior indicates a weight loss in processing, it cannot become a weight gain in the consolidation, and vice versa.

³ Only plant oils in recipes are an exception. The overall share of plant oils in a recipe must adhere to the $\pm 20\%$ bounds, but the composition of the different plant oils (e.g., olive oil and sunflower seed oil) may vary more strongly.

227

228 As an additional constraint, energy intake per capita per day is set to $\pm 3\%$ of the reference levels of 2,629
229 kcal per capita per day for adults, preventing the consolidation from resolving inconsistencies through
230 implausible inflation or deflation of total energy intake. We use a database from EFSA on the energy and
231 macronutrient content for each food f . Summing over the foods f , we obtain energy and macronutrient
232 intake per capita per day.

233 The consolidation is conducted at the national level, i.e. intake in tonnes per food per year for the whole
234 population of Germany. We use the age group differences reported in the intake survey to calculate the
235 national aggregate for the priors, and use them again for ex-post result reporting, assuming that age-specific
236 differences per food in the consolidated results match those in the intake survey, e.g., that the average
237 adolescent (14-17 years old) eats 2.33 times as much chocolate spread as the average across all age groups,
238 whereas the average adult (18-64 years) only 1.06 times as much. This way, we derive age-group-specific
239 consolidated intake quantities. See Supplementary Information 9 on energy intake and age proportions.

240 Together with the links within the quantity flow (Section 2.2), the objective function (Equation 2) constitutes
241 a discontinuous nonlinear programming problem, solved using the CONOPT solver in GAMS. Variables are
242 initialised at their priors.

243 The differences between prior and consolidated values quantify misreporting and biases. Estimating
244 misreporting this way reflects the limitations of existing approaches to intake quantification. Comparing
245 survey instruments, e.g., 24-hour recalls against food frequency questionnaires (Bailey, 2021; Hebert et al.,
246 1995), exposes discrepancies but cannot quantify distance to actual intake, as neither is unbiased.
247 Comparing survey responses against external references, i.e., biomarkers such as doubly labelled water
248 (Micha et al., 2018; Subar et al., 2003; Toozee et al., 2004), or energy requirements derived from body height,
249 weight and physical activity (Heuer et al., 2015; Krems et al., 2012), quantifies the misreporting of total
250 energy intake, but not per food.

251 Retaining food-level information requires an independent source of quantity information, like market
252 balances; we therefore treat the consolidation as a Bayesian estimation problem of the type applied to
253 underdetermined systems in agricultural economics (Gocht & Röder, 2014; Heckeley et al., 2008). The priors
254 state what is known about each data point before consistency is enforced, and the standard deviations state
255 how firmly it is known. The alternative, generalised maximum entropy, would require several support points
256 for each of the 7,420 data points (sum of Table 4). Heckeley et al. (2008) further show that under normally
257 distributed priors, the two approaches yield equivalent results.

258 We assume normally distributed priors, truncated at the bounds or imposed by other constraints (Table 5).
259 The Chen-Mangasarian term in the objective function is not part of this distributional assumption but a
260 numerical device that keeps the solver away from the bounds.

261 Ordinarily, the fit of a Bayesian estimation is assessed by comparing the distribution of the estimated values
262 against that of the priors. Our setting differs as consolidated values must satisfy the constraints of the
263 quantity flow as well as remain close to their priors. We are not aware of a study with a similar approach.
264 In lieu of existing benchmarks, we define three quality criteria: (i) consistency, i.e., whether adjustments
265 across datasets point in the same direction for foods with a single-commodity structure; (ii) spread, i.e.,
266 whether the consolidation achieves many small adjustments rather than few large ones; and (iii) correlation,
267 i.e., how closely the consolidated values track the priors within each dataset. We analyse these criteria and
268 their sensitivity to different parameterisations in Section 3.2.4 and Supplementary Information 12.

269 **2.5 Updating the food intake quantities**

270 The links comprising the logical framework hold by construction: quantities of market-balance products or
271 foods cannot appear or disappear mid-value-chain in ways other than those captured in the quantity flow.
272 Hence, for any set of market-balance quantities, food intake must be consistent with the quantity flow.

273 We assume that the coefficients and shares (i.e., avoidable and non-avoidable waste, meat partitioning,
274 processing yields, recipes) estimated through the consolidation are time-consistent. For example, in 2006
275 and 2025, the same share of apples is wasted as peels and core, the same share of a pork carcass weight is
276 muscle meat, the same quantity of wheat yields a ton of white wheat flour, and the apple content in apple
277 strudel is the same. The only exception is the proportions of plant oils in recipes, which are allowed to vary
278 analogously to the consolidation (see Table 5).

279 We exploit this property to update the food intake estimate, employing 2025 market balances from the
280 CAPRI model (Supplementary Table 9). Crucially, the quantity flow captures the linkages between market-
281 balance quantities: increased sugar availability cannot simply translate into higher intake of sugary foods,
282 but must be allocated in a way consistent with the other market-balance aggregates. Hence, the quantity
283 flow allows estimating synthetic food intake quantities bridging the time between surveys.

284 The resulting model is necessarily underdetermined: there are 945 foods, but only 44 market-balance
285 aggregates, so many food intake combinations are consistent with any given market balance. We solve a
286 second optimisation problem that finds the food intake consistent with 2025 market-balance quantities
287 while deviating as little as possible from the consolidated 2006 food intake. Its objective function (Equation
288 3) simplifies the consolidations' objective function (Equation 2), containing only the food intake deviations.
289 To ensure plausible results, the penalty for very large deviations $C_{j,f}(j_f)$, is higher than in the consolidation
290 through multiplication with $\theta = 20$. Average adult energy intake is bound within $\pm 3\%$ of 2025 reference

291 levels of 2,819 kcal per capita per day (Supplementary Information 10). Supplementary Equation 4 gives the
 292 detailed formulation of Equation 3.
 293

$$IntakeAdj(j_f) = \sum_{f \in F} \hat{j}_f \left(\frac{j_f - \hat{j}_f}{\sigma_{j,f}^0} \right)^2 + \theta C_{j,f}(j_f) \quad 3$$

$$\text{where: } \underline{\beta_j} \hat{j}_f \leq j_f \leq \overline{\beta_j} \hat{j}_f$$

