Supplementary Information

Optimised diets for improving human, animal, and environmental health in the Rhine-Ruhr Metropolis in Germany

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S1. Demographic data

Suppl. Table 1. Demographic characteristics of the study population

Variable	Categories	Frequencies/ mean values
Gender	Female	76.9%
	Male	23.1%
Age	25% percentile 32 y 50% percentile 44 y 75% percentile 56 y	Mean 44.8 y ± 1.2
Education	Secondary education or lower	6.56%
	Higher education entrance qualification (*Abitur*)	27.32%
	Advanced technical college	2.19%
	Graduation or higher (Bachelor, Master, Doctorate)	63.39%
	Not responded	0.55%
Marital status	Married	46.99%
	Single	27.32%
	Living with a partner or in an official civil partnership	19.67%
	Divorced	5.46%
	Not responded	0.55%
Nationality	German nationality	89.07%
	German with other nationality	4.37%
	European nationality	2.19%
	Other nationality	3.28%
	Undeclared	1.09%
Monthly median income (PPP Int$)	25% percentile $ 3,190.01 50% percentile $ 4,299.58 75% percentile $ 5,963.58	Mean $ 5,956.14 ± 370.32
Location	**Rhine-Ruhr Metropolis**	**92.97%**
	Ruhrgebiet	70.81%
	Bergisch Triangle	0.54%
	Cologne/Bonn	2.16%
	Düsseldorf	2.70%
	Ennepe-Ruhr-Kreis	3.24%

	Kreis Mettmann	0.54%
	Kreis Recklinghausen	5.95%
	Kreis Unna	3.24%
	Kreis Viersen	0.54%
	Kreis Wesel	1.08%
	Märkischer Kreis	1.62%
	Rheinisch-Bergischer Kreis	0.54%
	outside Rhine-Ruhr Metropolis	**4.32%**
	Not within a metropolis	**1.08%**
	Not responded	1.62%

Note: mean values at 95% Confidence Interval

S2. Dietary data

We classified the food items obtained from the EPIC FFQ according to EPICSOFT food group classification [1]. The raw data from the FFQ served to identify food item quantities within each food category. Food items were further reallocated to fit into the EFSA FoodEx classification [2] to match the food consumption foreground data with the food item LCA background data, as shown in **Suppl. Table 1.**

Suppl. Table 2. Mapping of food groups and subgroups from the EPICSOFT FFQ2 to EFSA (2018) database

EPICSOFT		EPIC FFQ2 questionnaire	Re-categorization & reallocation			Remarks
Group	**Subgroup**	**Food items**	**Group (EFSA)**	**Subgroup (EFSA)**	**Food items (EFSA)**	
alcoholic beverages	aniseed drinks (absinth)	-	alcoholic beverages	spirits	spirits	Reallocated to proxy "spirits"
	beer, cider	beer, wheat beer, strong beer	alcoholic beverages	beer and beer-like beverage	beer, regular	-
		light beer, low alcohol beer	alcoholic beverages	beer and beer-like beverage	beer and beer-like beverage	-
		malt beer, non-alcoholic beer	alcoholic beverages	beer and beer-like beverage	beer and beer-like beverage	Assumed as "beer"
	cocktails, punches	mixed drinks (e.g., cocktails, *Radler*, mulled wine and other wine-based drinks)	alcoholic beverages	alcoholic mixed drinks	spirits	Assumed as 1/3 spirit, 2/3 soft drink
	liqueurs	liqueur (e.g., amaretto, cream liqueur, egg liqueur, *Jenever*)	alcoholic beverages	liqueur	spirits	Reallocated to proxy "spirits"
	spirits, brandy	spirits (e.g., brandy, whiskey, grain, vodka, fruit liqueur, rum)	alcoholic beverages	spirits	spirits	-
	wine	red wine	alcoholic beverages	wine	wine, red	-
		white wine, rosé wine	alcoholic beverages	wine	wine, white	-
		sparkling wine, champagne, prosecco	alcoholic beverages	wine	wine, white	Assumed as "white wine"
cakes	cakes, pies, pastries, puddings	fruit cake	grains and grain-based products	fine bakery wares	pastries and cakes	Reallocated to proxy "pastries and cakes"
		cheesecake, cream or custard cake	grains and grain-based products	fine bakery wares	pastries and cakes	Reallocated to proxy "pastries and cakes"
		sponge cake (e.g., marble cake, cupcake, muffin)	grains and grain-based products	fine bakery wares	pastries and cakes	Reallocated to proxy "pastries and cakes"
	dry cakes, biscuits	biscuits (e.g., butter biscuits, cookies, double biscuits)	grains and grain-based products	fine bakery wares	biscuits	-

cereals	bread (1 slice), bun (1 piece)	whole-grain bread, rolls and toast bread	grains and grain-based products	bread and rolls	mixed wheat and rye bread and rolls	-
		grey bread, rye bread, spelt bread, mixed bread or rolls	grains and grain-based products	bread and rolls	rye bread and rolls	-
		wheat bread, rolls, baguette, toast, flatbread, pretzel pastries	grains and grain-based products	bread and rolls	wheat bread and rolls	-
		croissant, sliver roll	grains and grain-based products	fine bakery wares	pastries and cakes	Reallocated to proxy “pastries and cakes”
	breakfast cereals	muesli, cereals (e.g. cereal flakes, cereal meal, cornflakes, puffed rice)	grains and grain-based products	breakfast cereals	cereal flakes	-
	crisp bread, rusk	-	grains and grain-based products	bread and rolls	wheat bread and rolls	Assumed as “wheat bread and rolls”
	dough and pastry	egg pancakes, waffles	grains and grain-based products	grain milling products	wheat milling products	Assumed as “wheat milling products”
		pastries, cakes (e.g., cinnamon bun, filled cake)	grains and grain-based products	fine bakery wares	pastries and cakes	Reallocated to proxy “pastries and cakes”
	flour, flakes, starches, semolina	-	grains and grain-based products	grain milling products	wheat milling products	Allocated to food group “wheat milling products”. Rice and pasta are in the same FFQ question, making individual quantification impossible.
	pasta, rice, and other grain	rice, noodles, whole-grain pasta, pearl barley, cereals	grains and grain-based products	grain milling products	wheat milling products	
	salty biscuits, aperitif biscuits	salty biscuits, snacks (e.g., crisps, pretzels, salt sticks, crackers)	snacks, desserts, and other foods	snack food	pretzels	Assumed as “pretzels”
condiments, spices and flavourings	condiments	mustard	herbs, sauces and condiments	condiment	mustard, mild	-
		tomato ketchup, curry ketchup	herbs, spices and condiments	condiment	tomato ketchup	-
	dessert sauces	-	snacks, desserts, and other foods	ices and desserts	custard	Assumed as “custard”
	dressing sauces	salad dressings (diverse)	herbs, spices and condiments	dressing	dressing	-
	mayonnaise and similar	mayonnaise, tartar sauce	herbs, spices and condiments	dressing	mayonnaise, > 50% oil	-

