

1 **Supplementary Information**

2 **What do people really eat? Consolidating datasets to account for intake** 3 **from composite foods, misreporting and outdated survey data.**

4 The Supplementary Information follows the structure of the main text. Supplementary Tables and Figures
5 are provided in the Supplementary Excel file together with the Figures from the main text. Some of the
6 Supplementary Tables and Figures are also directly included below if they are directly referenced in the
7 Supplementary Information.

8 **Contents**

9	2 METHODS	2
10	2.1 TERMINOLOGY AND CLASSIFICATION	2
11	Supplementary Table 1: List of market-balance products and aggregates.	2
12	Supplementary Table 2: List of ingredients.	2
13	Supplementary Table 3: List of foods and aggregates.	2
14	2.2 LOGICAL FRAMEWORK OF THE QUANTITY FLOW	2
15	Supplementary Information 1: Roles in terminology	2
16	Supplementary Table 4: Links between market-balance aggregates, meat partitioning, market balance products,	
17	processes, ingredients, foods and food aggregates along the quantity flow as visualised in Figure 1.	3
18	2.3 DATA SOURCES	3
19	Supplementary Information 2: Datasets for initialisation	3
20	Supplementary Information 3: Meat partitioning proportions.	5
21	Supplementary Table 5: Proportions of meat parts per animal species. Prior values.	6
22	Supplementary Information 4: Waste shares	6
23	Supplementary Equation 1: Waste share calculation, exemplary for composite dishes.	7
24	Supplementary Information 5: Choice of recipe database	7
25	Supplementary Information 6: Preparation of recipe database	8
26	Supplementary Box 1: Derivation of ingredient list for the exemplary food apple strudel.	9
27	2.4 CONSOLIDATION	10
28	Supplementary Information 7: Standard deviations and bounds.	10
29	Supplementary Information 8: Penalisation in objective function	11
30	Supplementary Equation 2: Chen-Mangasarian penalty.	11
31	Supplementary Equation 3: Detailed formulation of the consolidation objective function (Equation 2).	12
32	Supplementary Figure 1: Visualisation of penalising deviations from an exemplary data point, reverse processing yield	
33	of deep frying potatoes, prior=1.92.	17
34	Supplementary Information 9: Scaling intake from per capita to total, national level	17
35	Supplementary Table 6: Age distribution in Germany in 2006 (Destatis, 2025)	18
36	Supplementary Table 7: Energy need in Germany in 2005 for average physical activity in kcal per capita per day.	18
37	2.5 UPDATING THE FOOD INTAKE QUANTITIES	19
38	Supplementary Information 10: Updating food intake quantities to 2025.	19
39	Supplementary Equation 4: Detailed formulation of the updating objective function (Equation 3).	19
40	3 RESULTS	20
41	3.1 PROBLEM 1: MANY FOODS CONSIST OF MULTIPLE AGRICULTURAL PRODUCTS. QUANTIFYING INTAKE THROUGH INGREDIENTS.	20
42	Supplementary Figure 2: Intake quantities per capita per day in grams for 15 ingredient aggregates. Extension of	
43	Figure 2.	20
44	3.2 PROBLEM 2: MISREPORTING. WHAT DID PEOPLE REALLY EAT IN 2006?	20
45	3.2.1 <i>What the adjustments reveal</i>	20
46	Supplementary Information 11: Details and visualisation of the adjustments.	20

47	Supplementary Figure 3: Distribution of adjustments in the consolidation for each of the seven datasets.	21
48	3.2.4 Quality check and sensitivity of consolidation to parameterisation	21
49	Supplementary Information 12: Sensitivity analysis	21
50	Supplementary Figure 4: Parallel coordinate plots showing relative adjustments (% deviation from prior) across five	
51	datasets for 404 single-ingredient foods.	23
52	Supplementary Figure 5: Lorenz curves for the distribution of absolute adjustments across datasets and consolidation	
53	scenarios.	25
54	Supplementary Table 8: Spearman correlation coefficients for each dataset and sub-set in the default consolidation	
55	parameterisation.	27
56	3.3 PROBLEM 3: OUTDATED INTAKE SURVEYS. WHAT DO PEOPLE REALLY EAT TODAY?	27
57	Supplementary Table 9: Market-balance quantities in consolidated 2006 and simulated 2025, in 1,000 tonnes.	27
58	Supplementary Figure 6: Co-intake of ingredients in the 2006 consolidated diet and changes in co-intake from 2006 to	
59	2025. Absolute quantities and percentage changes for 2025. Supplement to Figure 6.	27
60	Supplementary Figure 7: Co-intake of ingredients in the 2006 consolidated diet and changes in co-intake from 2006 to	
61	2025, per market balance aggregate. Supplement to Figure 6.	27
62	REFERENCES IN SUPPLEMENTARY INFORMATION	28

63

64 2 Methods

65 2.1 Terminology and classification

66 **Supplementary Table 1: List of market-balance products and aggregates.**

67 See the Excel file.

68

69 **Supplementary Table 2: List of ingredients.**

70 See the Excel file.

71

72 **Supplementary Table 3: List of foods and aggregates.**

73 See the Excel file.

74

75 2.2 Logical framework of the quantity flow

76 **Supplementary Information 1: Roles in terminology**

77 The same commodity can occupy different roles simultaneously: a tomato is a market-balance product, an
78 ingredient (for example, in lasagna), and a food consumed directly. This terminology allows us to capture
79 the full range of pathways through which a commodity moves from the agricultural supply to the consumer.
80 To illustrate how these roles, the links within the logical framework and the underlying datasets interact,
81 we trace lasagna as an exemplary composite food through the quantity flow. The example follows the
82 explanation in Section 2.2 of the main text and the stages visualised in Figure 1, moving from left to right.

83 The recipe for lasagna comprises 31 ingredients, drawing on 19 market-balance aggregates. It should be
84 interpreted not as a single household recipe but as a representation of recipe variations, both homemade
85 and industrial. We follow six of these ingredients, each illustrating one element of the framework.

From market-balance aggregates am to market-balance products m (blue to green in Figure 1). Among others, lasagna uses the market-balance products durum wheat (from the market-balance aggregate wheat), beef muscle (aggregate beef), tomatoes (aggregate tomatoes), onions (aggregate “other vegetables”), milk (aggregate fresh milk products) and butter (aggregate butter). While the quantity of most market-balance aggregates is simply the sum of the market-balance products, the meat aggregates are reported in carcass weight. Therefore, we consider the proportion of beef muscle and other meat parts to derive the beef carcass weight. Carcass parts that are not used as food leave the food value chain.

From market-balance products m to ingredients i (green to orange in Figure 1). A market-balance product is either processed, remains unprocessed, or leaves the value chain as non-avoidable waste such as onion peel or tomato stems. The remaining edible quantities are processed into ingredients. We employ reverse processing yield factors that determine how much market balance product is needed to produce 1 kg of an ingredient; for example, stewing beef evaporates water, so 1.54 kg of beef muscle is needed to produce 1 kg of stewed beef muscle. Some processes are coupled, producing several ingredients at once. For example, if 1 kg of the market balance product “common wheat grain” is fine-milled, 699 g of the ingredient “white wheat flour”, 180 g of “wheat bran” and 20 g of “wheat germ” are derived. Because the coupled ingredients are not consumed in the proportions in which the process produces them, unused quantities leave the value chain. Importantly, some more complex coupled processes like producing different dairy products from raw milk or oil from oilseeds are already accounted for in the CAPRI model and, thus, the market balance.

From ingredients i to foods f (orange to purple in Figure 1). Ingredients are combined in fixed proportions given by the recipe, determining the resulting quantity of the food. Instead of listing the ingredients of lasagna as in cooking instructions, i.e., pasta plates, bechamel sauce, bolognese sauce, our recipes condense intermediate steps and list the ingredients in the state they exit the processing step, i.e., durum wheat semolina, butter, milk, tomato purée, onions and stewed beef muscle. The recipes also capture weight change during preparation: baking evaporates water, so the ingredient quantities sum to more than the resulting quantity of lasagna.

From foods f to food intake (purple to red in Figure 1). The quantity of a food is either eaten or discarded as avoidable waste in retail, households and food away from home. The remainder is the intake quantity, which enters the food aggregate composite dishes together with the other foods belonging to it.

Supplementary Table 4 provides a complete list of the linkages along the quantity flow as explained above for the example of lasagna.

Supplementary Table 4: Links between market-balance aggregates, meat partitioning, market balance products, processes, ingredients, foods and food aggregates along the quantity flow as visualised in Figure 1.

See Excel file.

2.3 Data sources

Supplementary Information 2: Datasets for initialisation

Quantities of market-balance aggregates available for human consumption in Germany are taken from the CAPRI database, which draws on official statistics and harmonises across years and countries (BMEL, 2023; CAPRI Consortium, 2022b; Eurostat, 2026; FAOSTAT, 2026). In these market balances, quantities

126 available for human consumption are calculated as the difference between available quantities, i.e., from
127 production and imports, on the one hand, and other uses such as animal feed, biofuel production, industrial
128 uses, and exports, on the other hand. Trade data includes processed products as equivalents in market-
129 balance products. Any data error in quantities available for human consumption can, therefore, stem from
130 errors in other market balance items or miscalculations of equivalents. However, by using the market-
131 balance quantities provided by the CAPRI database rather than the quantities provided directly, e.g., by the
132 German Federal Ministry for Agriculture and Food, FAOSTAT, or Eurostat (BMEL, 2023; Eurostat, 2026;
133 FAOSTAT, 2026), some errors have already been accounted for. The CAPRI model processes global market
134 balances from FAOSTAT and Eurostat to generate a globally consistent and complete database in which,
135 e.g., global trade balance flows are consistent and plausible (CAPRI Consortium, 2022b).

136 We use 2006 data to match the year of the food intake survey. We use the same categorisation as the CAPRI
137 model to facilitate linking the quantity flow to the model in future research (CAPRI Consortium, 2022a). We
138 use quantities for 44 market balance aggregates (e.g., beef, wheat, rapeseed oil). The three remaining
139 market balance aggregates (water, other meat and other products) captured in the quantity flow are not
140 initialised with statistical data (see Figure 1).

141 **Meat partitioning shares:** Since the market balance reports meat in carcass weight, we collect data on the
142 proportions of different meat parts per carcass for beef (Branscheid, 1998b; Ender & Augustini, 1998;
143 Papstein et al., 1995), pork (Branscheid, 1998b; Höreth, 1995; von Lengerken et al., 1998), sheep and goat
144 (Branscheid, 1998b) and poultry (Branscheid, 1998b; Pingel et al., 1998; Ristic et al., 1995). We differentiate
145 17 meat parts (including muscle, fat tissue, liver, kidney, tongue, heart, blood, and giblets) across 8 animal
146 species (beef, veal, pork, sheep, chicken, turkey, duck, and goose). See Supplementary Information 3 for full
147 details of the calculation and Supplementary Table 5 for the prior values of meat partitioning proportions
148 in the format kg of beef muscle per kg of beef carcass weight.