Functions	
$IntakeAdj(j_f)$	Measure of adjustments for intake across all foods f compared to consolidated food intake quantities $\hat{j}_f$. Objective function minimised in the update to 2025.
$C_{j,f}(j_f)$	Chen-Mangasarian swan-neck function for intake per food f (Supplementary Equation 4).
Variables	
j_f	Intake quantity per year on national level in tonnes per food f for 2025. Decision variable.
Parameter	
$\hat{j}_f$	Intake quantities per year on national level in tonnes per food f for 2006. Consolidated value (denoted as j_f in Equations 1 and 2).
$\sigma_{j,f}^0$	Standard deviation of the intake quantity of food f , upscaled to national annual level, based on the standard deviations reported in the intake survey (Supplementary Information 7).
$\underline{\beta_j}, \overline{\beta_j}$	Lower and upper bound factors for food intake, expressed as multiples of the consolidated 2006 intake quantities $\hat{j}_f$ (Table 5). Enforced as bounds on the decision variable.
θ	Weight on the Chen-Mangasarian function, $\theta = 20$.
Sets	
$j \in K$	Indicates reference to dataset j , i.e., food intake (Table 4).
$f \in F$	945 foods, for which mean intake quantities are reported in the intake survey (Table 3).

294

295 3 Results

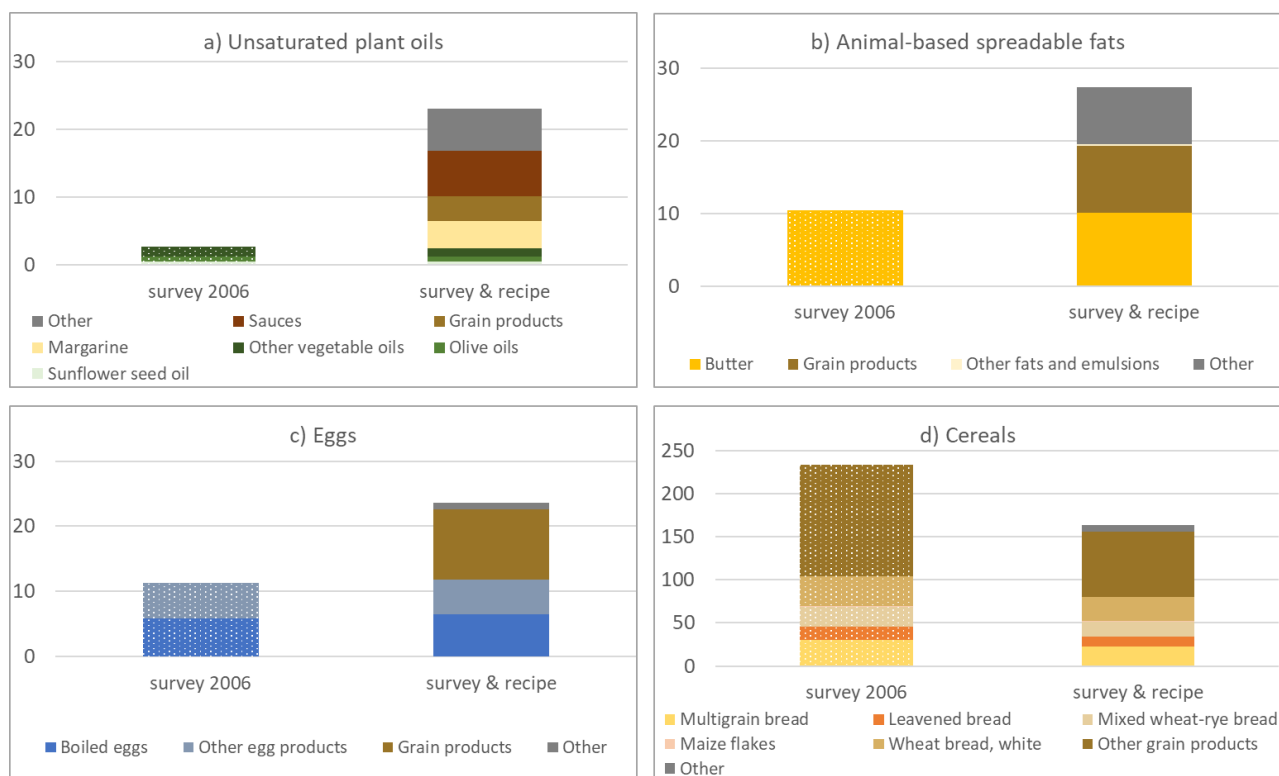
296 3.1 Problem 1: Many foods consist of multiple agricultural products. Quantifying 297 intake through ingredients

298 Assessing how much people eat of different agricultural products matters for health and environmental
 299 analyses and requires capturing all sources of intake, including commodities appearing as ingredients in
 300 composite foods. Eggs serve as a clear example: a boiled egg is easily captured in a survey, but the same
 301 person's egg intake through, e.g., pasta or cake must be traced through recipes. The same applies to plant
 302 oils in salad dressings or fried foods, in quantities far exceeding what direct consumption of oil-as-food
 303 suggests. Therefore, the closest-fitting food aggregate alone, e.g., egg products, does not always adequately
 304 capture total intake (Breidenassel et al., 2022; Springmann, 2026).

305 Linking food intake quantities from the survey to recipes, the quantity flow quantifies intake as ingredients.
 306 Figure 2 illustrates this for unsaturated plant oils, animal-based spreadable fats, eggs and cereals. The first
 307 column of each panel shows the intake reported in the survey for the food aggregate most directly
 308 associated with the respective commodity, i.e., plant oils, butter, egg products and grain products. The

309 second column reports the intake of the same raw product through all foods, adding intake from foods
 310 outside the initially assessed food aggregates, e.g., oil, egg and butter intake through grain products (brown,
 311 Figure 2a-c).