	spices, herbs and flavourings	-	herbs, spices and condiments	spices	pepper, black and white	Assumed as “black pepper”
	tomato sauces	tomato sauce (made from fresh or canned tomatoes)	vegetables and vegetable products	savoury sauces	savoury sauces	Assumed as “savoury sauce”
	unclassified other sauces	-	herbs, spices and condiments	savoury sauces	savoury sauces	
dairy products	cheeses	soft cheese (e.g., Camembert, mozzarella, feta)	milk and dairy products	cheese	cheese, Camembert	Assumed as “Camembert”
		sour milk cheese (e.g., *Harz* cheese)	milk and dairy products	cheese	cheese	Put into the "cheese" group, as no proxy was identified.
		semi-hard cheese, hard cheese (e.g., *Gouda*, parmesan, *Emmental*)	milk and dairy products	cheese	cheese, *Gouda*	Assumed as “*Gouda”*
	cream desserts, puddings	desserts (e.g., ice cream, chocolate mousse, pudding, tiramisu, fruit curd, red fruit jelly)	snacks, desserts, and other foods	ices and desserts	ices and desserts	-
	dairy creams	whipped cream	milk and dairy products	cream and cream products	cream	-
		cream, crème Fraiche	milk and dairy products	cream and cream products	cream	-
	fromage blanc, petit Suisse’s	cream cheese, granular cream cheese	milk and dairy products	cheese	cheese, processed spreadable	-
		quark, herb quark	milk and dairy products	cheese	quark	-
	milk	milk	milk and dairy products	liquid milk	cow milk	-
	milk beverages	buttermilk	milk and dairy products	fermented milk products	buttermilk	-
		cocoa, milkshake, mixed milk drink	milk and dairy products	milk-based beverages	flavoured milk	-
	yoghurt	fruit yoghurt and flavoured yoghurt	milk and dairy products	fermented milk products	yoghurt, cow milk, plain	Assumed as “plain yoghurt”
		natural yoghurt, soured milk, kefir	milk and dairy products	fermented milk products	yoghurt, cow milk, plain	-
	milk for coffee creamer	as coffee/tea additions	milk and dairy products	concentrated milk	evaporated milk	-

egg and egg products	egg	egg, fried (e.g., omelette, fried or scrambled)	composite food	egg-based meal (e.g., omelette)	egg-based meal	-
		egg, cooked	eggs and egg products	eggs, fresh	chicken egg	-
oils and fats	butter	butter	animal and vegetable fats and oils	animal fat	butter	-
	deep frying fats	other vegetable oil	animal and vegetable fats and oils	vegetable oil	vegetable oil	-
	fat (unclassified)	animal cooking fat	animal and vegetable fats and oils	animal fat	butter	Assumed as “butter”
	margarine	margarine	animal and vegetable fats and oils	margarine and similar products	margarine, normal fat	-
	other animal fat	other fat-lard	animal and vegetable fats and oils	fats of mixed origin	fats of mixed origin	Reallocated to proxy “fats of mixed origin”
	vegetable oils	olive oil, rapeseed oil	animal and vegetable fats and oils	vegetable oil	vegetable oil	
fish and shellfish	fish	fish, fresh, canned (e.g., herring, tuna, salmon, Pollock, trout)	fish and other seafood	fish meat	salmon and trout	Assumed as “salmon and trout”
	fish products, fish in crumbs	fish dishes (e.g., fish fingers, gourmet fillets)	fish and other seafood	fish products	fish fingers	-
	crustaceans, molluscs	seafood (e.g., shrimps, squid, mussels)	fish and other seafood	crustaceans	shrimps	Assumed as “shrimps”
fruits	fruits	apple, pear	fruit and fruit products	pome fruits	apple	-
		orange, *Mandarine*	fruit and fruit products	citrus fruits	oranges	-
		kiwi, pineapple	fruit and fruit products	miscellaneous fruits	kiwi	-
		banana	fruit and fruit products	miscellaneous fruits	bananas	-
		fig, *physalis*, pomegranate	fruit and fruit products	miscellaneous fruits	fig	Item added
		cherries, plums, *Mirabelle*, apricot	fruit and fruit products	stone fruits	cherries	Item added
		grape	fruit and fruit products	berries and small fruits	grape	Item added

		peach, nectarine	fruit and fruit products	stone fruits	peaches	-
		soft fruit (strawberry, gooseberry, blueberry)	fruit and fruit products	berries and small fruits	strawberries	-
		melon	vegetables and vegetable products	fruiting vegetables	melons	-
		avocado	fruit and fruit products	oil fruits	avocado	Item added
	mixed fruits	fruit compote	fruit and fruit products	other fruit products	fruit compote	-
		fresh fruit salad	fruit and fruit products	fruit and fruit products	a mix of apples, oranges, and bananas (1:3)	Assumed as a mix of apples, oranges, and bananas (1:3)
		dried fruit	fruit and fruit products	dried fruits	dried fruits	Item added
	nuts and seeds	nuts, fresh, roasted, salted (including peanuts, almonds, pistachios, trail mix)	legumes, nuts and oilseeds	tree nuts	tree nuts	A blend of almonds, cashews, hazelnuts and walnuts
		seeds (e.g. sunflower or pumpkin seeds, linseeds)	legumes, nuts and oilseeds	oilseeds	sunflower seed	Assumed as “sunflower seed”
	olives	olives		oil fruits	olives	Item added
legumes	legumes	legumes (beans, peas, chickpeas, lentils)	legumes, nuts and oilseeds	legumes, beans, dried	lentils	-
		As an ingredient of vegetarian stew (e.g., vegetable, lentil, bean stew without meat); stew with meat (e.g., vegetable, lentil, bean stew with meat).	-	-	-	No identifiable individual intake quantified within other food groups
meat and meat products	beef	beef	meat and meat products	livestock meat	beef meat	-
	chicken, hen	poultry meat	meat and meat products	poultry	chicken meat	-
	game	veal, lamb, rabbit, game	meat and meat products	game mammals	red deer	Item added
	mutton, lamb	veal, lamb, rabbit, game	meat and meat products	livestock meat	mutton/lamb meat	-
	offal	offal (e.g., liver, kidney, stomach)	meat and meat products	edible offal farmed animals	pork liver	Item added
	other poultry	poultry meat	meat and meat products	poultry	turkey meat	-
	pork	pork	meat and meat products	livestock meat	pork/piglet meat	-