149 **Non-avoidable waste shares** (inedible parts such as peels, pits, and cores that are removed before
150 consumption or processing) and **avoidable waste shares** (edible food discarded in retail, food service, and
151 households) are taken from Vanham et al. (2015) and complemented with data from Kranert et al. (2012).
152 An important boundary condition is that the market-balance quantities available for human consumption
153 are already net of losses occurring on the farm, during transport and market handling and are, therefore,
154 not modelled in the quantity flow. The quantity flow thus starts at the point where food reaches the
155 consumption stage, and the only waste we model explicitly is that occurring from this point onward. We do
156 not differentiate where the waste occurs; instead, we differentiate between non-avoidable and avoidable
157 waste, capturing all settings in which waste occurs (e.g., retail, household, restaurants, and other out-of-
158 home consumption venues). Shares of non-avoidable waste are assigned to market-balance products.
159 Shares of avoidable waste are assigned to foods, because they are defined as completely edible. To avoid
160 double-counting, no waste shares are assigned to ingredients. Any losses of those are captured by the
161 avoidable waste share of the corresponding food. See Supplementary Information 4 for more details of the
162 derivation of waste shares.

163 **Processing yield factors and recipes** are taken from the Raw Primary Commodity (RPC) model developed
164 by the European Food Safety Authority (EFSA et al., 2019). The processing yield factors describe how much
165 of a market-balance product is used to derive one unit of an ingredient (e.g., processing wheat grain into
166 white wheat flour). The RPC model draws these factors from technical conversion factors published by the
167 FAO and others (Bergström, 1994; Bognár, 2002; FAO, 2000; USDA, 1992) and lists them in the conversion
168 table. The recipe data is based on the Mintel Global New Products Database (GNPD) and the website

169 www.allrecipes.com (Dotdash Meredith publishing family, 2024; Mintel, 2023). For the quantity flow, we
170 use the quantities of ingredients needed to produce one unit of a food (e.g., g of apples for 100 g of apple
171 strudel), listed in the disaggregation table of the RPC model. Whenever not already included in the recipe
172 data from the RPC model, we add weight changes associated with the final preparation of food items (e.g.,
173 water evaporation during baking the apple strudel) (FSANZ, 2020). Modelling processing and recipes
174 separately in the quantity flow allows us to capture the different origins of the data and account for
175 potential differences in errors and biases in the data.

176 The RPC model uses the classification system FoodEx, which is the predecessor of the FoodEx2 system in
177 which the food intake data is classified (see below). While other recipe databases are available, the RPC
178 model is the only one in the FoodEx or FoodEx2 classification system. This makes it the recipe database best
179 compatible with the food intake data, allowing us to avoid introducing errors and vagueness by matching
180 different food classifications to each other. See Supplementary Information 5 for a discussion of the other
181 recipe databases considered and Supplementary Information 6 on how the recipes from the RPC model
182 were prepared for use in the quantity flow.

183 **Per-capita intake quantities** of the 945 foods are taken from the German National Nutrition Survey II
184 (NVSII), conducted in 2006 among 13,926 randomly selected participants aged 14 to 80, representative of
185 the German-speaking population. The NVSII is the most recent representative German intake survey. Mean
186 intake quantities and standard deviations are given for four age groups: adolescents (14-17), adults (18-64),
187 elderly (65-75) and very elderly (older than 75). We use the 24-hour recall data that is freely available on
188 EFSA's comprehensive food consumption database (Brombach et al., 2006; EFSA, 2023; Krems et al., 2006).
189 Because we model the quantity flow at the national level and per year, we aggregate the per-capita per-day
190 intake quantities, accounting for the different intake patterns in the age groups and their share in the
191 German population of 2006 (Destatis, 2025). For children below 14 that are not represented in the intake
192 survey, we assume intake patterns similar to the adolescents' but with lower quantities. We use the
193 standard deviations of food intake for adults and scale them from per capita, per day in g to annual, national
194 level in tonnes.

195 Misreporting is a well-known issue in intake surveys, including the NVSII (Heuer et al., 2015; Krems et al.,
196 2012). Survey participants tend to underreport intake of socially stigmatised foods, like sweets, and overall
197 energy intake (Heuer et al., 2015; Krems et al., 2012).

198

199 **Supplementary Information 3: Meat partitioning proportions.**

200 For meat, the market-balance quantities of the market balance aggregates are given in carcass weight.
201 Therefore, we account for the proportions of the different meat parts, e.g., muscle meat in beef carcass
202 weight. We differentiate for all meat parts mentioned as ingredients in the recipes for the foods named in
203 the intake survey. In the recipe data, there is no differentiation between different types of muscle meat.
204 Therefore, also in the meat partitioning proportions, we do not differentiate between muscle meat from
205 different parts of the animal. Following the ingredients mentioned in the recipe data leads to a subdivision
206 of the market balance aggregates "beef" into beef and veal and "poultry" into chicken, turkey, duck and
207 goose. We collect data from literature on the carcass weight of the animal and of the weight of the meat
208 parts and cross-check the plausibility of the proportions against different sources: For beef (Branscheid,
209 1998b; Ender & Augustini, 1998; Papstein et al., 1995), pork (Branscheid, 1998b; Höreth, 1995; von
210 Lengerken et al., 1998), sheep and goat (Branscheid, 1998b) and poultry (Branscheid, 1998b; Pingel et al.,

1998; Ristic et al., 1995). By dividing the weight of the meat part (e.g., veal muscle meat) by the carcass weight (e.g., of veal), we derive the proportions of the meat parts shown in Supplementary Table 5.

We accounted for the different definitions of carcass weight per animal, i.e., which animal parts are removed before and thus not included in the carcass weight, e.g., beef tail, pork tongue (Branscheid, 1998a). Because we calculate the proportions of the different meat parts per carcass weight, including the parts that are not part of the carcass weight definition, the sum of the proportions can be larger than one. This is the case for beef and pork. Also, when not all parts of the carcass weight are edible or are not observed in the recipes of the foods mentioned in the intake survey, the sum of the proportions can be smaller than one. This is the case for veal, sheep and goat, and all poultry.

Therefore, we initialise the proportions of the meat parts in the animal, e.g., muscle meat in the beef carcass. In the consolidation, we allow for the possibility that this data is not perfectly representative or is biased and thus allow for adjustments during the consolidation process. The adjustments are limited by the bounds and are included in the objective function, i.e., are subject to minimisation and penalised. In contrast, there is no initial data on the proportions of the different animals within the market balance aggregate, e.g., beef and veal in the aggregate “beef”.

Supplementary Table 5: Proportions of meat parts per animal species. Prior values.

	Beef		Sheep and goat Sheep	Pork Pork	Poultry			
	Beef	Veal			Chicken	Turkey	Duck	Goose
Muscle	0.5530	0.6070	0.6070	0.5483	0.6200	0.7100	0.5470	0.5400
Fat tissue	0.2670	0.2090		0.2657	0.0460	0.0460	0.0460	0.0460
Liver	0.0191	0.0293	0.0359	0.0190	0.0200	0.0200	0.0200	0.0200
Kidney	0.0033	0.0063	0.0200	0.0039				
Lungs	0.0088			0.0057				
Spleen	0.0031			0.0017				
Thymus		0.0063						
Tongue	0.0056	0.0055	0.0093	0.0057				
Heart	0.0069	0.0104	0.0138	0.0035				
Stomach	0.0510			0.0100				
Marrowbone	0.1620			0.1181				
Tail	0.0140							
Brain			0.0016	0.0016				
Blood	0.0558	0.0584	0.0678	0.0394				
Feet		0.0407		0.0111				
Skin				0.0730				
Giblet					0.0691	0.0485	0.1201	0.0828

Supplementary Information 4: Waste shares

The quantity flow starts with quantities available for human consumption at the market level. Losses at the field and on the market are already subtracted; hence, they do not fall within the borders of the quantity flow. However, waste in retail, households, restaurants or communal catering is still included in the market-balance quantities; thus, we account for these wasted quantities explicitly in the quantity flow. We differentiate between non-avoidable waste, e.g., inedible parts like vegetable peel or fruit pits, and avoidable waste, i.e., any waste of edible foods. We separately model non-avoidable waste quantities as shares of market-balance products in the quantity flow (e.g., the share of apples consisting of pits and stems) and avoidable waste as shares of foods (e.g., the wasted share of apple strudel or of the edible parts of apples).

238 The majority of the literature on food waste reports either absolute quantities of food waste, food waste as
 239 a share of total waste, or avoidable and non-avoidable food waste as shares in total food waste (Kranert et
 240 al., 2012). We derive shares of non-avoidable waste in market-balance products and shares of avoidable
 241 waste in foods mainly from Vanham et al. (2015). Vanham et al. partly build on FAO data (FAO, 2011) but
 242 differentiate between avoidable and non-avoidable waste. They employ a different differentiation between
 243 foods than the model; therefore, the market-balance products and foods employed in the quantity flow are
 244 mapped to the product groups utilised by Vanham et al. (2015). For the foods not covered in Vanham et al.
 245 (2015), such as composite dishes, we use additional literature, e.g. Kranert et al. (2012). For foods for which
 246 waste shares are not available in the literature, we combine absolute waste quantities from the literature
 247 together with the available quantities of foods to calculate shares of avoidable waste. For example, Figure
 248 12 of Kranert et al. (2012) shows that the quantity of wasted composite foods is roughly half of the quantity
 249 of wasted vegetables. Therefore, we calculate the share of avoidable waste in composite dishes (F_{CD}) by
 250 setting the absolute quantity of wasted composite dishes equal to half of the absolute quantity of wasted
 251 vegetables (F_{VEG}), following Supplementary Equation 1.

252
 253 **Supplementary Equation 1: Waste share calculation, exemplary for composite dishes.**

$$\sum_{f \in F_{CD}} \frac{aw_f^0}{1 + aw_f^0} * j_f^0 = 0.5 * \sum_{f \in F_{VEG}} \frac{aw_f^0}{1 + aw_f^0} * j_f^0$$

Parameter	
aw_f^0	Share of avoidable waste per food f
j_f^0	Intake quantities per year on national level in tonnes per food f
Sets	
$f \in F$	945 foods, for which mean intake quantities are reported in the intake survey.
$F_{CD} \subseteq F$	Foods belonging to the food aggregate “composite dishes”, subset of all foods F
$F_{VEG} \subseteq F$	Foods belonging to the food aggregate “vegetable products”, subset of all foods F

254
 255 **Supplementary Information 5: Choice of recipe database**

256 The recipe dataset is the largest dataset we use in the quantity flow. We chose the composition table from
 257 EFSA’s RPC model as the base for our recipe dataset, despite other recipe databases being available. We
 258 appreciate the benefits of these other databases, but making them usable in the quantity flow would have
 259 required substantial effort, which we deemed not worth it, given that every additional step of data
 260 preparation on our side may introduce additional errors and biases and make reproducibility more difficult.