312 For unsaturated plant oils, the survey records approximately 3 g per capita per day of oil-as-food intake
 313 (first column, Figure 2a). Accounting for oils as ingredients in margarine, grain products, sauces, and others
 314 raises this figure to 23 g per day, i.e., almost eight times the direct intake (second column, Figure 2a). Intake
 315 as ingredients accounts for more than half of total intake for animal-based spreadable fats and eggs (Figure
 316 2b and c). Considering intake at the ingredient level also allows subtracting other ingredients, i.e.,
 317 quantifying the cereal content of grain products only (Figure 2d).



318 **Figure 2: Intake quantities per capita per day in grams for four ingredient aggregates. First column (dotted): intake**
 319 **of the food aggregate most directly associated with the ingredients, as reported in the NVS II survey. Second column:**
 320 **total intake of the ingredient, including as ingredients in composite foods, calculated using prior survey intake**
 321 **quantities and prior recipe data. See Supplementary Figure 2 for intake of 15 ingredient aggregates.**
 322

323 3.2 Problem 2: Misreporting. What did people really eat in 2006?

324 3.2.1 What the adjustments reveal

325 Linking food intake quantities to recipes improves the picture of what people eat. Yet food intake data is
 326 imperfect. The nutritional literature documents systematic misreporting in intake surveys (Burrows et al.,
 327 2019; Hebert et al., 1995; Subar et al., 2003). Errors potentially also exist in the other datasets: recipes may
 328 not reflect typical German cooking practices; waste shares are approximated from the literature, and
 329 processing yields are international averages. Inserting the priors from the seven datasets into the
 330 framework of the quantity flow confirms these errors: the priors do not result in a consistent quantity flow
 331 in which all quantities from market balance to intake are accounted for. The consolidation uses these

332 inconsistencies as a signal of where and how much the data need to be adjusted; the pattern of adjustments
333 from prior to consolidated values reveals where the priors are more or less biased or imprecise.

334 Market-balance quantities are adjusted least: 42 out of 44 market-balance aggregates show no or negligible
335 change (–1% to +1%). The aggregates requiring adjustments, whey powder and sheep and goat meat, are
336 cases for which consistency could not be fully achieved through adjusting the other six datasets within the
337 allowed bounds.

338 For intake quantities and waste shares, increases clearly dominate decreases. 54% of avoidable waste data
339 points are adjusted upward and only 22% downward. Non-avoidable waste shows a similar pattern (46%
340 upward vs 19% downward). For intake quantities, 49% are adjusted upward, and 35% are adjusted
341 downward (up to the bound of -90%), with substantially larger increases (up to the bound of +900%). This
342 asymmetry reflects the widespread underreporting: because prior intake quantities are systematically too
343 low to account for the market-balance quantities, the consolidation adjusts intake and avoidable waste
344 strongly upward for many foods, with waste being another outlet for the market-balance products too
345 abundant to match the intake quantities of foods containing them. Processing yields, meat partitioning
346 shares, and recipes show more balanced distributions of increases and decreases, reflecting errors that are
347 less systematic. See Supplementary Information 11 for details and Supplementary Figure 3 for a visualisation
348 of the adjustments.

349 Figure 3 shows that misreporting is not random across foods, but consistent with known social desirability
350 biases. Downward adjustments, indicating overreporting, are concentrated in fruit products and juices.
351 Consolidated intake of all juices combined is 68% lower than the survey reports, and of fruit products 50%
352 lower. Fruit is perceived as virtuous and may be reported to an extent not matching the quantities available
353 on the market, even when allowing for an error margin in the other data points along the quantity flow.

354 Upward adjustments, indicating that the survey participants underreported intake, predominate for animal-
355 based products (fish, dairy, egg and meat), grain and sugar products, and alcoholic beverages. In relative
356 terms, the largest upward adjustments are for sugar products (+326%), followed by fish products (+95%)
357 and fats and oils (+87%). Underreporting of sugar products and alcoholic beverages is consistent with the
358 social desirability bias documented for German dietary surveys (Eisinger-Watzl et al., 2015; Heuer et al.,
359 2015; Krems et al., 2012).