	processed meat	liver sausage	meat and meat products	sausages	sausages	Reallocated to major food category
		salami, pork sausage, *cabanossi*	meat and meat products	sausages	dry sausage	-
		meat sausage, ham sausage	meat and meat products	sausages	fresh and lightly cooked sausage	Reallocated to proxy
		poultry sausage	meat and meat products	sausages	fresh and lightly cooked sausage	Reallocated to proxy
		red sausage, black pudding, aspic, head cheese	meat and meat products	sausages	sausages	Reallocated to proxy
		raw ham, cooked ham	meat and meat products	preserved meat	ham, pork	-
		bratwurst (1 whole), liver loaf, meatloaf (1 slice)	meat and meat products	sausages	fresh and lightly cooked sausage	Assumed as "bratwurst" -fresh and lightly cooked sausage
		boiled sausage (*Wiener, Frankfurter, bock, knack, Weißwurst*)	meat and meat products	sausages	cooked smoked sausage	-
	rabbit (domestic)	veal, lamb, rabbit, game	meat and meat products	livestock meat	rabbit meat	Item added
	red meat (unclassified)	-	meat and meat products	meat and meat products (including edible offal)	meat and meat products (including edible offal)	-
	where meat was an ingredient (not possible to quantify individually), already quantified within several meat food groups	*Frikadelle*, *Boulette*	composite food	meat-based meals	meatballs	No identifiable individual intake quantified within other food groups
		delicatessen salad (e.g. meat, egg, herring, poultry salad)	-	-	-	
		stew with meat (e.g. vegetable, lentil, bean stew with meat)	composite food	meat-based meals	meat stew	
		meat-based dishes (e.g. casseroles, lasagne, pizza, kebab, filled puff pastry)	composite food	meat-based meals	meat-based meals	
	veal	veal, lamb, rabbit, game	meat and meat products	livestock meat	veal meat	-
miscellaneous	artificial sweeteners	as coffee/tea additions	-	-	-	Assumed as sugar

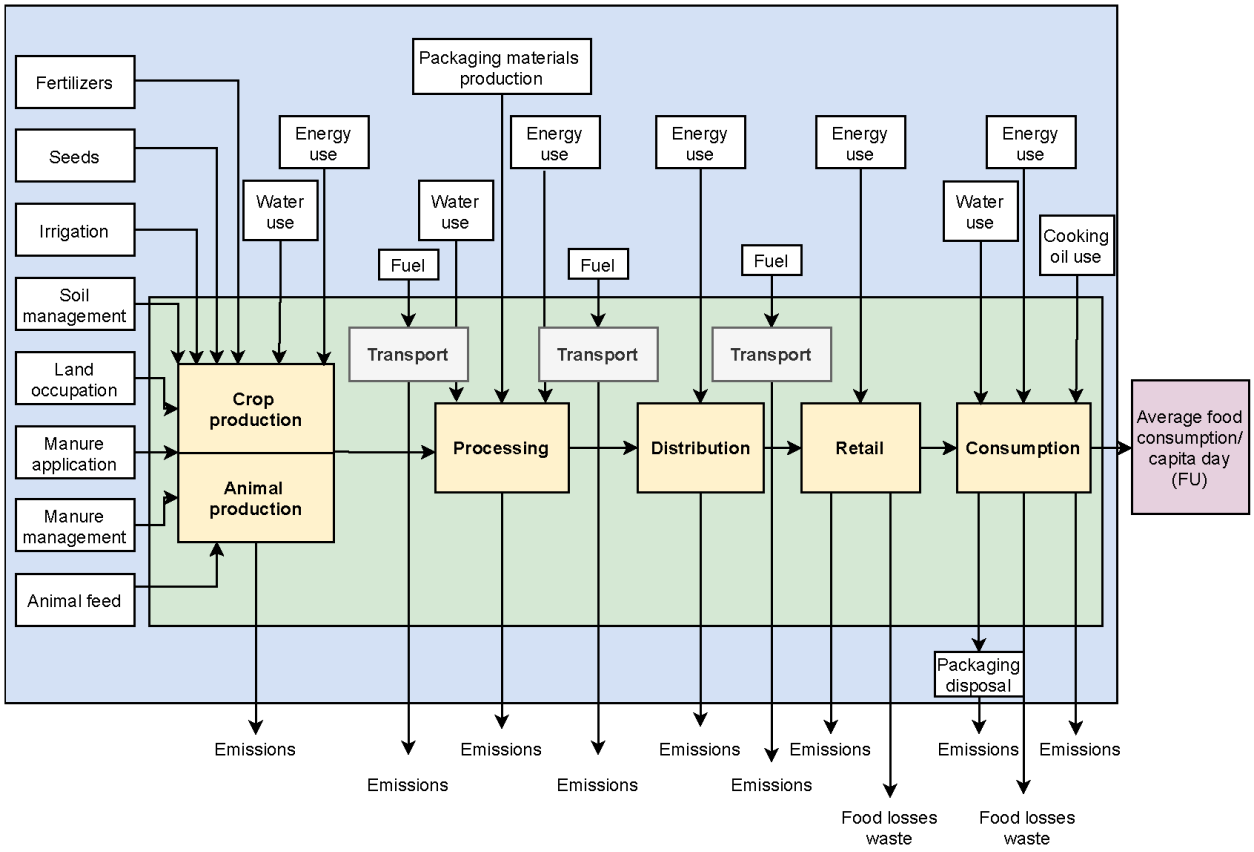
	miscellaneous (unclassified)	-	-	-	-	Assumed as unclassified sugars
	soya products	soymilk	animal protein substitutes		soymilk	Item added
		soy sauce			salt, iodised	Assumed as salt, iodised
		Tofu	animal protein substitutes		Tofu	Item added
	sweeteners unclassified	-	-	-	-	Assumed as unclassified sugars
non-alcoholic beverages	carbonated/soft/isotonic drinks	lemonade, cola	non-alcoholic beverages	soft drinks	soft drink, flavoured	-
		diet lemonade, diet cola	non-alcoholic beverages	soft drinks	soft drink, flavoured	Assumed as a soft drink
	chicory, substitutes	coffee without caffeine	non-alcoholic beverages	coffee (beverage)	decaffeinated coffee	Item added
	coffee	coffee, espresso (also cappuccino, café latte, then tick "with milk")	non-alcoholic beverages	coffee (beverage)	coffee	-
	fruit and vegetable juices	orange juice	fruit and vegetable juices	fruit juice	juice, orange	-
		apple juice	fruit and vegetable juices	fruit juice	juice, apple	-
		multivitamin juice	fruit and vegetable juices	fruit juice	fruit juice	Assumed as "fruit juice"
		other fruit juices	fruit and vegetable juices	fruit juice	fruit juice	Assumed as "fruit juice"
		vegetable juice	fruit and vegetable juices	vegetable juice	vegetable juice	-
	water	mineral water, tap water	drinking water	bottled water tap water	bottled water tap water	-
	tea	herbal tea	non-alcoholic beverages	tea (infusion)	herbal tea, infusion	-
		fruit tea, herbal tea	non-alcoholic beverages	tea (infusion)	herbal tea, infusion	Assumed as "herbal tea"
		tea, black or green	non-alcoholic beverages	tea (infusion)	black tea, infusion	-
	non-alcoholic beverages (unclassified)	-	non-alcoholic beverages	-	-	Assumed as tap water