261 In the following, we explain the criteria for choosing the recipe data for the specific purpose of using them
 262 in the quantity flow and describe how we weight the advantages and disadvantages of different datasets.

263 1. **Compatibility with other datasets:** The composition table of the RPC model categorises foods according
 264 to the FoodEx classification system. This ensures compatibility with other datasets used in the quantity
 265 flow: First, the intake survey, which is categorised in FoodEx’s successor, FoodEx2 and thus only requires
 266 manageable manual mapping (see Supplementary Information 6). Second, the dataset on energy
 267 content of the individual foods also follows FoodEx2. Using datasets with different classification systems
 268 always bears the risk of introducing inconsistencies. Third, the processing yield dataset, which is also
 269 taken from EFSA’s RPC model and categorised following FoodEx. For compatibility with the processing
 270 yield dataset, it is helpful that not only the foods of the recipe dataset are categorised in FoodEx2, but
 271 also the ingredients. Other recipe datasets do not have uniform ingredient naming and use different

names for the same ingredient (for example, some food composition lists in OpenFoodFacts name “Magerquark” as an ingredient, while others name “Quark, Magerstufe”). Making such a database operable for the quantity flow would require identifying and matching synonyms.

The FoodEx classification of the RPC model contains not only the foods mentioned in the German intake survey but also all foods reported in other intake surveys published in EFSA’s Comprehensive Food Consumption Database. Although these databases are not used in this application of the quantity flow to the German case, choosing databases with the FoodEx or FoodEx2 classification system makes transfer to other EU member states with intake surveys published in EFSA’s Comprehensive Food Consumption Database easy.

2. **Completeness in terms of foods:** The composition table of the RPC model covers all foods listed in the intake survey, i.e., including beverages, complex composite dishes, foods that are typically industrially manufactured as well as those typically home-made and accordingly combines different data sources (see Supplementary Information 2). Databases like OpenFoodFacts or Mintel GNPD only feature foods with back-of-package ingredient listings, i.e., only industrially manufactured foods. Recipe websites like allrecipes.com or chefkoch.de only feature home-made recipes. Capturing the full range of foods reported in the intake survey would require combining several of these databases, which is what the RPC model does with Mintel GNPD and allrecipes.com. At the same time, the quantity flow does not require the complexity provided by these databases. E.g., OpenFoodFacts reports 11 recipes for “Käsekuchen” (i.e., the German word for cheesecake); chefkoch.de provides 4,349. Making these databases operable would require condensing these recipes into one representative recipe first, which in turn requires assumptions on how to weigh the different recipes in a representative average.
3. **Completeness in terms of ingredients:** The quantity flow is built on the logical framework in which all quantities available for human consumption at the market level are accounted for. For this, it is critical that the databases we use are also complete in the sense that they account for all ingredients in reliable quantities. This criterion disqualified, for example, OpenFoodFacts. Here, all ingredients are listed, but not necessarily correctly quantified. In some cases, minor ingredients, like starches or skimmed milk powder, are listed without absolute quantities (e.g., “<2%”) and consequently, the quantities of ingredients do not add up to 100% (OpenFoodFacts, 2017). In other cases, the quantities are implausible (e.g., 100 ml of Coca-Cola consisting of 60% water and 18% sugar while the nutrition facts report 10.6 g of sugars per 100 ml) (OpenFoodFacts, 2015).
4. **Public access:** To keep the option of making the quantity flow open access in the future and allow for others to reproduce our findings, we gave priority to using publicly available data. This disqualified proprietary databases like Mintel GNPD.
5. **Ready-to-use format:** Additional aspects we considered were the format in which the data was provided. The composition table of EFSA’s RPC model is a downloadable Excel file that can be read into GAMS without further data preparation, i.e., reducing the risk of introducing errors and reducing barriers to reproduction by other researchers later. Further, we gave preference to databases in English to facilitate access for non-German-speaking researchers, which limits the use of German recipe websites, such as chefkoch.de.

Supplementary Information 6: Preparation of recipe database

The recipe database is prepared based on the composition table of EFSA’s RPC model (EFSA et al., 2019). It uses the FoodEx classification, which is the predecessor of the FoodEx2 classification used to categorise the intake survey. Consequently, to make the recipe database and intake data compatible, it is necessary to

317 match FoodEx and FoodEx2. Only around 20% of the foods named in the German intake surveys have the
 318 same name in FoodEx and FoodEx2 (e.g., “spelt grain”). Another 20% of FoodEx names have direct
 319 equivalents to FoodEx2 names (e.g., “wheat grain, durum” and “durum wheat grain”) that are listed in the
 320 RPC model’s conversion table. In around 10% of cases, the newer FoodEx2 name is a broader aggregate
 321 than the FoodEx names (e.g., “milkshakes” in FoodEx2 and “chocolate milkshake” and “fruit milkshake” in
 322 FoodEx). Here, the probability table of the RPC model provides the composition of the broader aggregate.
 323 In 50% of the cases, the match is manually determined.

324 Further, the structure of the recipe database is adjusted to fit the requirements of the quantity flow, which
 325 is to link foods with ingredients. In the form provided by the RPC model, 100 g of the food “apple strudel”
 326 consists of 50 g puff pastry, 48 g apple compote, and 2 g dried vine fruits. Dried vine fruits are an ingredient
 327 in the terminology and logic of the quantity flow, but apple compote and puff pastry consist of several
 328 ingredients themselves. Hence, they are further broken down. 100 g of puff pastry consists of 29 g of butter,
 329 30 g of tap water, 40 g of white wheat flour and 1 g of salt. 100 g of apple compote consists of 96 g of apples
 330 and 4 g of white sugar (EFSA et al., 2019). Puff pastry loses 20% of its weight when baked; the final apple
 331 strudel loses another 11% (FSANZ, 2020). Consequently, the recipe for “apple strudel” is operationalised as
 332 the ingredient list in Supplementary Box 1.

333
 334 **Supplementary Box 1: Derivation of ingredient list for the exemplary food apple strudel.**

2.3 g dried vine fruits	Weight loss apple strudel $\frac{1}{1 - 0.11}$	Dried vine fruits in 100g of apple strudel ingredients 2 g		
20.4 g of butter	Weight loss apple strudel $\frac{1}{1 - 0.11}$	Share of puff pastry in apple strudel ingredients $\frac{50}{100}$	Weight loss puff pastry $\frac{1}{1 - 0.20}$	Butter in 100 g puff pastry ingredients 29 g
28.1 g of white wheat flour	Weight loss apple strudel $\frac{1}{1 - 0.11}$	Share of puff pastry in apple strudel ingredients $\frac{50}{100}$	Weight loss puff pastry $\frac{1}{1 - 0.20}$	White wheat flour in 100 g puff pastry ingredients 40 g
	Weight loss apple strudel $\frac{1}{1 - 0.11}$	Share of puff pastry in apple strudel ingredients $\frac{50}{100}$	Weight loss puff pastry $\frac{1}{1 - 0.20}$	Tap water in 100 g puff pastry ingredients 30 g
	Weight loss apple strudel	Share of puff pastry in apple strudel ingredients	Weight loss puff pastry	Salt in 100 g puff pastry ingredients

	$\frac{1}{1 - 0.11}$	$\frac{50}{100}$	$\frac{1}{1 - 0.20}$	1 g
51.8 g of apples	Weight loss apple strudel $\frac{1}{1 - 0.11}$	Share of apple compote in apple strudel ingredients $\frac{48}{100}$		Apples in 100 g apple compote ingredients 96 g
2.2 g of white sugar	Weight loss apple strudel $\frac{1}{1 - 0.11}$	Share of apple compote in apple strudel ingredients $\frac{48}{100}$		White sugar in 100 g apple compote ingredients 4 g

The RPC model from EFSA, from which we derive the recipes, disaggregates the ingredient list even further, e.g., butter to milk, white wheat flour to wheat grain, white sugar to sugar beet and sugar cane and dried vine fruits into table grapes (EFSA et al., 2019). For two reasons, we do not copy this disaggregation. Firstly, some processes are already accounted for in the market-balance quantities that we use. For example, the market-balance quantities report quantities of sugar (not sugar beet or sugar cane) and butter (not milk). We choose to reflect the processing steps when possible in the market-balance quantities because, there, coupled processes can also be reflected; for example, that fresh milk is used for producing butter and whey together. Calculating with the milk equivalents from the recipe data would lead to inaccurate requirements of fresh milk. Secondly, when this first processing step is not reflected in the market balance, we include it as a separate step in the logical framework of the quantity flow. Even though we take both the recipes and the processing yields from EFSA's RPC model, the recipes and the processing yields are derived from different data sources. We want to account for this and capture the adjustments to both datasets in the consolidation separately. This is only possible when we explicitly model processing yields and recipes as two separate steps, instead of combining them into one recipe dataset.

2.4 Consolidation

Supplementary Information 7: Standard deviations and bounds.

The standard deviation of food intake is obtained together with the average per-capita intake quantities from the Comprehensive Food Consumption Database (EFSA, 2023) and multiplied by population and 365 to fit the annual, national scope of the quantity flow instead of the individual, daily scope of the food intake survey. The standard deviations for the market quantities are calculated based on market quantities for 1996-2016.

For the remaining datasets (waste, recipe, processing, and meat partitioning, not energy and macronutrient contents of foods), repeated observations are unavailable, so we set the standard deviation to $\pm 10\%$ of the prior value, an approach similarly employed in Gocht & Röder (2014). This is an assumption about prior precision rather than measured dispersion.

For all datasets reporting shares or coefficients (i.e., avoidable and non-avoidable waste, meat partitioning, processing yields, recipes), the maximum deviations from the prior value are set to $\pm 20\%$. Only plant oils in

363 recipes are an exception. The overall share of plant oils in a recipe must adhere to the $\pm 20\%$ bounds, but
 364 the composition of the different plant oils (e.g., olive oil and sunflower seed oil) may vary more strongly.
 365 Further, shares (e.g., avoidable waste) cannot be larger than 1. If a prior value indicates a weight loss in
 366 processing, it cannot become a weight gain in the consolidation, and vice versa. Market balance and food
 367 intake quantities can increase tenfold. Market-balance quantities can decrease to zero; food intake
 368 quantities can decrease to 10% of their prior value. Negative values are not allowed.

369
 370 **Supplementary Information 8: Penalisation in objective function**

371 The objective function measures total adjustments of all datasets combined (Equation 2). These total
 372 adjustments are minimised during consolidation, i.e., the formulation of the objective function determines
 373 the penalties associated with the deviations from the prior values.

374 The additional Chen-Mangasarian penalty, included as $C_{k,e}(x_{k,e})$ in Equation 1, is given in full in
 375 Supplementary Equation 2.