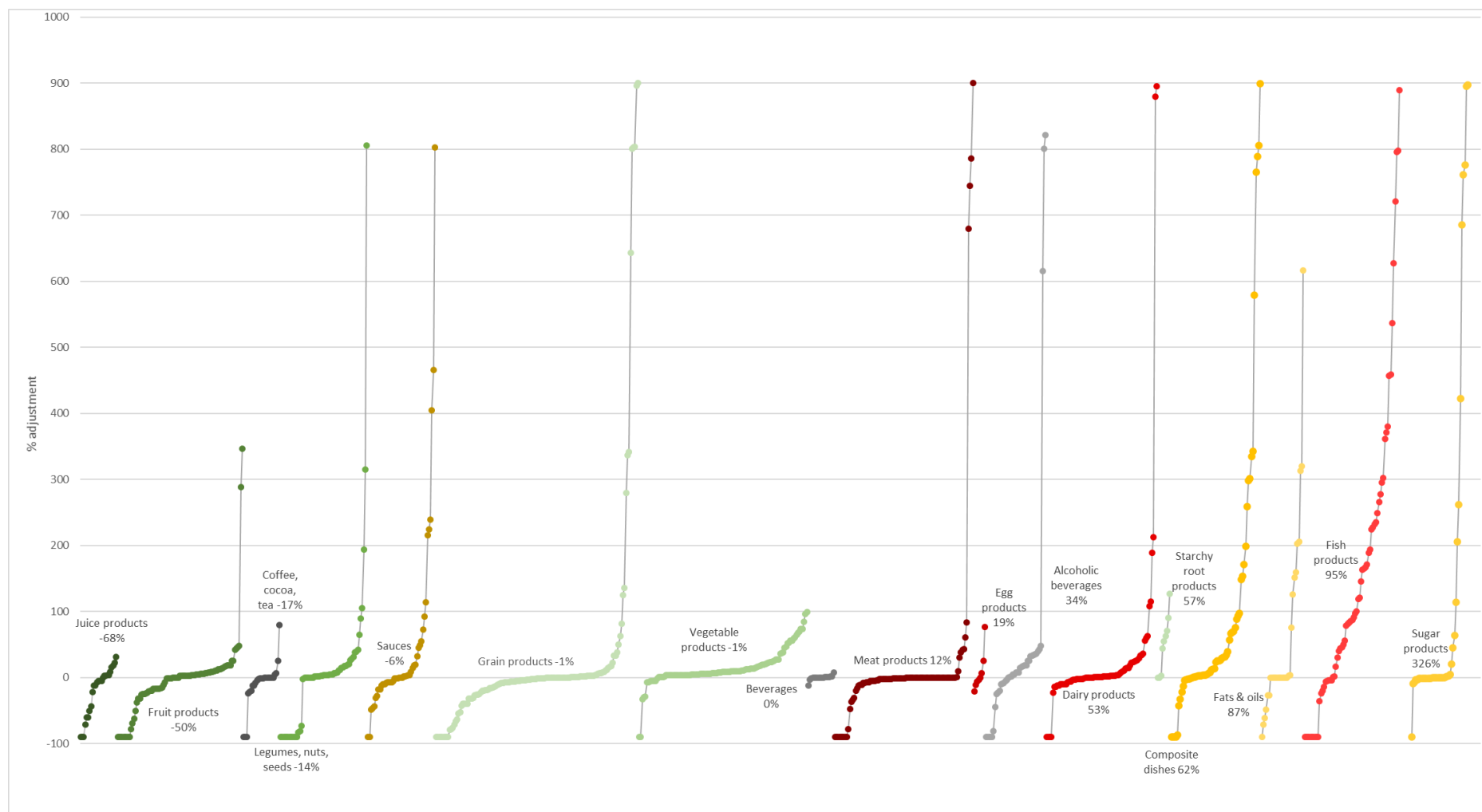


Figure 3: Relative adjustments to food intake quantities (% deviation from prior) for all 945 foods, sorted by magnitude of relative adjustment within each food aggregate (see label). Each dot represents one food. Colour denotes food group: red = animal-based; green = plant-based; yellow = mixed; grey = beverages and other. Small aggregates (“products for non-standard diets” and “isolated ingredients”) not shown.

3.2.2 Food intake by age group

To assess the status quo diet in substantive terms, we turn to the absolute intake quantities. Figure 4 shows the average consolidated intake per food aggregate (orange line) alongside the prior survey average (blue line). The gaps between survey and consolidated values describe the extent of misreporting in absolute terms. Overreporting is largest for fruit products (82 g per capita per day), and underreporting is largest for dairy products (99 g), composite dishes (71 g) and sugar products (62 g). These absolute differences matter when deriving energy and nutrient intake and distance from recommended food intake levels. For the latter, differentiation between age groups is important to account for physiological differences.

The columns in Figure 4 differentiate food intake by age group. For several food aggregates, including legumes, nuts, seeds, sauces and egg products, age-group variation is modest. Fruit products show the widest age-group variation both in prior and consolidated intake. The very elderly consume around 2.5 times more fruit products than adolescents.

The consolidation was conducted at the national level. We assume, for simplicity, that the degree of misreporting per food is constant across age groups and apply the survey's age-group proportions to the consolidated national averages for the intake per food. However, at the level of food aggregates, the age-group proportions change when the consolidation adjusts the separate foods within the aggregates differently. For example, sugar products show larger differences between age groups in the consolidated data. In this aggregate, underreporting of foods consumed by adolescents and adults (e.g., jelly candies and chocolate-coated confectionery) is stronger than among those consumed by elderly and very elderly.