potatoes and other tubers	potatoes	potato preparations (e.g., fried potatoes, French fries, potato pancakes, potato salad)	starchy roots and tubers	potatoes and potatoes products	potatoes and potatoes products	-
soups, bouillon	bouillon	clear soups (e.g., vegetable broth, noodle soup)	composite food	ready-to-eat soups	ready-to-eat soups	-
	soups	cream soups (e.g., from pumpkin, asparagus, broccoli)	composite food	ready-to-eat soups	vegetable/herb soup	-
sugar and confectionery	chocolate, candy bars, paste	chocolate, sweets with chocolate (e.g., chocolate bars, chocolates, dried fruits with chocolate coating)	sugar and confectionery	chocolate (cocoa) products	chocolate (cocoa) products	-
	confectionery non-chocolate	confectionery without chocolate (e.g., gummy bears, sweets, liquorice confectionery)	sugar and confectionery	confectionery (non-chocolate)	confectionery (non-chocolate)	-
	ice cream	inside "desserts (e.g., ice cream, chocolate mousse, pudding, tiramisu, fruit curd, red fruit jelly)"	snacks, desserts, and other foods	ices and desserts	ices and desserts	-
	sugar, honey, jam	jam, honey, sugar, syrup	sugar and confectionery	sugars	white sugar (proxy)	Reallocated to “white sugar”
	syrup	jam, honey, sugar, syrup	sugar and confectionery	molasses and other syrups	molasses and other syrups	-
	unclassified	-	sugar and confectionery	-	-	No identifiable intake or respective food item
vegetable	cabbages	sauerkraut	vegetables and vegetable products	Brassica vegetables	head cabbage (proxy)	Reallocated to representative “head cabbage”
		cabbage (white, green, pink, purple)	vegetables and vegetable products	Brassica vegetables	head cabbage	-
		broccoli, cauliflower	vegetables and vegetable products	Brassica vegetables	head cabbage	Reallocated to proxy
	fruiting vegetables	tomato, pepper cooked	vegetables and vegetable products	fruiting vegetables	tomatoes	Assumed as tomatoes
		cucumber, gherkin	vegetables and vegetable products	fruiting vegetables	cucumbers	-
		aubergine, courgette	vegetables and vegetable products	fruiting vegetables	zucchini	Item added

		tomato, pepper, raw	vegetables and vegetable products	fruiting vegetables	tomatoes	Assumed as tomatoes
	grain and pod vegetables	legumes (beans, peas, chickpeas, lentils)	vegetables and vegetable products	legume vegetables	beans with pods	Assumed as beans, with pods
	leafy vegetables	spinach	vegetables and vegetable products	leafy vegetables	spinach (fresh)	-
		green salad, leaf vegetables	vegetables and vegetable products	leafy vegetables	lettuce, excluding iceberg-type lettuce	-
	mixed salad, mixed vegetables	vegetable mix	composite food	prepared salads	prepared mixed vegetable salad	-
	mushrooms	mushrooms	vegetables and vegetable products	fungi, cultivated	cultivated mushroom	-
	onion, garlic	onion, garlic	vegetables and vegetable products	bulb vegetables	onions, bulb	-
	root vegetables	carrot cooked	vegetables and vegetable products	root vegetables	carrots	-
		carrot, kohlrabi (raw)	vegetables and vegetable products	root vegetables	carrots	-
	stalk vegetables, sprouts	asparagus	vegetables and vegetable products	stem vegetables (fresh)	leek (proxy)	Assumed as "stem vegetables" and reallocated to “leeks”
unclassified (other)	where vegetables are ingredients (not possible to quantify individually)	"vegetarian dishes (e.g. vegetable casserole, cereal or vegetable fritters, filled puff pastry without meat"	vegetable-based meals	vegetable-based meals	vegetable-based meals	No identifiable individual intake. Food items are quantified among other food groups

S3. Life Cycle Assessment

The method based on our previous study framework to integrate One Health into the LCA [3], where more information can be found. The system boundaries, the LCI for environmental impacts and animal welfare indicators for the added food items are available in **Suppl. Figure 1 and Suppl. Tables 3 and 4**.