376
 377 **Supplementary Equation 2: Chen-Mangasarian penalty.**

$$C_{k,e}(x_{k,e}) = \varepsilon^2 \left(\ln \left(1 + e^{\frac{\tau_k x_{k,e}^0 - x_{k,e}}{\varepsilon x_{k,e}^0}} \right) \right)^2 + \varepsilon^2 \left(\ln \left(1 + e^{\frac{x_{k,e} - \bar{\tau}_k x_{k,e}^0}{\varepsilon x_{k,e}^0}} \right) \right)^2$$

Function	
$C_{k,e}(x_{k,e})$	Chen-Mangasarian swan-neck function. Part of the objective function (Equation 1).
Variables	
$x_{k,e}$	Consolidated value of data point e in dataset k . Decision variable.
Parameter	
$x_{k,e}^0$	Prior value of entry e in dataset k , taken from the dataset.
$\underline{\tau}_k, \bar{\tau}_k$	Lower and upper threshold factors for dataset k , expressed as multiples of the prior. Beyond the thresholds, the additional Chen-Mangasarian penalty applies.
ε	Chen-Mangasarian smoothing factor. $\varepsilon = 0.001$
Index	
$k \in K = \{q, c, nw, y, r, aw, j\}$	Set of the seven datasets used to initialise the quantity flow.
Sets	
$e \in E_k$	Set of data entries in dataset k .

378 For improved clarity, Supplementary Equation 3 formulates the objective function (Equation 2) in detailed
 379 form.

$$TotalAdj(x_{k,e}) =$$

$$\begin{aligned}
& \omega_q \gamma_q \sum_{am \in AM_{bal}} \left[\left(\frac{q_{am} - q_{am}^0}{\sigma_{q,am}^0} \right)^2 + \varepsilon^2 \left(\ln \left(1 + e^{\frac{\tau_q q_{am}^0 - q_{am}}{\varepsilon q_{am}^0}} \right) \right)^2 + \varepsilon^2 \left(\ln \left(1 + e^{\frac{q_{am} - \bar{\tau}_q q_{am}^0}{\varepsilon q_{am}^0}} \right) \right)^2 \right] \\
& + \omega_c \gamma_c \sum_{\substack{m \in M_{meat} \\ d \in D \\ am \in AM_{meat}}} \left[\left(\frac{c_{m,d,am} - c_{m,d,am}^0}{\sigma_{c,m,d,am}^0} \right)^2 + \varepsilon^2 \left(\ln \left(1 + e^{\frac{\tau_c c_{m,d,am}^0 - c_{m,d,am}}{\varepsilon c_{m,d,am}^0}} \right) \right)^2 + \varepsilon^2 \left(\ln \left(1 + e^{\frac{c_{m,d,am} - \bar{\tau}_c c_{m,d,am}^0}{\varepsilon c_{m,d,am}^0}} \right) \right)^2 \right] \\
& + \omega_{nw} \gamma_{nw} \sum_{m \in M} \left[\left(\frac{nw_m - nw_m^0}{\sigma_{nw,m}^0} \right)^2 + \varepsilon^2 \left(\ln \left(1 + e^{\frac{\tau_{nw} nw_m^0 - nw_m}{\varepsilon nw_m^0}} \right) \right)^2 + \varepsilon^2 \left(\ln \left(1 + e^{\frac{nw_m - \bar{\tau}_{nw} nw_m^0}{\varepsilon nw_m^0}} \right) \right)^2 \right] \\
& + \omega_y \gamma_y \sum_{\substack{m \in M \\ p \in P_{chg} \\ i \in I}} \left[\left(\frac{y_{m,p,i} - y_{m,p,i}^0}{\sigma_{y,m,p,i}^0} \right)^2 + \varepsilon^2 \left(\ln \left(1 + e^{\frac{\tau_y y_{m,p,i}^0 - y_{m,p,i}}{\varepsilon y_{m,p,i}^0}} \right) \right)^2 + \varepsilon^2 \left(\ln \left(1 + e^{\frac{y_{m,p,i} - \bar{\tau}_y y_{m,p,i}^0}{\varepsilon y_{m,p,i}^0}} \right) \right)^2 \right] \\
& + \omega_r \gamma_r \sum_{\substack{f \in F_{comp} \\ i \in I}} \left[\left(\frac{r_{f,i} - r_{f,i}^0}{\sigma_{r,f,i}^0} \right)^2 + \varepsilon^2 \left(\ln \left(1 + e^{\frac{\tau_r r_{f,i}^0 - r_{f,i}}{\varepsilon r_{f,i}^0}} \right) \right)^2 + \varepsilon^2 \left(\ln \left(1 + e^{\frac{r_{f,i} - \bar{\tau}_r r_{f,i}^0}{\varepsilon r_{f,i}^0}} \right) \right)^2 \right] \\
& + \omega_{aw} \gamma_{aw} \sum_{f \in F} \left[\left(\frac{aw_f - aw_f^0}{\sigma_{aw,f}^0} \right)^2 + \varepsilon^2 \left(\ln \left(1 + e^{\frac{\tau_{aw} aw_f^0 - aw_f}{\varepsilon aw_f^0}} \right) \right)^2 + \varepsilon^2 \left(\ln \left(1 + e^{\frac{aw_f - \bar{\tau}_{aw} aw_f^0}{\varepsilon aw_f^0}} \right) \right)^2 \right] \\
& + \omega_j \gamma_j \sum_{f \in F} \left[\left(\frac{j_f - j_f^0}{\sigma_{j,f}^0} \right)^2 + \varepsilon^2 \left(\ln \left(1 + e^{\frac{\tau_j j_f^0 - j_f}{\varepsilon j_f^0}} \right) \right)^2 + \varepsilon^2 \left(\ln \left(1 + e^{\frac{j_f - \bar{\tau}_j j_f^0}{\varepsilon j_f^0}} \right) \right)^2 \right]
\end{aligned}$$

where:

$$\begin{aligned}\underline{\beta}_q q_{am}^0 &\leq q_{am} \leq \overline{\beta}_q q_{am}^0 \\ \underline{\beta}_{nw} nw_m^0 &\leq nw_m \leq \overline{\beta}_{nw} nw_m^0 \\ \underline{\beta}_c c_{m,d,am}^0 &\leq c_{m,d,am} \leq \overline{\beta}_c c_{m,d,am}^0 \\ \underline{\beta}_y y_{m,p,i}^0 &\leq y_{m,p,i} \leq \overline{\beta}_y y_{m,p,i}^0 \\ \underline{\beta}_r r_{f,i}^0 &\leq r_{f,i} \leq \overline{\beta}_r r_{f,i}^0 \\ \underline{\beta}_{aw} aw_f^0 &\leq aw_f \leq \overline{\beta}_{aw} aw_f^0 \\ \underline{\beta}_j j_f^0 &\leq j_f \leq \overline{\beta}_j j_f^0\end{aligned}$$

Variables	
<i>TotalAdj</i>	Measure of adjustments across all data entries. Objective function minimised in the consolidation.
q_{am}	Consolidated value for market-balance quantity in 1,000 tonnes for market balance aggregates am, e.g., wheat. Decision variable.
$c_{m,d,am}$	Consolidated value for proportion of meat part (subset of m, e.g., veal muscle meat) per carcass weight for animal species d (e.g., veal) in meat market balance aggregate am (e.g., beef). Decision variable. Zero for all non-meat market-balance products m and non-meat market balance aggregates am.
nw_m	Consolidated value for share of non-avoidable waste in market-balance products m, e.g., peel and core of apples. Decision variable.
$y_{m,p,i}$	Consolidated value for reverse processing yield for process p, defining the quantity of a market-balance product m, e.g., common wheat grain, required to produce one unit of ingredient i, e.g., white wheat flour. Decision variable.
$r_{f,i}$	Consolidated value for recipe quantity per ingredient i, e.g., white wheat flour, required to produce food f, e.g., lasagna. Decision variable.
aw_f	Consolidated value for share of avoidable waste per food f, e.g., lasagna. Decision variable.
j_f	Consolidated value for intake quantity per year on national level in tonnes per food f, e.g., lasagna. Decision variable.
Parameter	
q_{am}^0	Market-balance quantity in 1,000 tonnes for market balance aggregate am, e.g., wheat (44 non-zero entries). Prior value.
$c_{m,d,am}^0$	Proportion of meat part (subset of m, e.g., veal muscle meat) per carcass weight for animal species d (e.g., veal) in meat market balance aggregate am (e.g., beef) (58 entries). Prior value. Zero for all non-meat market-balance products m and non-meat market balance aggregates am.
nw_m^0	Share of non-avoidable waste in market-balance product m, e.g., peel and core of apples (281 non-zero entries). Prior value.
$y_{m,p,i}^0$	Reverse processing yield for process p, defining the quantity of a market-balance product m, e.g., common wheat grain, required to produce one unit of ingredient i, e.g., white wheat flour (758 non-zero entries). Prior value.
$r_{f,i}^0$	Recipe quantity per ingredient i, e.g., white wheat flour, required to produce food f, e.g., lasagna (4,398 non-zero entries). Prior value.
aw_f^0	Share of avoidable waste per food f, e.g., lasagna (936 non-zero entries). Prior value.
j_f^0	Intake quantity per year on national level in tonnes per food f, e.g., lasagna (945 non-zero entries). Prior value.
$\sigma_{q,am}^0$	Standard deviation of the market-balance quantities of market-balance aggregate am.
$\sigma_{c,m,d,am}^0$	Standard deviation of the meat partitioning shares.
$\sigma_{nw,m}^0$	Standard deviation of the shares of non-avoidable waste of market-balance product m.
$\sigma_{y,m,p,i}^0$	Standard deviation of the reverse processing yields.
$\sigma_{r,f,i}^0$	Standard deviation of the recipes.