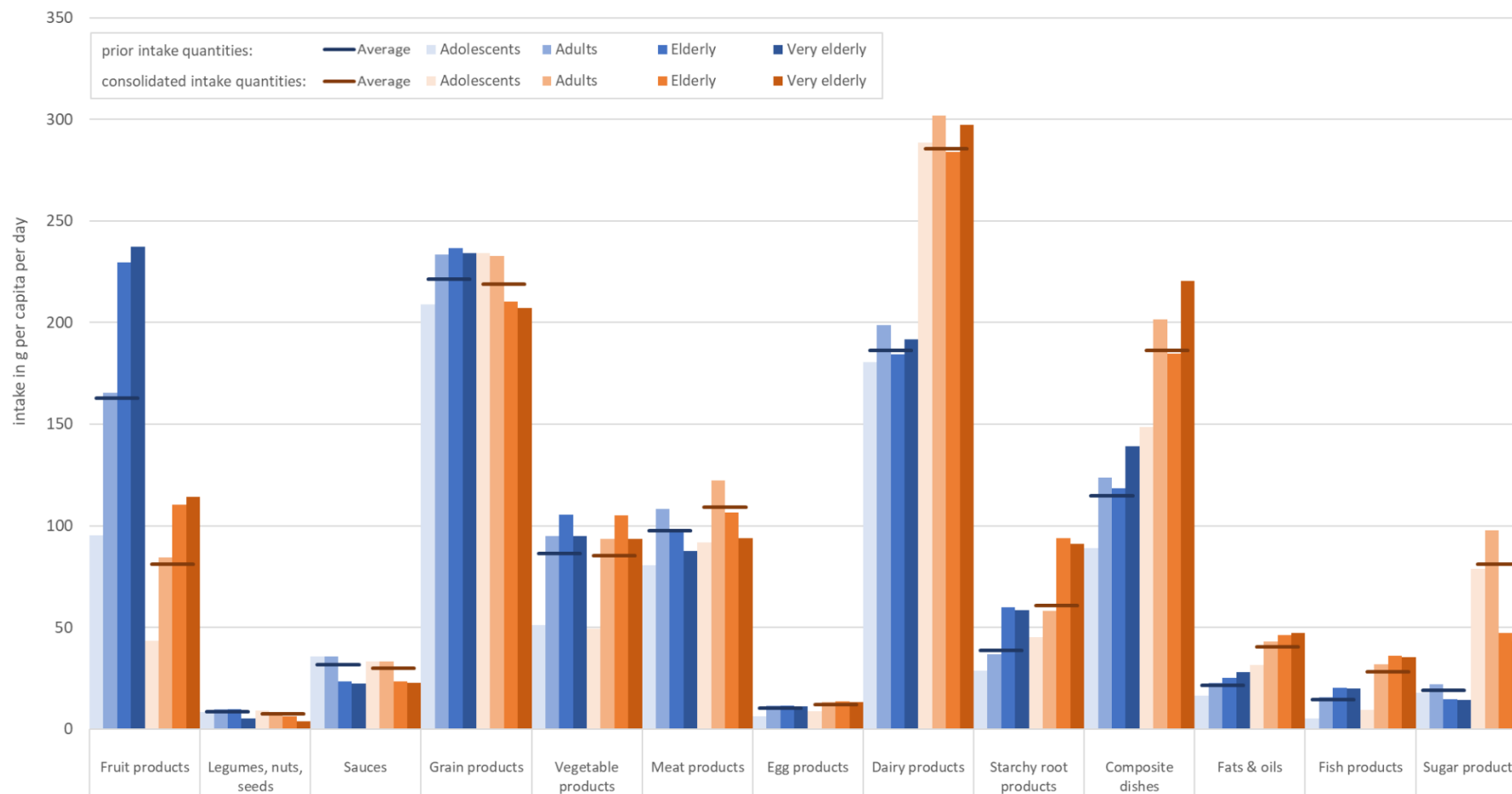


Figure 4: Food intake in g per capita per day per food aggregate, differentiated per age group. The horizontal lines show the population-weighted average across age groups. Prior survey data (blue) and consolidated data (orange). Ordered from the most negative relative adjustment of the average intake quantity per food aggregate to the most positive. Beverage aggregates (juice products, coffee, cocoa, tea, beverages, alcoholic beverages) and small aggregates (products for non-standard diets, isolated ingredients) are not shown. Age proportions are held constant between survey and consolidated values at food-level. Hence, when age proportions differ at food aggregate level, this stems from heterogeneous intake adjustments of foods within the aggregate.

3.2.3 Sources of energy intake

The adjustments to food intake quantities identified in Sections 3.2.1 and 3.2.2 translate directly into changes in the estimated energy and macronutrient intake. Following the survey, average daily energy intake per adult is 2,002 kcal. This implausible value, below average energy needs (Supplementary Table 7), aligns with previous findings on underreporting of energy intake in this and other surveys (Krems et al., 2012; Micha et al., 2018; Subar et al., 2003). The energy intake associated with the consolidated data is 2,623 kcal, i.e., close to the reference level, exceeding average energy needs and, thus, aligning with the prevalence of obesity in Germany (Schienkiewitz et al., 2022) (see Section 2.4 and Supplementary Information 9).

Figure 5 shows daily energy intake per capita decomposed by food, comparing the prior survey-based calculation (Figure 5a) with the consolidated estimate (Figure 5b). Aggregates paler in Figure 5a than in Figure 5b (e.g., sugar and dairy products, pink and blue) are underreported, mirroring upward adjustments explained above. The survey suggests 88 kcal per capita per day from sugar products and 227 kcal from dairy products, whereas consolidated intake is 389 kcal for each aggregate.

Other food aggregates show a mix of bold and pale, indicating a heterogeneous pattern of misreporting. For example, the survey makes butter the primary energy source in fats and oils (yellow, 56 kcal) ahead of traditional margarine (44 kcal), whereas the consolidation suggests the reverse (margarine 183 kcal, butter 22 kcal). Overreporting the more prestigious and expensive butter aligns with the bias in recipes towards more expensive ingredients used in home cooking and findings on social desirability bias (Springmann, 2026).

The intake of apples and apple juice (red, orange) is substantially lower in the consolidated estimate, hitting the lower bound of 0.1 of the prior. We suspect the gap between the prior and the implausibly low consolidated value comes both from overreporting and from non-marketed apples from home gardening. We acknowledge this limitation in Section 4.2.