Suppl. Figure 1. Life Cycle Assessment system boundary
Source: Paris et al. (2022)[3]

Suppl. Table 3. Life cycle inventory data sources and assumptions made in the estimation of environmental impact categories for food items added

Food item	Life Cycle (sub) stage	Parameters and assumptions	Data source
Olives	Green olive Spanish style (agricultural and processing stages) Ripe olive Californian style (only processing stage)	Agricultural phase, primary packaging (jar), pasteurisation secondary packaging (box), different processing methods (green and ripe olives); • Eutrophication [kg P eq.] • Global warming [kg CO_2 eq.] • energy use [MJ/100 kg or FU]	For green olives [4]; for Californian style olives [5]; conversion to kilograms of oil equivalent (kgoe) [6]

Decaffeinated coffee	Agricultural, transportation and processing (steaming, extraction, washing, degassing, evaporation, crystallisation	blend coffee (60% Arabica, 40% Robusta); Supercritical CO_2 extraction of caffeine from coffee beans; Emissions to water, air and soil; • climate change [kg CO_2 eq] • terrestrial acidification [kg SO_2 eq] • freshwater eutrophication [kg P eq] • marine eutrophication [kg N eq] • agricultural land occupation [m^2 x yr.] • water depletion [m^3] • fossil fuel depletion [kg oil eq]	Caffeine extraction [7]
Rabbit meat	Feed cultivation stage, feed processing stage, breeding stage, slaughtering stage, manure treatment, biogas generation	The standard weight of 2.6 kg after 140 days of breeding adult rex rabbits with an output of 1.5 kg meat, and 1kg fur; • Acidification [kg SO_2 eq] • climate change [kg CO_2 eq] • Land occupation [m^2yr]	Rex rabbit LCA [8]
Game meat	Census of wild red deer, bullets used, hunting trips, hunting activity, transportation to the Control Centre (culling and evisceration)	Wild red deer standard mass at the Control Centre (i.e. carcass weight already eviscerated); Allocation is given to the carcass as offal is not a commercial product; • Global warming [kg CO_2 eq] • Particulate matter formation [kg $PM_{2.5}$ eq] • Acidification potential conversion [mol H^+ eq] 1 kg sulphur oxides = 1.31 mol H^+ eq • Freshwater eutrophication [kg P eq] • Marine eutrophication [kg N eq]	Red deer hunting [9]; Conversion of units [10]
Tofu	Soybean cultivation, transport, processing (washing, soaking, grinding, curd boiling, filtering, clumping, forming, frying)	Tofu is produced in Jakarta (Indonesia) and Grobogan (Java); • Global warming [kg CO_2 eq] • Acidification [kg SO_2 eq] • Eutrophication [PO_4 eq] • Fine dust [kg $PM_{2.5}$ eq] • Oil & gas depletion [kg oil eq]	Processing [11] Cradle to gate [12]

Soymilk	Agricultural production, transportation to the processing plant and retail, processing, retail	Soybean produced in Illinois (USA); Processing: steaming, boiling, grinding, sterilization, homogenisation and cooling; • GWP [kgCO_2 eq/ kg] • Eutrophication [kg N eq/L milk] • Fossil fuel depletion [MJ/kg] • Water [L/kg] • Fossil fuel depletion [kg oil eq/kg] • Water [m^3/kg]	Soymilk LCA [13]
Cherries	Nursery, orchard infrastructure, orchard full life cycle, packing, waste (cradle to grave) Transports, storage, retail	Fruit cultivation to consumption in Norway; Different fruit grades are not split; • Climate change [kg CO_2 eq] • Acidification [g SO_2 eq] • Eutrophication [g PO_4 eq] • Depletion potential fossil [MJ]	LCA of fruits [14]; Unit conversion [6]
Grapes	Manufacturing of fertilizer, machinery, plant protection and fuel; vineyard cultivation, transport to the winery	Red and white grapes; Conventional, low input and organic vineyards in Cyprus; • Acidification [mol H^+ eq] • Climate change [kg CO_2 eq] • Eutrophication freshwater [kg P eq] • Eutrophication marine [kg N eq] • Resource use, energy [MJ] • Water scarcity [m^3 depriv.]	LCA of vineyards [15]; conversion of units [6,10]
Avocado	Raw materials (fertilizers, fuel), Agricultural production, post-harvest, transportation to the sailing point, packaging waste management (bio-waste)	Origin Tampico, Mexico; Sale point in Europe; Consumption stage is not included; • Climate change [kgCO_2-eq] • Land occupation [$m^2 * a$] • Water depletion [m^3]	Avocado LCA [16]
Broccoli	Cradle to grave including production of fertilisers and pesticides, agricultural production, distribution (retail), home preparation, consumption,	Origin countries UK and Spain; Producing, processing, the packaging on the farm, distribution directly to supermarkets; • LU [$m^2 \cdot yr$] • PEU [MJ] • WU [L]	LCA of broccoli [17], conversion of units [6]

	sewage system and food waste	• AP [kg SO_2-eq] • EP [kg Phosphate-eq.] • GWP [kg CO_2-eq]	
Zucchini	Carbon footprint of selected food items	GWP values (kg CO_2 eq./kg produced)	Source: [18]
Dried fruits	Agricultural production, dry fruit processing (selection, sorting, washing, peeling, cutting, drying, packaging and labelling), and waste generation.	Pineapple and sweet bananas are produced in Uganda as packed dried fruit including non-edible parts; Package (poly-ethylene 0.00370 kg and poly-vinyl chloride 0.00159 kg); Included: energy use, raw materials, emissions and other releases; • Global warming [kg CO_2 eq.] • Energy [MJ]	LCA [19]; conversion of units [6]

Suppl. Table 4. Criteria, parameters, data sources, and assumptions used in the estimation of animal welfare indicators for the food items added