$\sigma_{aw,f}^0$	Standard deviation of the shares of avoidable waste of food f.
$\sigma_{j,f}^0$	Standard deviation of the intake quantity of food f.
γ_q	Correction term for the market-balance quantities.
γ_c	Correction term for the meat partitioning shares.
γ_{nw}	Correction term for the shares of non-avoidable waste.
γ_y	Correction term for the reverse processing yields.
γ_r	Correction term for the recipes.
γ_{aw}	Correction term for the shares of avoidable waste.
γ_j	Correction term for the food intake quantities.
ω_q	Weight for the market-balance quantities.
ω_c	Weight for the meat partitioning shares.
ω_{nw}	Weight for the shares of non-avoidable waste.
ω_y	Weight for the reverse processing yields.
ω_r	Weight for the recipes.
ω_{aw}	Weight for the shares of avoidable waste.
ω_j	Weight for the food intake quantities.
$\underline{\tau}_q, \overline{\tau}_q$	Lower and upper threshold factors for the market-balance quantities.
$\underline{\tau}_c, \overline{\tau}_c$	Lower and upper threshold factors for the meat partitioning shares.
$\underline{\tau}_{nw}, \overline{\tau}_{nw}$	Lower and upper threshold factors for the shares of non-avoidable waste.
$\underline{\tau}_y, \overline{\tau}_y$	Lower and upper threshold factors for the reverse processing yields.
$\underline{\tau}_r, \overline{\tau}_r$	Lower and upper threshold factors for the recipes.
$\underline{\tau}_{aw}, \overline{\tau}_{aw}$	Lower and upper threshold factors for the shares of avoidable waste.
$\underline{\tau}_j, \overline{\tau}_j$	Lower and upper threshold factors for the food intake quantities.
$\underline{\beta}_q, \overline{\beta}_q$	Lower and upper bound factors for the market-balance quantities.
$\underline{\beta}_c, \overline{\beta}_c$	Lower and upper bound factors for the meat partitioning shares.
$\underline{\beta}_{nw}, \overline{\beta}_{nw}$	Lower and upper bound factors for the shares of non-avoidable waste.
$\underline{\beta}_y, \overline{\beta}_y$	Lower and upper bound factors for the reverse processing yields.
$\underline{\beta}_r, \overline{\beta}_r$	Lower and upper bound factors for the recipes.
$\underline{\beta}_{aw}, \overline{\beta}_{aw}$	Lower and upper bound factors for the shares of avoidable waste.
$\underline{\beta}_j, \overline{\beta}_j$	Lower and upper bound factors for the food intake quantities.
ε	Chen-Mangasarian smoothing factor. $\varepsilon = 0.001$.

Indices	
q	Indicates reference to market-balance quantities.
c	Indicates reference to meat partitioning.
nw	Indicates reference to non-avoidable waste shares.
y	Indicates reference to processing yields.
r	Indicates reference to recipes.
aw	Indicates reference to avoidable waste shares.
j	Indicates reference to food intake quantities.
Sets	
$am \in AM$	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 products are not part of AM_{bal}
$AM_{meat} \subseteq AM$	Four are meat market-balance aggregates, i.e., beef, pork, poultry, sheep and goat.
$m \in M$	426 market-balance products (e.g., common wheat grain). 58 are meat market-balance products (e.g., veal muscle meat).
$M_{meat} \subseteq M$	58 are meat market-balance products (e.g., veal muscle meat).
$d \in D$	8 animal species (e.g., veal).
$p \in P$	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).
$P_{chg} \subseteq P$	81 processes with a weight change or coupled processes. Generic processes like “unspecified” with processing yields of 1:1 are excluded.
$i \in I$	682 ingredients (e.g., white wheat flour) produced from a market-balance product m by one processing step p .
$f \in F$	945 foods, for which mean intake quantities are reported in the intake survey (e.g., apple strudel).
$F_{comp} \subseteq F$	466 foods which consist of several ingredients and/or are subject to weight changes in final processing. Foods consisting of one ingredient (e.g., apple) are excluded.

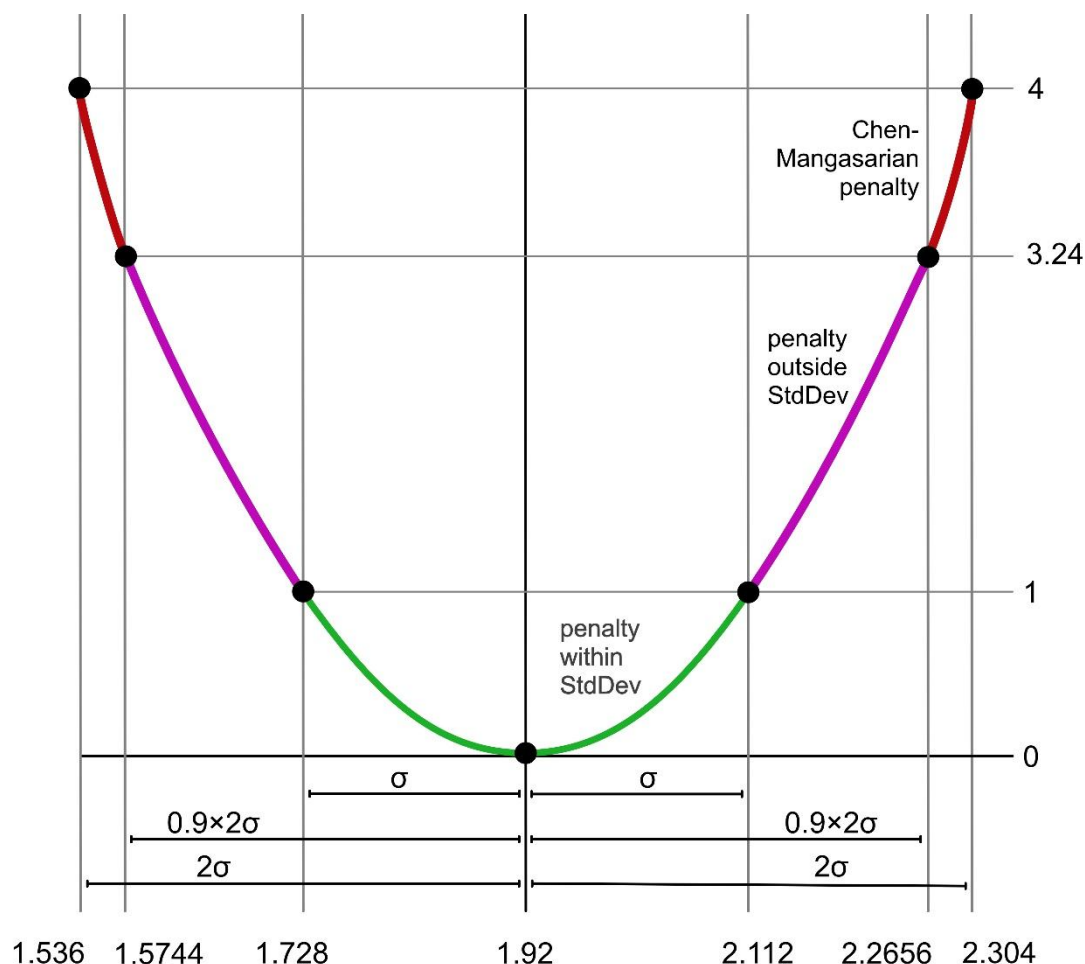
381

382

383 In the following, we explain the size of the penalty depending on the extent of the deviation from the prior
384 value for one exemplary data point. We show how we construct the objective function to achieve a
385 consistent quantity flow through many small adjustments to the prior data, rather than a few large
386 adjustments. As the structure in the objective function is the same for each data set, the explanations can
387 be transferred to other data points. Supplementary Figure 1 visualises the penalties for adjustments from
388 the prior value for the reverse processing yield for deep-frying potatoes, which is 1.92, i.e., 1.92 kg of fresh
389 potatoes are required to produce 1 kg of deep-fried potatoes, e.g. French fries. We set the bounds at $\pm 20\%$
390 ($\pm 2\sigma$), meaning that the variable for this data point can vary between 1.536 and 2.304. The standard
391 deviation σ is, therefore, $\pm 10\%$. In the first part of the objective function, the adjustment in comparison to
392 the prior value is divided by the standard deviation and then squared. Hence, if the adjustment is larger
393 than the standard deviation, this fraction is larger than one, and squaring will increase the term, penalising
394 adjustments exceeding the standard deviation more than those staying within. The penalty applied to
395 adjustments within the standard deviation, i.e., values between 1.728 and 2.112, is moderate, as depicted
396 by the green part of Supplementary Figure 1. When the adjustments correspond exactly to the standard
397 deviation, i.e., when the variable takes the value of 1.728 or 2.112, the penalty is one. Following the squared
398 term, adjustments outside the standard deviation are penalised more (red part of Supplementary Figure 1).

399 At 90% of the allowed variation, i.e., 1.5744 and 2.2656, the penalty is 3.24. When a variable gets close to
400 the bounds, i.e., exceeding 90% of the allowed variation, the additional Chen-Mangasarian (swan-neck)
401 penalty is applied (purple part of Supplementary Figure 1), culminating in a penalty of 4.0004 when the
402 variable hits the bounds (at 1.536 or 2.304).

403



Supplementary Figure 1: Visualisation of penalising deviations from an exemplary data point, reverse processing yield of deep frying potatoes, prior=1.92.

Supplementary Information 9: Scaling intake from per capita to total, national level

The intake survey reports average per capita per day intake quantities, differentiated by age groups. Because the quantity flow consolidation is conducted at the national level and for annual quantities, we scale the quantities correspondingly. While the temporal scaling (from daily to annual quantities) is trivial, scaling from individual to national level requires accounting for population structure.

The Comprehensive Food Consumption Database (CFCD) provides information differentiated between six age groups: infants, toddlers, other children, adolescents, adults, elderly, and very elderly (EFSA, 2023). See Supplementary Table 6 for age borders of the groups. The intake survey utilised in the consolidation, the NVSII, features participants between the ages of 14 and 80, which corresponds to the full inclusion of the age groups adults and elderly, and the partial inclusion of the age groups of adolescents (age 10-18, only 14-18 included in the NVSII) and very elderly (over 75 years, only 75-80 included). Following the population statistics for Germany in 2006 (Destatis, 2025), these groups accounted for the following shares of the total population, as shown in Supplementary Table 6.

423 **Supplementary Table 6: Age distribution in Germany in 2006 (Destatis, 2025)**

Age in years	Age groups in the CFCD (EFSA, 2023)	Share in total population
0-1	Infants	0.8%
1-3	Toddlers	1.7%
3-10	Other children	6.5%
10-18	Adolescents	8.3%
10-14	Excluded from NVSII	3.9%
14-18	Included in NVSII	4.4%
18-65	Adults	62.9%
65-75	Elderly	11.5%
Over 75	Very elderly	8.3%
75-80	Included in NVSII	3.7%
80-100	Excluded from NVSII	4.6%
Total population		82,267,000

424

425 The age-specific energy needs, as presented in Supplementary Table 7, were used to calculate intake
 426 quantities of food items for the age groups not or not fully included in the NVSII. Several assumptions were
 427 made to calculate total intake quantities at the national level based on intake quantities per capita per age
 428 group.

- 429 1. We assume that the intake of the partially represented group (75-80) of the very elderly in NVSII is
 430 representative of the whole group of the very elderly (75+). Hence, the 75-80-year-olds in the NVSII
 431 are assumed to eat the same quantities and follow the same dietary patterns as anyone older than
 432 80.
- 433 2. We assume that the 10-14-year-old adolescents eat 20% less than the 14-18-year-old adolescents,
 434 but otherwise follow the same dietary patterns.
- 435 3. We assume that the group of children (ages 0 to 9) consumes 55.96% of what the 10-18-year-olds
 436 consume (scaled according to energy need as shown in Supplementary Table 7), but otherwise
 437 follows the same dietary patterns.