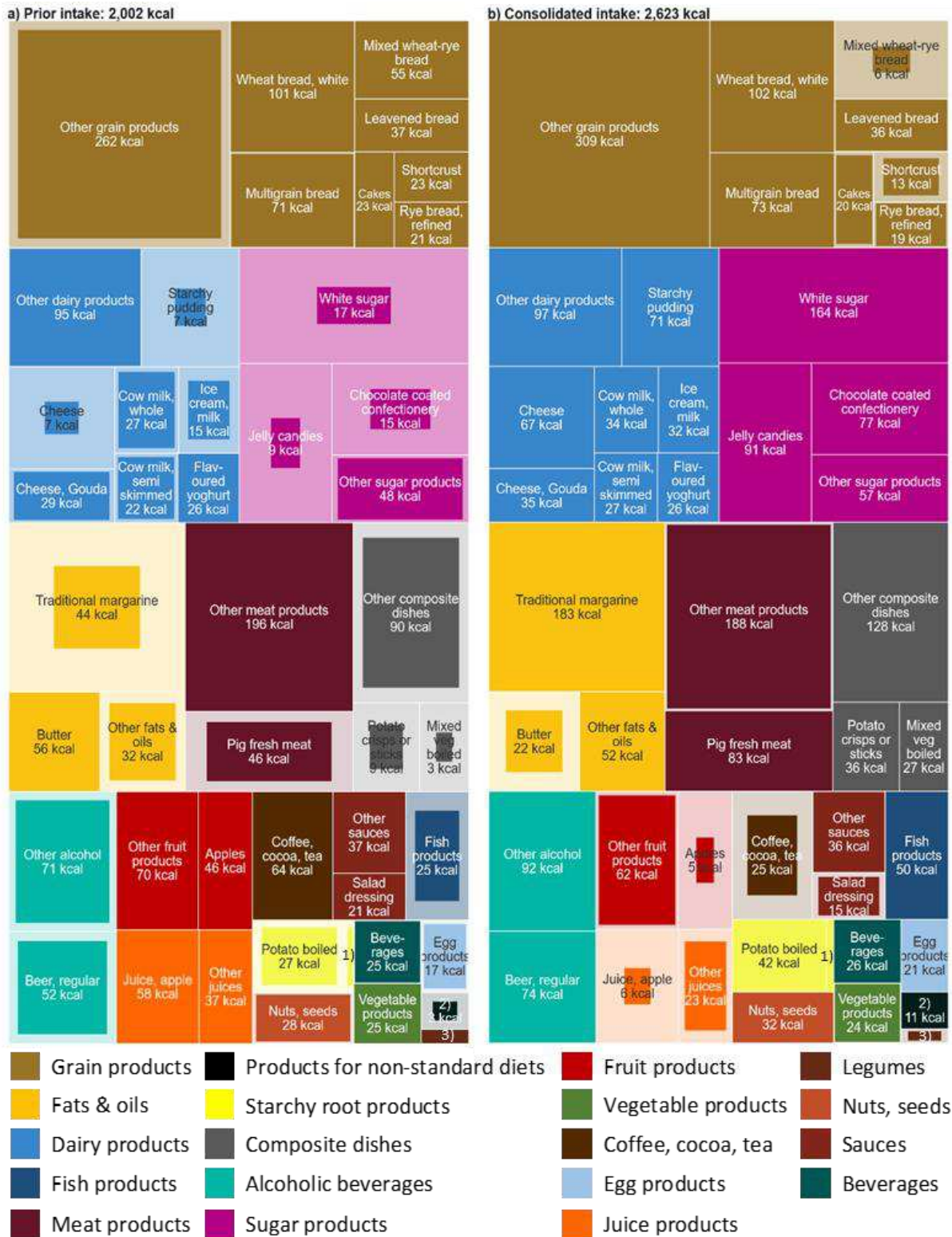


Figure 5: Energy intake per capita per day (kcal) by food. Left panel: prior intake according to the NVS II survey (total: 2,002 kcal). Right panel: consolidated intake (total: 2,623 kcal). The rectangle size is proportional to energy contribution; foods are grouped and coloured by food aggregate following the FoodEx2 hierarchy. Each bold-coloured rectangle represents the energy intake of a food or food group, coloured by food aggregate. Pale frames

418 around the rectangles indicate higher energy intake from a food in the other scenario, i.e., a small bold rectangle
419 with a pale frame in Figure 5a indicates underreporting, as the intake is increased in the consolidated estimate (large
420 bold rectangle in Figure 5b). Conversely, a large bold rectangle in Figure 5a implies overreporting. The food
421 aggregate “Legumes, nuts, seeds” is split into two aggregates.

422 3.2.4 Quality check and sensitivity of consolidation to parameterisation

423 We assess the consolidation along three quality dimensions: consistency, spread, and correlation, as defined
424 in Section 2.4. We examine how results change under four alternative parameterisations, varying the two
425 parameters we set deliberately rather than using external data: the bounds on proportions of meat
426 partitioning, shares of non-avoidable waste, processing yields, recipes and shares of avoidable waste, and
427 the relative weighting of the market balance and intake in the objective function (see Table 6). Further, we
428 assess how the parameterisations affect the function of the market balances as an anchor and thus the
429 compatibility of the quantity flow with sectoral models.

430 Table 6 summarises the quality assessment. The default parameterisation performs acceptably or well
431 across all three quality dimensions. The default parameterisation performs best regarding consistency.
432 Regarding spread and correlation, the results are robust against variation of the bounds. Lowering the
433 weight difference improves performance in spread and correlation, but comes at the expense of
434 inconsistent adjustments. Also, a lower weight difference causes the loss of market balances as an anchor,
435 forfeiting the option to combine the quantity flow with sectoral models. See Supplementary Information 12
436 for the full sensitivity analysis.

437 **Table 6: Consolidation quality across three dimensions for the default consolidation run and four alternative**
438 **parameterisations. MB = market balance. Dark green = good/yes, green = acceptable, light green = poor/no.**

	Consistency	Spread	Correlation	MB as anchor?
Default parameterisation: Bounds: $\beta_k = \pm 20\%$ for $k \in \{c, nw, y, r, aw\}$ Weights: $\omega_q = 10,000$; $\omega_j = 0.0001$	good	acceptable	acceptable	yes
Tight bounds: Bounds: $\beta_k = \pm 10\%$ for $k \in \{c, nw, y, r, aw\}$ Weights: $\omega_q = 10,000$; $\omega_j = 0.0001$	acceptable	acceptable	acceptable	yes
Loose bounds: Bounds: $\beta_k = \pm 30\%$ for $k \in \{c, nw, y, r, aw\}$ Weights: $\omega_q = 10,000$; $\omega_j = 0.0001$	acceptable	acceptable	acceptable	yes
Low weight difference: Default bounds: $\beta_k = \pm 20\%$ for $k \in \{c, nw, y, r, aw\}$ Weights: $\omega_q = 100$; $\omega_j = 0.01$	poor	good	good	no
No weight difference: Default bounds: $\beta_k = \pm 20\%$ for $k \in \{c, nw, y, r, aw\}$ Weights: $\omega_q = \omega_j = 1$	poor	good	good	no

q: market – balance quantities, nw: non – avoidable waste, c: meat partitioning, y: processing, r: recipe, aw: avoidable waste

439

440 3.3 Problem 3: Outdated intake surveys. What do people really eat today?

441 Section 3.2 quantifies what people in Germany ate in 2006, but these data are too old for a policy-relevant
442 reference. In principle, the consolidation could be applied to a more recent intake survey; in practice,

443 however, sufficiently recent surveys often do not exist, as representative, high-quality intake surveys are
444 costly and, therefore, infrequent. In contrast, market-balance quantities are usually published annually. We
445 use 2025 market-balance quantities together with the quantity flow to generate food intake quantities for
446 2025, bridging the gap until the next survey becomes available.

447 Trends in obesity prevalence imply that mean average energy intake is higher in 2025 than in 2006
448 (Schienkiewitz et al., 2022) (Supplementary Information 9). Further, market-balance quantities changed
449 across products (Supplementary Table 9). As most foods combine several ingredients, i.e., are subject to
450 several, potentially different changes in market availability of the ingredients, simply scaling the 2006 intake
451 quantities to meet the increased energy intake is not sufficient to derive 2025 food intake quantities.
452 Instead, we use the quantity flow to estimate updated intake for all 945 foods consistent with the changes
453 in all 44 market-balance aggregates. Among the possible solutions, we determine plausible intake patterns
454 minimising the deviations from the 2006 food intake quantities (Equation 3).

455 Figure 6a visualises the co-intake of ingredients in the consolidated 2006 diet. Each cell shows the average
456 quantity of the ingredient on the horizontal axis eaten together with one kilogram of the ingredient on the
457 vertical axis (e.g., an average kg of cereals is eaten with 65 g of eggs and 45 g of butter, as in cakes). Darker
458 cells indicate higher co-intake of the respective ingredients.