Animal	**criteria**	**Parameter, data and assumptions**	**Data source**
Rabbit	Slaughter age	Weight of 2.6 kg after 140 days of breeding	[8]
	Life duration (years)	Life expectancy 10 years Life expectancy fattening rabbits 10 weeks	[20]
	Yield (kg/animal)	Weight of 2.6 kg after 140 days of breeding 1.5 meat, 1 fur	[8]
	Moral value	Domestic rabbit (*Oryctolagus cuniculus*); body mass g (4,600); brain mass g (9.132); brain neurons (494.20E +06); cortical neurons (71.45E +06)	[21]
	Slaughter duration (years)	Electro stunning of warm-blooded animals 10 (prone bleeding) 20 (for hanging bleeding), Max 12 hours of transportation for rabbits (EU regulation)	[22,23]
	Space allowance index/ Life Quality	Floor area for each animal (fattening rabbit) at least 300 cm^2 In the case of breeding rabbits, the number increases to 600 cm^2 Space allowance index in kg/m^2: $I = 2.5*(16-8)$ Life Quality: $Q = (2.6077* I - 0.051672*I^2 + 0.00050863* I^3)/100$	[24 25]
Red deer (game meat)	Slaughter age	Calves (age <12 months), yearlings (12–23 months), sub-adults (2–4 yrs.), and adults (≥ 5 yrs.) for males; calves, yearlings, and adults (≥ 2 yrs.) for females	[26]
	Life duration (years)	The sample includes hinds and stags aged up to 15 and 12 years	[26]

	Yield (kg/animal)	Eviscerated weight red deer male: adult (130kg), sub-adult (102.2 kg), yearling (69.7 kg), calf (40 kg); Eviscerated weight red deer female: adult (72.6 kg), yearling (56.7 kg); calf (37.6 kg)	[26]
	Moral value	*Cervus elaphus*; mean brain mass 409.3g, mean body mass 200 kg	[27]
	Slaughter duration (years)	13 days of hunting; 4 deer per hunter	[9]
	Space allowance index/ Life Quality	2.60 to 2.05 deer/100 ha (population density) Assumed as maximum space allowance index as animals live in the wild; Q = 1	[27]
Sheep (mutton/lamb)	Slaughter age	Lifespan sheep 5 years Lifespan lamb 4 to 12 months	[20]
	Life duration (years)	Life expectancy 12 years	[20]
	Slaughter duration (years)	15 seconds stunning; transport must not exceed eight hours travel time	[22,23]
	Yield (kg/animal)	Extensive breeds 30kg; semi extensive breeds 38 kg, intensive breeds 42kg	[28]
	Moral value	Sheep 14 g brain mass; 0.8 Encephalization Quotient (EQ)	[29]
	Space allowance index/ Life Quality	0.75 m^2 per sheep/ pasture year-round, winter months in steel Space allowance index in days of pasture I = 100*(8*30/365) Q = (-37.324 + 4.0151* I - 0.045721 * I^2+0.00019303*I^3)/100	[30] [25]
Shrimp (crustaceans)	Life Quality	Different stocking densities and yield/m2 including survival rate in survived kg shrimp/m2, with the equation: Q = 0.8047*I - 0.523 Q=>1, then Q=1	[31,32]
	Yield (kg/animal)	Several sizes and densities ranging from 0.091 to 2.6 kg shrimp/m^2	[31,32]
Custard	Proportion of eggs	Assumed as vanilla sauce: 250 ml cream, 250 ml milk, 6 eggs (yolk), 80g sugar, vanilla 6g, salt 1g	[33]
Mayonnaise	Proportion of eggs	Ingredients for processing mayonnaise: Egg yolk, vinegar, egg albumen, salt, sugar, water, rapeseed/ soy oil	[34,35]
Pork liver	Pork yield	Liver weight of crossbred pigs and mini-pigs Carcass yield of breeds commonly in Germany	[36–38]
Fats of mixed origin	Proportion of butter	Assumed as ½ butter and ½ other vegetable oil	[39]
Dressing	Proportion of mayonnaise	Mayonnaise-based, assumed as 1/3 mayonnaise proportion	[39]

S4. Health Nutritional Index (HENI)

Diet exposure

Mean intake of the 15 dietary risks and associated non-communicable diseases (NCDs) were obtained from the Institute of Health Metrics and Evaluation website stratified by age-sex group [40]. All NCDs associated with the studied DRFs, DRF definition and exposure risk can be found in **Suppl. Table 5**.

Suppl. Table 5. Dietary risk factors, risk exposure level, life cycle inventory (LCI) related to food/nutrients used and non-communicable diseases.

Dietary risk factor	Risk exposure[1]	Food/nutrient intake (LCI[2])	Non-communicable diseases
processed meat	>2 g/day	daily intake of cooked smoked sausage; dry sausage; fresh and lightly cooked sausage, ham (pork), and sausages	colon and rectum cancer, diabetes mellitus type 2, ischemic heart disease
red meat	>22.5 g/day	daily intake of beef meat, meat and meat products, mutton/lamb meat, pork/piglet meat, veal meat, game meat and rabbit meat	colon and rectum cancer, diabetes mellitus type 2, ischemic heart disease, intracerebral haemorrhage, ischemic stroke, subarachnoid haemorrhage, breast cancer
sodium[3]	>3.49 g/day	daily intake of sodium in g/day of the whole diet	aortic aneurism, atrial fibrillation and flutter, chronic kidney disease (due to diabetes mellitus type 1 and 2, glomerulonephritis, hypertension and unspecified causes), endocarditis, hypertensive heart disease, intracerebral haemorrhage, ischemic heart disease, ischemic stroke, non-rheumatic calcific aortic valve disease, other cardiomyopathies, peripheral artery disease, rheumatic heart disease, stomach cancer, subarachnoid haemorrhage
sugar-sweetened beverages	>2.5 g/day	daily intake of sugar-sweetened beverages: soft drink (flavoured)	diabetes mellitus type 2, ischemic heart disease
trans-fatty-acids	>0.5% total energy intake	percentage of daily intake to the total energy intake (e%) of trans-fatty-acids in g/day of the whole diet	ischemic heart disease
polyunsaturated fatty acids (PUFA)	<11% total energy intake	percentage of daily intake to the total energy intake (e%) of PUFA in g/day of the whole diet	ischemic heart disease