438 This way, we derive food intake quantities also for the age groups not or not fully included in the NVSII.
 439 Weighting the group-specific intake quantities according to their share in the total population
 440 (Supplementary Table 6), we calculate total national-level intake quantities.

441

442 **Supplementary Table 7: Energy need in Germany in 2005 for average physical activity in kcal per capita**
 443 **per day.**

444 **Data provided by Marco Springmann (UCL).**

Age in years	0-9	10-19	20-39	40-64	20-64*	65+	All ages
Energy need	1373.37	2454.38	2531.86	2334.20	2482.77*	2069.16	2259.37

*Own calculations as weighted average for age group 20-64.

445

446 The consolidation is conducted at the national level, i.e. capturing intake in tonnes per food per year for the
 447 whole population in Germany. We use the information on age group differences reported in the food intake
 448 survey to calculate this national aggregate from the prior values for the consolidation and use them to derive
 449 age-group-specific intake quantities for the consolidated values.

2.5 Updating the food intake quantities

Supplementary Information 10: Updating food intake quantities to 2025.

When updating the food intake quantities to 2025, we set a constraint for the average energy intake for adults to be within $\pm 3\%$ of 2,819 kcal per capita per day (data provided by Maria Schubring and Marco Springmann, UCL). With the quantity flow, we estimate a total, national-level food intake that is consistent with the 2025 market-balance quantities (Section 2.5) and an average per capita food intake that is consistent with this energy intake constraint. As in the consolidation, we hold the relative differences in intake of one food between age groups stable. For example, we found in the intake survey that the average adolescent eats 2.33 times as much chocolate spread as the average across all age groups, and we keep this proportion for the consolidated as well as the updated food intake patterns. However, consolidation and updating lead to heterogeneous adjustments in the intake of different foods. Therefore, the proportions of energy intake between the age groups in the consolidated and updated data differ from the energy intake reported in the survey.

To calculate the per capita intake from the national total intake, we use 2025 population numbers.

Supplementary Equation 4 is the detailed formulation of the objective function minimised in the updating of the food intake quantities from 2006 to 2025 (Equation 3).

Supplementary Equation 4: Detailed formulation of the updating objective function (Equation 3).

$IntakeAdj(j_f) =$

$$\sum_{f \in F} \left[\hat{j}_f \left(\frac{j_f - \hat{j}_f}{\sigma_{j,f}^0} \right)^2 + \theta \left(\left(\frac{\tau_j \hat{j}_f - j_f}{\hat{j}_f} - \frac{\varepsilon \hat{j}_f \ln \left(1 + e^{\frac{\tau_j \hat{j}_f - j_f}{\varepsilon \hat{j}_f}} \right)}{\hat{j}_f} \right)^2 + \left(\frac{j_f - \frac{\hat{j}_f}{\tau_j}}{\hat{j}_f} - \frac{\varepsilon \hat{j}_f \ln \left(1 + e^{\frac{j_f - \frac{\hat{j}_f}{\tau_j}}{\varepsilon \hat{j}_f}} \right)}{\hat{j}_f} \right)^2 \right) \right]$$

where: $\beta_j \hat{j}_f \leq j_f \leq \bar{\beta}_j \hat{j}_f$

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.
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.
$\sigma_{j,f}^0$	Standard deviation of the intake quantity of food f , upscaled to national annual level, based on the standard deviations reported in the intake survey.
$\beta_j, \bar{\beta}_j$	Lower and upper bound factors for food intake, expressed as multiples of the consolidated 2006 intake quantities $\hat{j}_f$. Enforced as bounds on the decision variable.
θ	Weight on the Chen-Mangasarian function, $\theta = 20$.
$\tau_j, \bar{\tau}_j$	Lower and upper threshold factors for intake quantities, expressed as multiples of the consolidated 2006 intake quantities $\hat{j}_f$. Beyond the thresholds, the additional Chen-Mangasarian penalty applies.
ε	Chen-Mangasarian smoothing factor. $\varepsilon = 0.001$.
Index	
j	Indicates reference to food intake quantities.
Sets	
$f \in F$	945 foods, for which mean intake quantities are reported in the intake survey.

469 3 Results

470 3.1 Problem 1: Many foods consist of multiple agricultural products. Quantifying intake 471 through ingredients.

472
473 **Supplementary Figure 2: Intake quantities per capita per day in grams for 15 ingredient aggregates.**
474 **Extension of Figure 2.**

475 See the Excel file.

476

477 3.2 Problem 2: Misreporting. What did people really eat in 2006?

478 3.2.1 What the adjustments reveal

479 **Supplementary Information 11: Details and visualisation of the adjustments.**

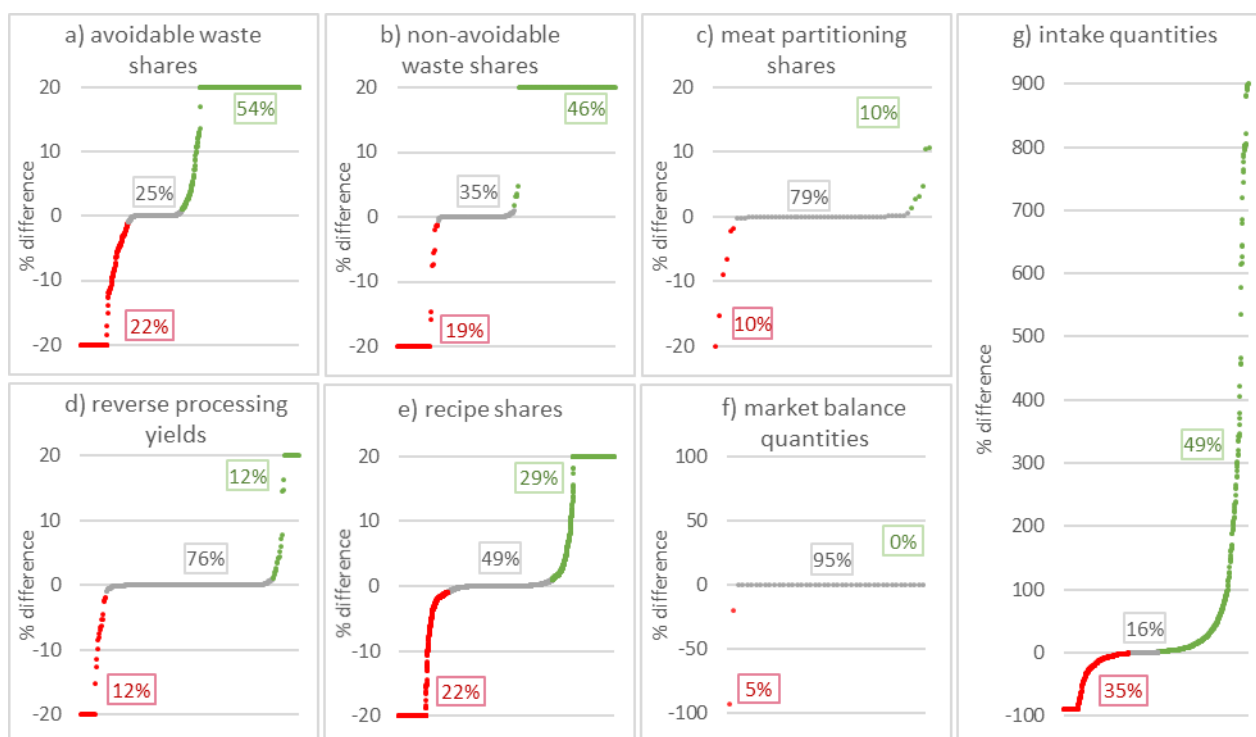
480 Supplementary Figure 3 shows the adjustments relative to the prior value of the respective data point. Each
481 panel plots all data points of a given dataset sorted from most negative to most positive adjustment, with
482 the size of the adjustments on the y-axis. Each grey dot marks the relative difference between its prior and
483 its consolidated value. Several patterns emerge.

484 The swan-neck shape is clearly visible. A substantial share of the data points cluster near zero, with a smooth
485 increase in the size of adjustments as one moves toward the tails, and few data points reaching the
486 maximum bound. This is the expected signature of the objective function's design: penalising large
487 adjustments disproportionately more than small ones encourages the consolidation to spread the required
488 corrections across many small adjustments rather than concentrating them in a few large ones. The
489 sensitivity analysis in Supplementary Information 12 examines in detail how the spread of adjustments
490 responds to alternative parameterisations.

491 As determined by the model parameterisation, market-balance quantities (Supplementary Figure 3f) are
492 adjusted least: 95% of data points show no or negligible change (−1% to +1%), and only 2 out of 44
493 commodities are adjusted to a meaningful extent. The aggregates of market-balance products that do
494 require adjustments, whey powder and sheep and goat meat, are cases where it was not possible to achieve
495 consistency in the quantity flow through adjustments to the other six datasets. For whey powder, the recipe
496 database contains too few entries for whey-containing foods to permit sufficient upward adjustment; the
497 market-balance quantity is therefore reduced slightly. Whey powder is an ingredient typically used in
498 industrial manufacturing of processed and composite foods, seldom present in home-made dishes. Its near
499 absence in the recipe data points to a bias towards homemade recipes. This bias is also reflected in the
500 overrepresentation of premium or aspirational ingredients that we identified in preliminary consolidation
501 runs. The more expensive olive oil is overrepresented in the recipe data at the expense of rapeseed and
502 sunflower seed oil. The same applies to beef relative to pork and chicken. To address this, we adjusted the
503 recipe data to feature oil and meat mixes in proportions consistent with the market balance composition
504 before running the final consolidation.

505 For intake quantities and waste shares, increases clearly dominate decreases. 54% of avoidable waste data
506 points are adjusted upward and only 22% downward (Supplementary Figure 3a). Non-avoidable waste

507 shows a similar pattern (46% upward vs 19% downward, Supplementary Figure 3b). For intake quantities,
 508 49% are adjusted upward, and 35% are adjusted downward (up to the bound of -90%), with substantially
 509 larger increases (up to the bound of +900%; Supplementary Figure 3g). This asymmetry reflects the
 510 widespread underreporting: because prior intake quantities are systematically too low to account for the
 511 market-balance quantities, the consolidation adjusts intake and avoidable waste strongly upward for many
 512 foods, with waste being another outlet for the market-balance products too abundant to match the intake
 513 quantities of foods containing them. Processing yields, meat partitioning shares, and recipes show more
 514 balanced distributions of increases and decreases, reflecting errors that are less systematic (Supplementary
 515 Figure 3c,d,e).