459 When the market availability of all ingredients in a food changes to a similar degree, the food's intake
460 changes proportionally. In contrast, when their availability changes to different extents or in opposite
461 directions, the food combining them fits less naturally into the consistent quantity flow, and its intake
462 decreases in the optimisation process. Figure 6b shows this shift in co-intake between 2006 and 2025, with
463 ingredients ordered by the direction and size of their market balance change. For example, market-balance
464 quantities of poultry increase (+20%, Supplementary Table 9), while red meat decreases (-15%).
465 Consequently, intake of foods containing both decreases (e.g., sausages). While in 2006, an average kg of
466 poultry is eaten with 1.28 kg of red meat (Figure 6a), in 2025 it is only 0.74 kg (Supplementary Figure 6).
467 Figure 6b depicts the difference (-0.54 kg) and makes the pattern visible. More abundant ingredients (like
468 poultry) are less often eaten with ingredients that are less abundantly available (like red meat), captured by
469 negative values and red shades in the upper right of Figure 6b. Correspondingly, less abundant ingredients
470 (like butter, for which market quantities are 22% lower in 2025 than in 2006, Supplementary Table 9) are
471 more often eaten with ingredients that are more abundantly available (like cereals +15%, blue shades, lower
472 left). Co-intake tends to change less between ingredients that moved in the same direction (pale shades for
473 joint increases in the upper-left and decreases in the lower-right). Our analysis of co-intake assumes largely
474 fixed recipes. We discuss the limitations of this assumption in Section 4.2.

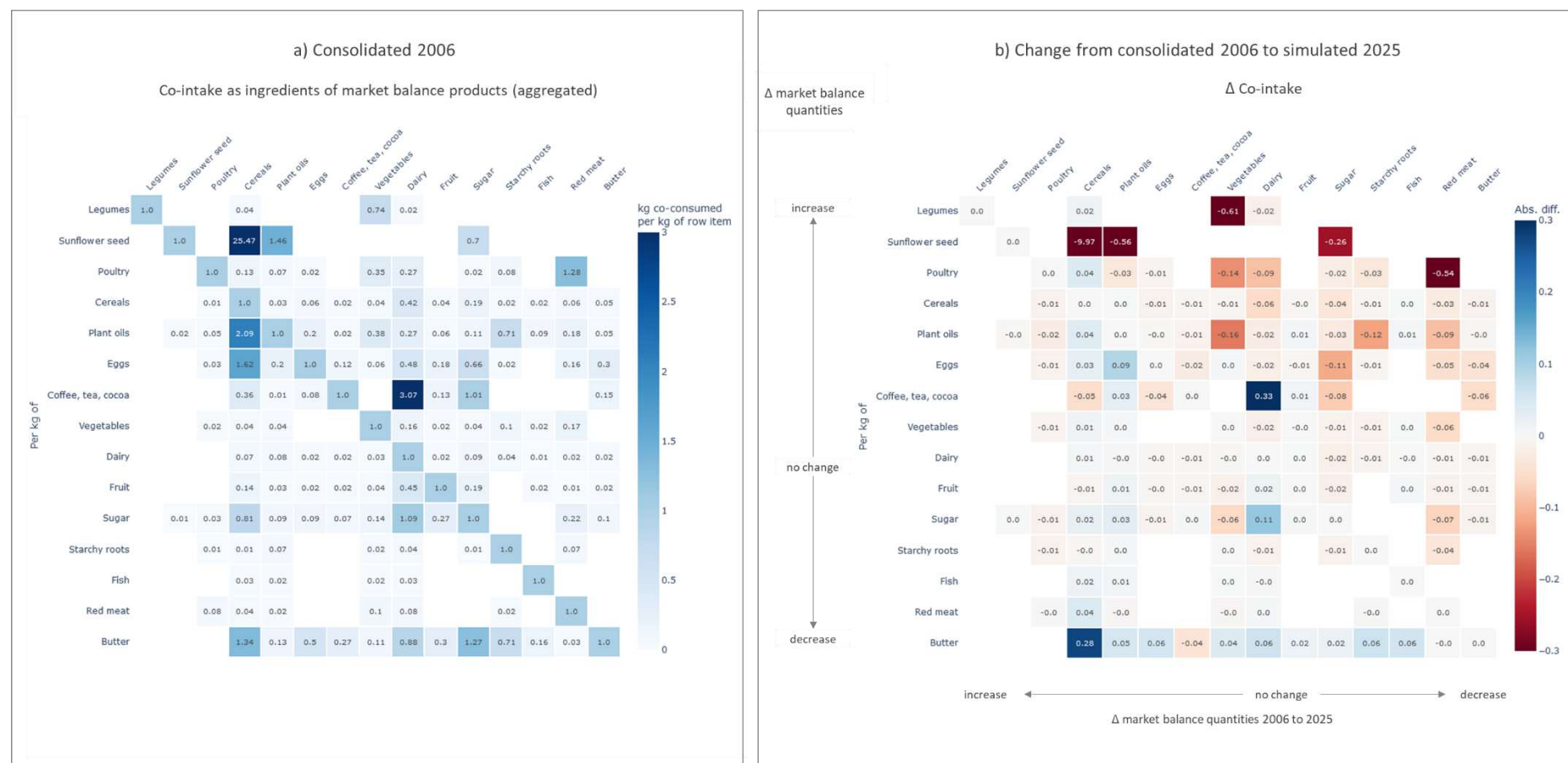


Figure 6: Co-intake of ingredients in the 2006 consolidated diet and changes in co-intake from 2006 to 2025. (a) Average quantity of ingredients (horizontal axis) eaten per kilogram of the ingredients on the vertical axis, 2006 consolidated data. Darker cells indicate higher co-intake. (b) Change in co-intake proportions from the 2006 consolidated to the 2025 simulated diet. Aggregated to 15 super-aggregates of market-balance products according to Table 1. See Supplementary Figure 6 for absolute quantities and percentage changes for 2025. See Supplementary Figure 7 for co-intake for the 44 market-balance aggregates.