omega-3 fatty acids	<250 mg/day	daily intake of omega-3 fatty acids (EPA + DHA[4]) in mg/day of the whole diet	ischemic heart disease
vegetables	<360 g/day	daily intake of broccoli, carrots, tomatoes, head cabbage, lettuce (excl. ice-berg type), leafy vegetables, cucumbers, leek, onions, peppers (paprika), spinach (fresh), cultivated mushroom, zucchini	intracerebral haemorrhage, ischemic heart disease, ischemic stroke, subarachnoid haemorrhage, oesophageal cancer
legumes	<60 g/day	daily intake of beans (green, without pods), beans (with pods), lentils	ischemic heart disease
fruits	< 250 g/day	daily intake of apple, bananas, strawberries, peaches, oranges, pear, fruit compote, fruit sauce kiwi, figs, grapes, cherries	intracerebral haemorrhage, ischemic heart disease, ischemic stroke, subarachnoid haemorrhage, diabetes mellitus type 2, tracheal, bronchus, and lung cancer
whole grains	<125 g/day	daily intake of mixed wheat and rye bread and rolls, rye bread and rolls, multigrain bread and rolls, cereal flakes	diabetes mellitus type 2, ischemic heart disease, ischemic stroke
fibre	<23.5 g/day	daily intake of fibre in g/day of the whole diet	colon and rectum cancer, diabetes mellitus type 2, ischemic heart disease, intracerebral haemorrhage, ischemic stroke, subarachnoid haemorrhage,
nuts and seeds	<20.5 g/day	daily intake of sunflower seeds, tree nuts	diabetes mellitus type 2, ischemic heart disease
calcium	<1.25 g/day	daily intake of calcium in mg/day of the whole diet	colon and rectum cancer
milk	<435 g/day	cow milk, flavoured milk, evaporated milk	colon and rectum cancer

[1] Risk exposure retrieved from [41]; DRF are listed in the GBD database [42]

[2] Life cycle inventory: EFSA food and nutrient database available as background data in Optimeal® [43], complemented with the food composition data [44], output nutrient intake in g/day acquired through the FFQ EPICSOFT and the Dutch food and nutrient database [45].

[3] Sodium dietary risk factor represents both direct effects from the daily intake of sodium and the mediated effect of systolic blood pressure [46]

[4] Seafood Omega-3 fatty acids: Eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA)

Dietary Risk Factors (DRFs)

The Comparative Risk Assessment approach was used to estimate the DRFs for each age-sex-outcome-disease pair. The intake distribution was assumed to follow a gamma function (we assumed a coefficient of variation of 70%). The general equation to calculate the DRFs is as follows:

$$DRF = \frac{\ln(RR)}{Ref} \cdot \frac{BR}{\sum_x P_x RR^{X/Ref}}$$

Where:

$\Delta x \rightarrow 0$: assumed log-linear dose-response association;

RR: population-weighted relative risk;

Ref: reference exposure in grams per day;

BR: health burden in µDALYs per person and day;

Px: population fraction exposed to a daily x level of the risk intake;

Note: morbidity (YDLs) and mortality (YLL) are reported separately and further summed to estimate DALYs.

DRFs were aggregated by summing the DRFs for different outcomes calculated for the same dietary risk and aggregated by averaging the DRFs over the age-sex group weighted by population size. The characterised and standardised DRFs for the German population expressed in µDALYs are in **Suppl. Table 6.** We performed sensitivity analysis by varying DRFs using a wider range of coefficient of variation from 35% to 140%, as seen in **Suppl. Table 7.**

Suppl. Table 6.Characterised and population-standardised dietary risk factors in µDALYs

GBD Dietary risk factors	Characterized DRF (µDALYs)
vegetables	-0.0489
calcium	-10.7879
fruits	-0.0722
legumes	-0.1901
milk	-0.0144
processed meat	0.4197
red meat	0.323
whole grains	-0.2699
trans-fatty-acids	13.2458
nuts and seeds	-2.5343
polyunsaturated fatty acids (PUFA)	-0.7821
omega-3 fatty acids	-13.567
sugar-sweetened beverages (ssbs)	0.0398
sodium direct effect	0.4063
sodium mediated by systolic blood pressure	10.9694
sodium total effect	11.3758

Suppl. Table 7. Dietary Risk factor variation by different coefficients of variation in µDALYs

GBD Dietary risk factors	**DRF 35%**	**DRF 49%**	**DRF 70%**	**DRF 105%**	**DRF 140%**
vegetables	-0,057	-0,054	-0,049	-0,039	-0,031
calcium	-11,263	-11,068	-10,788	-10,430	-10,126
fibre	-1,932	-1,647	-1,234	-0,774	-0,542
fruits	-0,083	-0,079	-0,072	-0,062	-0,055

legumes	-0,174	-0,178	-0,190	-0,204	-0,209
milk	-0,015	-0,015	-0,014	-0,014	-0,014
processed meat	0,429	0,442	0,420	0,316	0,252
red meat	0,411	0,389	0,323	0,271	0,232
whole grains	-0,297	-0,286	-0,270	-0,235	-0,194
trans-fatty-acids	15,168	15,293	13,246	9,840	7,820
nuts and seeds	-2,289	-2,370	-2,534	-1,904	-1,492
polyunsaturated fatty acids (PUFA)	-1,117	-0,992	-0,782	-0,521	-0,366
omega-3 fatty acids	-12,556	-13,077	-13,567	-12,251	-11,628
sugar-sweetened beverages (ssbs)	0,040	0,040	0,040	0,040	0,040
sodium total effect	11,643	11,557	11,376	11,150	10,936

Sodium mediated by systolic blood pressure

Sodium is mediated by systolic blood pressure, which depends on ethnicity and prevalence of hypertension in the population. The prevalence hypertension in Germany (31.6%) was based on epidemiological studies in Germany [47,48]. The more vulnerable population to hypertension was taken as the percentage of blacks in the population (0.65%), assumed to be proportional to the number of foreigners in Germany from African countries [49]. Sodium has a direct effect on health (stomach cancer) and an indirect effect, mediated by increase in the systolic blood pressure (SBP). Age, race, and hypertension status are found to be effect modifiers [46].