516
 517 **Supplementary Figure 3: Distribution of adjustments in the consolidation for each of the seven datasets.**
 518 **Each data point of a given dataset is plotted as a dot, sorted from most negative to most positive**
 519 **adjustment (% deviation from prior). Note that y-axis scales differ across panels. Red dots: decreases**
 520 **below -1%, grey dots: negligible change [-1%;1%], green dots: increases above +1%.**

521 3.2.4 Quality check and sensitivity of consolidation to parameterisation

522 Supplementary Information 12: Sensitivity analysis

523 The consolidation delivers a single best-fitting set of values rather than a range: we do not report
 524 uncertainty intervals around the consolidated values. The sensitivity analysis addresses this by varying the
 525 parameterisation of the bounds of the five structural variables (proportions of meat partitioning, shares of
 526 non-avoidable waste, processing yields, recipes and shares of avoidable waste) and the relative weights in
 527 the objective function, i.e., the only two parameters deliberately chosen rather than based on external data.

528 Though set deliberately, too, we do not vary the bounds for intake and market-balance quantities. While
 529 the bounds for the structural variables β_k for $k \in \{c, nw, y, r, aw\}$ are set at $\pm 20\%$, the bounds for
 530 intake and market-balance quantities are already wide ($\underline{\beta}_j = 0.1$ and $\overline{\beta}_j = 10$; $\underline{\beta}_q = 0$ and $\overline{\beta}_q = 10$). Due
 531 to the non-negativity constraint, widening the lower bound is not meaningful. Widening the upper bounds

would not affect market-balance quantities, as their adjustments stay well within the default bounds. Widening the upper bounds for intake would risk making results less plausible, given that the upper bound is already high at +900%. Tightening the bounds, however, would impact feasibility: Despite additional penalties for large deviations through the Chen-Mangasarian term, these large deviations are necessary for some foods and some market balance aggregates to achieve consistency.

In the following, we compare five parameterisation setups:

- Default parameterisation: Bounds: $\beta_k = \pm 20\%$ for $k \in \{c, nw, y, r, aw\}$, weights: $\omega_q = 10,000$; $\omega_j = 0.0001$
- Tight bounds: Bounds: $\beta_k = \pm 10\%$ for $k \in \{c, nw, y, r, aw\}$, weights: $\omega_q = 10,000$; $\omega_j = 0.0001$
- Loose bounds: Bounds: $\beta_k = \pm 30\%$ for $k \in \{c, nw, y, r, aw\}$, weights: $\omega_q = 10,000$; $\omega_j = 0.0001$
- Low weight difference: Default bounds: $\beta_k = \pm 20\%$ for $k \in \{c, nw, y, r, aw\}$, weights: $\omega_q = 100$; $\omega_j = 0.01$
- No weight difference: Default bounds: $\beta_k = \pm 20\%$ for $k \in \{c, nw, y, r, aw\}$, weights: $\omega_q = \omega_j = 1$

We assess the impact of varying the parameterisation, first, on the consistency of the consolidation, second, on the spread, and third, on the correlation between prior and consolidated values. In the following, we present the analysis on which the overall assessment captured in Table 6 is based.

Consistency of the consolidation

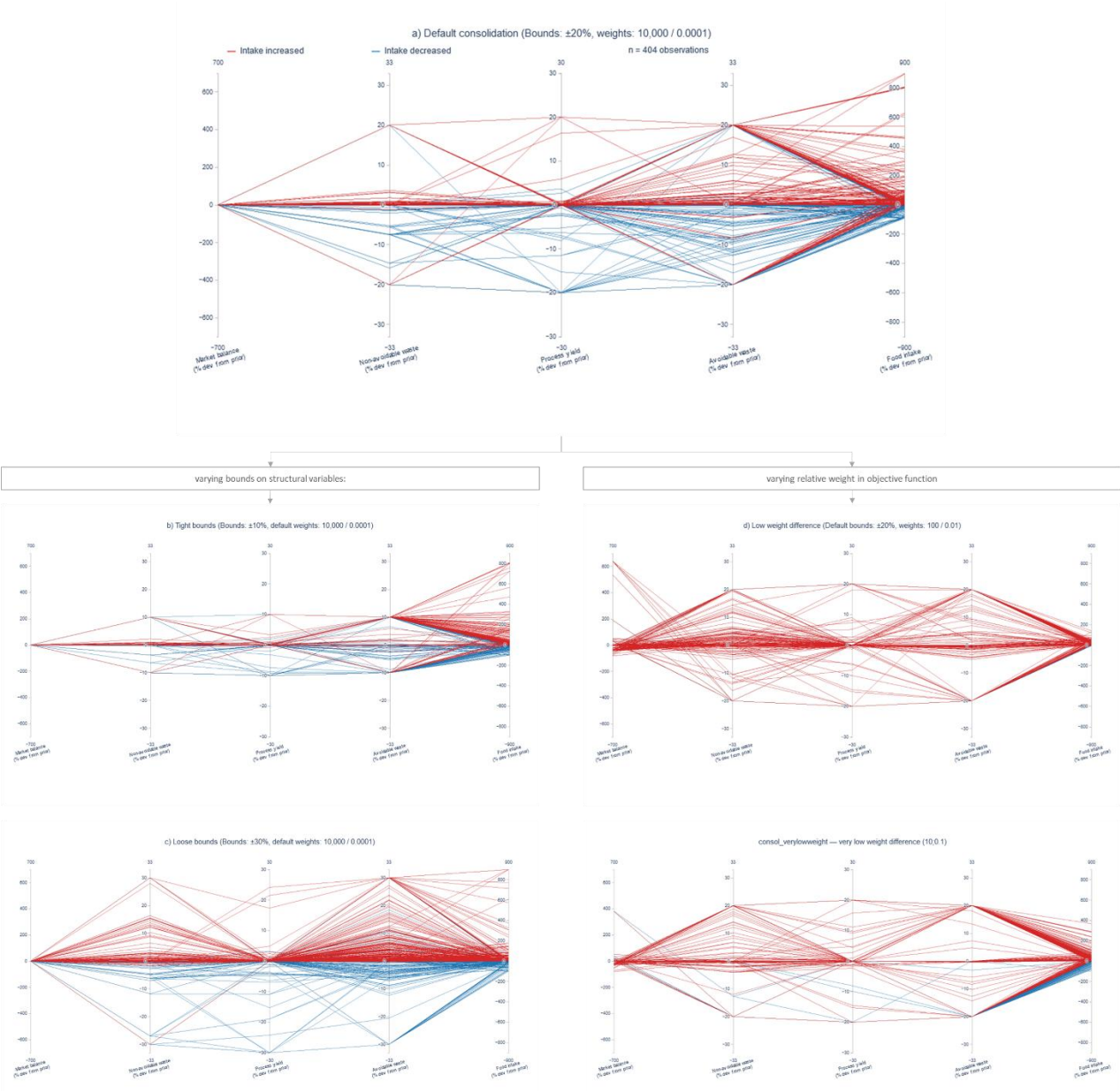
To assess the consistency of the consolidation, we restrict the analysis to the 404 foods that consist of a single ingredient which is not from a coupled process, e.g., shrimp or apple compote. We exclude foods like lasagna from this analysis, because multiple simultaneous mismatches between the market-balance products and intake quantities make it impossible to isolate the driver. For the single-ingredient foods, all variables should adjust in the same direction: if the apple market balance is too small to accommodate reported apple intake, then intake of apple compote, waste shares, and processing yields (i.e., apples needed to produce 100 g of apple compote) should all decrease together.

Supplementary Figure 4 shows the adjustments across all five consolidation scenarios. Each line represents one of the 404 single-ingredient foods. Red lines represent foods with upward-adjusted intake; blue lines represent downward-adjusted intake. A perfectly consistent consolidation would show all red lines above zero and all blue lines below zero for all variables. However, most foods in the quantity flow consist of more than one ingredient, so data mismatches across ingredients and foods are linked and spillovers exist. A perfect division between all-positive and all-negative adjustments is implausible, because the foods depicted here are linked to the composite foods by shared ingredients (e.g., apple compote is a one-ingredient food consisting only of apples, but the composite food apple strudel also uses apple as an ingredient).

In the default parameterisation (Supplementary Figure 4a), 156 of the 404 foods showed consistent adjustments, i.e., adjustments are either all ≤ 0 or all ≥ 0 across all five variables (depicted as red lines all above and blue lines all below 0). Changing the bounds decreases consistency. With tighter bounds, 32 foods show consistent adjustments; with looser bounds, it is 45 (Supplementary Figure 4b and c).

When the weight difference between market balance and intake is reduced (Supplementary Figure 4d and e), the consolidation resolves overreporting by increasing market-balance quantities rather than decreasing intake as in the default parameterisation. This produces an implausible result: only 12 out of the 404 foods

are identified as overreported, i.e., almost all adjustments of the food intake quantities are positive, depicted by red lines in Supplementary Figure 4d. For both scenarios with reduced weight difference, only one food shows consistent adjustments across all five variables.



Supplementary Figure 4: Parallel coordinate plots showing relative adjustments (% deviation from prior) across five datasets for 404 single-ingredient foods. Red lines: foods with upward-adjusted intake. Blue lines: foods with downward-adjusted intake. Top panel: baseline consolidation ($\pm 20\%$ bounds, weights 10,000:0.0001). Left column, below: bound sensitivity ($\pm 10\%$ and $\pm 30\%$). Right column, below: weight sensitivity (weights 100:0.01 and equal weights 1:1).