4 Discussion

Our results show that a substantial share of intake is consumed as ingredients in composite foods, that misreporting is quantifiable, and that intake patterns can be carried forward to a recent year if a new survey is lacking. We now turn to what this means for dietary guidance and for sectoral modelling.

4.1 Contributions to scientific policy advice and policymaking

Our approach extends earlier approaches deducing intake from market-balance quantities (Springmann, 2026; Tallard et al., 2022) by tracking co-intake of ingredients in composite foods. The immediate contribution of this article is an improved status quo reference for dietary recommendations. Dietary guidelines orient national food policies, e.g., public procurement. Without a reliable status quo reference, recommended intake levels carry no clear implication for whether, or by how much, consumers should change their intake of a given food to meet recommendations. The DGE, responsible for the German food-based recommendations, publishes recommended alongside status quo intake levels, currently using the unadjusted intake survey (Schäfer et al., 2024), while acknowledging that these are inaccurate for composite-food intake, subject to misreporting, and outdated (Breidenassel et al., 2022). Our 2025 food intake data address all three issues at once. The choice of reference shapes the behavioural implications to be drawn from the recommendations. Comparing the DGE's recommended 13 g of oil intake against the survey's 3 g implies a considerable increase in intake to comply with recommendations. Factoring in misreporting, oil intake as ingredients in composite foods and the 2025 update, however, the status quo intake of 47 g (Supplementary Figure 2) is substantially above recommended levels such that the dietary recommendation would be to consume less oil. The 2025 intake data, as a reference, can help improve the derivation and communication of future food-based recommendations and allow meaningful derivation of changes necessary to meet raw-product-based recommendations like the Planetary Health Diet (PHD), recommending 40 g of plant oils, regardless of how they are consumed (Rockström et al., 2025).

Beyond the direct results, the approach itself opens applications for scientific policy advice. First, it translates average food intake quantities into market-level demand changes, making food-based recommendations and their environmental impact simulable with sectoral models like CAPRI rather than relying on fixed coefficients (Schäfer et al., 2024), and therefore opening up a method frequently used for the assessment of raw product-based recommendations such as the PHD (Gibson et al., 2026; Rockström et al., 2025; Sundiang et al., 2025).

Second, it can translate raw-product-based recommendations like the PHD into concrete food-level guidance as close as possible to present dietary patterns, turning flexible but vague recommendations into tangible, specific suggestions of what they can look like on people's plates.

Third, the quantity flow can enhance demand depiction in sectoral models widely used in policy advice (Agora Agriculture, 2024; Hristov et al., 2024). In models such as CAPRI, dietary-change scenarios are market-level demand shifts (Thom et al., 2025). The quantity flow shows what these mean for food intake, improving interpretation of any dietary-change scenario. Further, it can inform scenario design directly: Differently from existing approaches that simulate, for instance, scenarios of reduced sugar intake through decreased market demand for sugar alone (Tallard et al., 2022), the quantity flow can identify the foods contributing most sugar, derive the food-level reductions needed to meet a recommended threshold while

519 staying close to status quo intake, and translate these into market-level demand changes for all ingredients
520 in sugary foods, not sugar alone.

521 **4.2 Limitations and further research**

522 Several limitations point to further research. As similar approaches, the quantity flow considers only
523 marketed quantities (Springmann, 2026), excluding non-market food, such as home-grown fruit and
524 vegetables. Because the consolidation resolves any gap between reported intake and market-balance
525 quantities, this likely overstates overreporting where home production is common, e.g., apples, though a
526 lack of reliable quantification prevents us from saying by how much.

527 Further, market-balance quantities may not correspond to intake in the same year for storable
528 commodities, since stockholding can smooth consumption across years. We suspect this for legumes, whose
529 2006 market-balance supply quantity is implausibly low relative to neighbouring years, more likely reflecting
530 stock smoothing than an actual intake drop. Consequently, pulses intake may be larger than our
531 consolidation finds. Averaging market-balance priors across several years for storable commodities could
532 account for such fluctuations. Similarly, using multiple datasets to generate priors for recipes and processing
533 yields, as we did for waste and meat partitioning shares, can reduce bias toward home-made dishes and
534 better capture country-specific practices.

535 Currently, the framework is applied only to Germany, but is built on the FoodEx2 classification specifically
536 so it can be applied to other countries' surveys in EFSA's Comprehensive Food Consumption Database.
537 Based on the wider literature (Burrows et al., 2019; Hebert et al., 1995; Subar et al., 2003), we expect several
538 findings, specifically the underreporting of energy intake, to generalise, though this remains to be tested.

539 The main limitation regarding the update to 2025 concerns the vintage of the NVS II: our approach reflects
540 only changes in market-balance quantities. It cannot capture trends beyond that, such as genuinely new
541 foods or changes in the quality and acceptance of existing ones. This matters most for plant-based
542 alternatives to meat and dairy, which have grown substantially in market share and product variety since
543 2006 (UBA, 2022). The update therefore likely overstates intake of long-established foods in categories
544 affected by such product innovation.

545 Further, we assume recipes to remain largely unchanged from 2006 to 2025. In reality, changes in market-
546 balance quantities would not only be reflected through adjustments in food intake, but also in recipes. To
547 account for this, we allow substitution between plant oils in recipes to mirror market balance changes.
548 However, this could be extended. For example, the increase in poultry and decrease in red meat could be
549 reflected in an adjusted meat mix in foods like lasagna, with consequently smaller adjustments in the intake
550 of the respective foods.

551 **5 Conclusion**

552 This article challenges what counts as evidence on intake. Survey responses, market balances, recipes, waste
553 shares and processing yields are ordinarily treated as separate sources. Instead, treated as constraints on
554 one another, they help identify a diet "people really eat", that no single source reports: one that quantifies
555 intake of, e.g., oils and sugar, as ingredients, one in which underreported energy intake is accounted for,
556 and one that can be updated as new market data is published. How close this is to the "true diet" cannot
557 be verified directly, since no unbiased measurement exists to test it against. However, it reconciles the

principal statistics describing the German agrifood value chain, offering a firmer basis for dietary guidance and sectoral modelling than any single source alone.

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