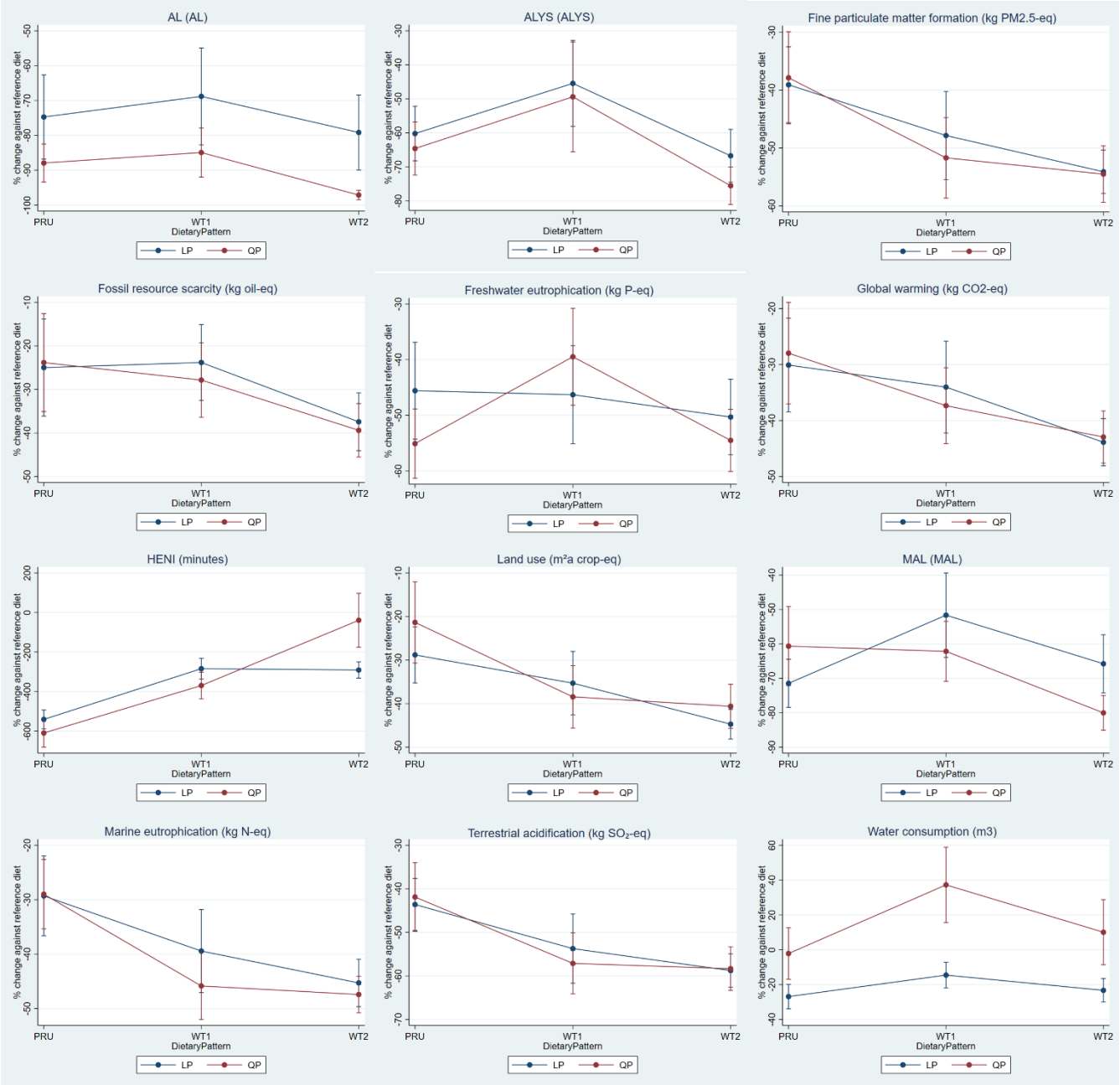
$$DRF_{d.sodium,o,b}^{a,g,m} = \frac{lnRR_{SBP,o,b}^{a,g}}{Ref_{SBP}} \cdot \frac{\Delta SBP^{a,g,m}}{\Delta u.sodium} \cdot f_{u.sodium \to d.sodium} \cdot \widehat{BR_{d.sodium,o,b}^{a,g}}$$

$$\widehat{BR_{d.sodium,o,b}^{a,g}} = \frac{BR_{o,b}^{a,g}}{\sum x\, P_{x\ d.sodium}^{a,g} \cdot RR_{SBP,o,b}^{a,g\left(\frac{x_{d.sodium}}{Ref_{SBP}} \cdot \frac{\Delta SBP^{a,g}}{\Delta u.sodium} \cdot f_{u.sodium \to d.sodium}\right)}}$$

Where: $RR_{SBP,o,b}^{a,g}$ is the relative risk for the systolic blood pressure and the outcomes for the age group *a,* sex *g,* and disease burden *b,* corresponding to a reference exposure Ref_{SBP} of 10mmHg. The age-sex-specific-modifier conversion coefficient is given by $\frac{\Delta SBP^{a,g,m}}{\Delta u.sodium}$, and characterizes the change in SBP levels in mmHg for each change in the urinary sodium. This value was assumed to be 4.64, obtained using the equation proposed in Mozaffarian et al. (2014) [46]. The parameters used were: mean Germany population age: 53 years old [50], prevalence of hypertense: 31.6%, prevalence of blacks: 0.65%. The conversion factor $f_{u.sodium \to d.sodium}$ was assumed 86%, i.e., for 1 g of sodium consumed (*d.sodium*) 0,86g are excreted in the urine (*u.sodium*) [51]. $\widehat{BR_{d.sodium,o,b}^{a,g}}$ is the age-sex-burden rate of the outcome *o* adjusted for the background dietary sodium population exposure (*x d.sodium*) in µDALYs/person/day.

S5 Optimisation sensitivity analysis results (quadratic and linear programing)

We conducted both linear and quadratic programming and performed a robust regression analysis to predict marginal variation of impacts by optimisation and dietary pattern. Apart from water consumption, no significant differences between linear and quadratic was observed (see **Supplementary Data**).



Suppl. Figure 2. Quadratic and Linear programming optimisation of observed dietary patterns.
Dots represent the plot of predicted margins resulting from robust regression analysis of the correlations between dietary patterns and optimisation changes against the baseline diet. Standard error bars are present when $p < 0.05$. WT1: Western-type 1; WT2: Western-type 2; PRU: Prudent; HENI: Health nutritional index; LP: linear programming; QP: quadratic programming.

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