584 Spread of the adjustments

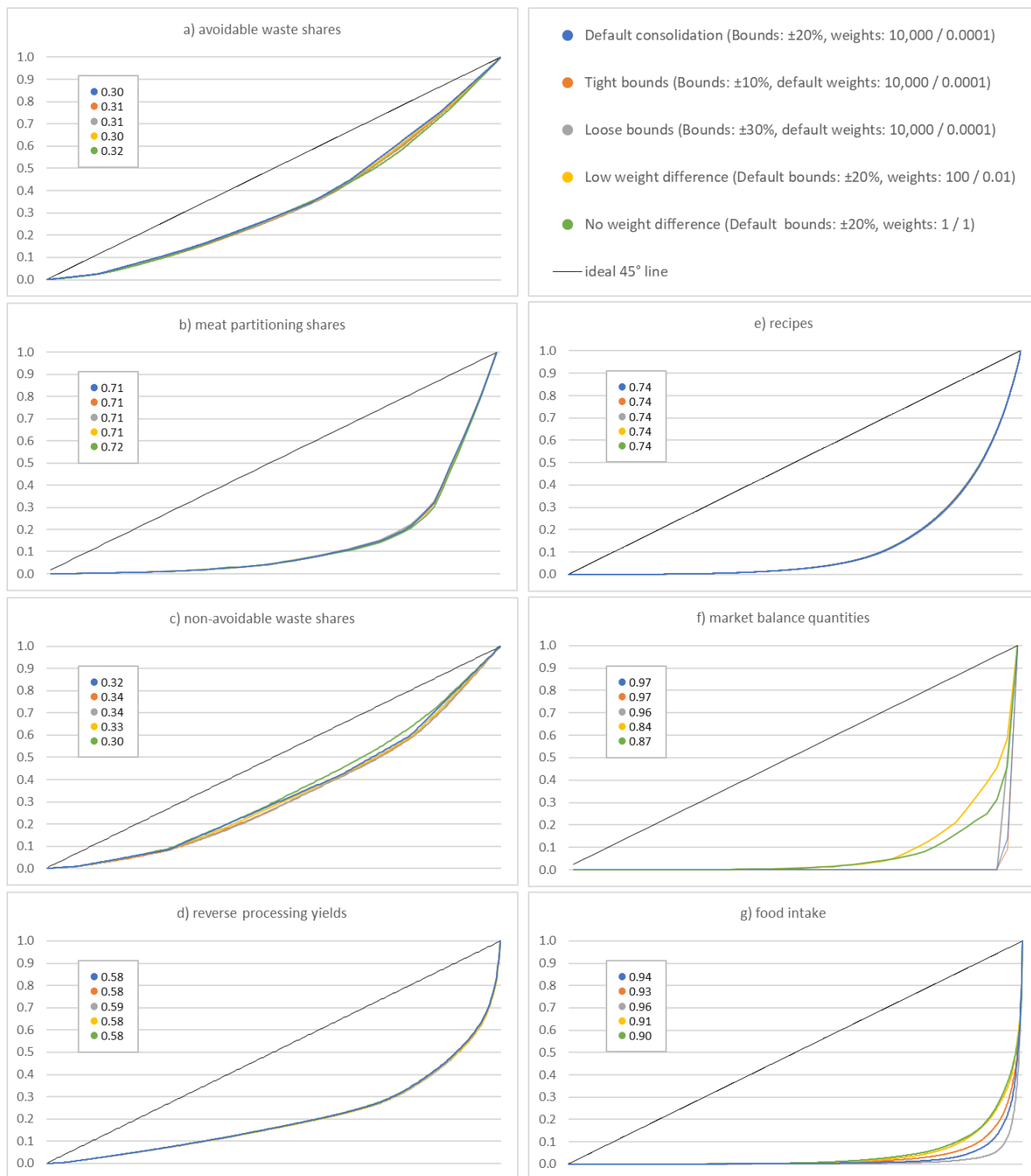
585 To assess the spread of the adjustments, i.e., whether the model setup achieved consistency through many
586 small instead of a few large adjustments, we depict the absolute adjustments for each parameterisation
587 and each dataset as Lorenz curves (Supplementary Figure 5). Curves closer to the 45° line correspond to
588 more equally distributed adjustments. The Gini coefficients reported for each dataset quantify this: a
589 coefficient of 0 indicates perfectly equal distribution; 1 indicates complete concentration in a single data
590 point and no adjustment of any other data point in this dataset.

591 Across the different parameterisations, the adjustments are more equally distributed for the structural
592 variables (the most for the waste shares (Supplementary Figure 5a and c)), while the adjustments for intake
593 quantities and market-balance quantities (Supplementary Figure 5f and g) are more unequal. This can be
594 explained by the model setup and the differences in data types. The structural variables have tighter bounds
595 than the market balance and intake quantities, i.e., the variation of adjustments is limited through this
596 parameterisation choice. While the structural variables describe shares or coefficients, the market balance
597 and intake data represent absolute quantities, which have a consequently larger variation in the prior values
598 (market balance (per year): from 3,000 tonnes (whey powder) to 7 million tonnes (fresh milk products);
599 intake (in g per capita per day): from 5E-6 g (stock cubes) to 395 g (coffee beverages)), resulting in a larger
600 variation potential in terms of absolute adjustments. Further, the high concentration in market balance
601 reflects its anchor role. Almost all data points are held at their prior values, and only the quantities of a few
602 market-balance products are adjusted.

603 The adjustment spread of the structural variable is robust to the parameterisation and hardly changes if the
604 bounds or the weighting are varied (Supplementary Figure 5a-e). The effect of varying the bounds on the
605 adjustment distribution of food intake and market-balance quantities is also minor (Supplementary Figure
606 5f and g). Tightening the bounds of the structural variables to $\pm 10\%$ makes the adjustments of food intake
607 quantities slightly more similar in magnitude (orange curve compared to blue in Supplementary Figure 5g).
608 The opposite happens when loosening the bounds of the structural variables to $\pm 30\%$ (grey curve compared
609 to blue in Supplementary Figure 5g).

610 Decreasing the difference in weight in the objective function, i.e., decreasing the penalty on adjustments of
611 market-balance quantities relative to those in food intake, leads to more adjustments in market-balance
612 quantities (yellow and green curves in Supplementary Figure 5f). In the default parameterisation (blue),
613 only for two market-balance products, quantities are adjusted. Consequently, more adjustments in the
614 scenarios with lower weight differences mean a more equal distribution. The opposite applies for food
615 intake. In the default parameterisation, consistency of the quantity flow was foremost achieved through
616 large adjustments of food intake quantities. The change in weight makes adjusting food intake more costly,
617 while making market balance adjustments cheaper. Therefore, some of the substantial adjustments in the
618 default parameterisation are reduced, and the distribution of adjustments in intake is more equal (yellow
619 and green curves in Supplementary Figure 5g). However, as noted above, this comes at the cost of foregoing
620 the market balance anchor.

621



Supplementary Figure 5: Lorenz curves for the distribution of absolute adjustments across datasets and consolidation scenarios.

Gini coefficients in the inset legends.

Correlation between prior and consolidated values

We assess the correlation between prior and consolidated values by calculating the Spearman correlation coefficient for each dataset and for each aggregate within the dataset separately. Supplementary Table 8

shows high correlation above 0.94 in every dataset for the default parameterisation. Correlation coefficients below 0.90 are flagged in light yellow; coefficients below 0.80 are flagged in dark yellow.

The correlation within the aggregates of the datasets is also mostly above 0.90. Within the food intake dataset, the lowest sub-group correlations are for products for non-standard diets (0.71), isolated ingredients (0.75) and fats & oils (0.78), indicating that the consolidation makes the largest rearrangements within these groups relative to the prior survey. The lower correlations within the food intake dataset reflect the lower penalty on intake adjustments in the objective function; it is, thus, by design and matches the unequal distribution identified in Supplementary Figure 5. The interpretation of the correlation coefficients of the avoidable waste sub-aggregates warrants a brief note: low correlation coefficients reflect the limited variation in the prior waste shares, i.e., within the dairy aggregate and the aggregate for fats and oils.

Tightening the bounds slightly increases the correlation of the structural variables at the cost of the correlation of and within the food intake quantities, which is still acceptable at 0.87 (see full Supplementary Table 8 in the Excel file).

Correlations of and within the food intake quantities are highest when the weight difference in the objective function (Equation 2) is reduced. Decreasing the relative weight difference means decreasing the incentive for the model to achieve consistency predominantly through intake adjustments and forgo adjustments of other datasets. Consequently, very large intake adjustments that lower the correlation between prior and consolidated intake quantities can be avoided, and more, smaller adjustments can be made to the other datasets, resulting in higher correlation coefficients.

All correlation coefficients remain within an acceptable range across all consolidation runs, confirming that the baseline parameterisation does not introduce unreasonable distortions relative to the prior data.

651

a) Default consolidation (Bounds: $\pm 20\%$, weights: 10,000 / 0.0001)

	recipes	food intake	avoidable waste ¹		market balance	processing	non-avoidable waste ¹		meat partitioning
full dataset	0.9991	0.9591	0.9564	full dataset	0.9999	0.9929	0.9471	full dataset	0.9985
	4398	945	936		44	758	281		58
Fruit products	0.9973	0.9760	NA ¹	Oilseed	1.0000	1.0000	NA ¹	Beef	0.9987
	173	85	85		2	5	2		21
Dairy products	0.9994	0.9842	0.7361	Cereals	1.0000	0.9804	NA ³	Sheep and goat	1.0000
	166	75	75		6	71	0		7
Egg products	0.9969	0.9762	NA ¹	Other crops	1.0000	0.9979	NA ¹		1.0000
	18	8	8		2	27	7	Pork	14
Alcoholic beverages	0.9985	0.9420	NA ¹	Vegetables and fruit	1.0000	0.9941	0.8432	Poultry	0.9778
	169	41	41		8	414	165		16
Products for non-standard diets	0.9978	0.7143	0.9290	Coffee, cocoa, tea	1.0000	0.9570	NA ³		
	28	8	8		3	11	0		
Coffee, cocoa, tea	0.9943	0.9538	NA ¹	Meat	1.0000	0.9980	NA ³		
	50	25	25		4	55	0		
Composite dishes	0.9981	0.9108	NA ¹	Eggs	NA ¹	1.0000	NA ¹		
	994	61	61		1	7	1		
Fish products	0.9994	0.8988	NA ¹	Fish and aquatic products	1.0000	0.9615	NA ¹		
	117	65	65		3	69	42		
Juice products	0.9970	0.9515	NA ¹	Dairy products	1.0000	NA ²	0.4312		
	62	25	25		8	75	57		

Grain products	0.9987 936	0.9651 137	NA ¹ 137
Legumes, nuts, seeds	0.9996 83	0.8977 59	NA ¹ 59
Meat products	0.9983 658	0.9574 94	NA ¹ 88
Sauces	0.9984 438	0.9646 46	NA ¹ 46
Starchy root products	1.0000 10	0.9500 9	NA ¹ 9
Sugar products	0.9979 201	0.9443 39	NA ¹ 39
Vegetable products	1.0000 145	0.9970 114	NA ¹ 114
Beverages	0.9980 69	1.0000 18	NA ¹ 15
Fats & oils	0.9999 72	0.7828 29	0.3292 29
Isolated ingredients	1.0000 9	0.7500 7	NA ¹ 7

Oils	1.0000 5	NA ² 7	NA ³ 7
Secondary products	1.0000 2	0.9941 17	NA ³ 0

¹ NA because the prior value is the same for all items in the category (by assumption in avoidable and non-avoidable waste)

² Processing of dairy products and oil is part of the CAPRI model and was therefore not included in the data consolidation.

³ NA because prior and consolidated values are zero.

Supplementary Table 8: Spearman correlation coefficients for each dataset and subset in the default consolidation parameterisation.

For the full Supplementary Table 8 with the other parameterisation setups, see the Excel file.

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

Supplementary Table 9: Market-balance quantities in consolidated 2006 and simulated 2025, in 1,000 tonnes.

See the Excel file.

Supplementary Figure 6: Co-intake of ingredients in the 2006 consolidated diet and changes in co-intake from 2006 to 2025. Absolute quantities and percentage changes for 2025. Supplement to Figure 6.

See the Excel file.

Supplementary Figure 7: Co-intake of ingredients in the 2006 consolidated diet and changes in co-intake from 2006 to 2025, per market balance aggregate. Supplement to Figure 6.

See the Excel file.

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