Diet optimization for sustainability: INDIGOO, an innovative multilevel model combining individual and population objectives.

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Online Supplementary Material

Table S1. Food categorization

Food group (N = 8)	Food subgroups (N = 29)
Fruits & vegetables	
	Fresh & processed fruits
	Dried fruits & oilseeds
	Raw, cooked vegetables & soups
Starches	
	Breakfast cereals
	Unrefined starches
	Refined starches
Meat/eggs/fish	
	Eggs
	Fish
	Ruminant meat
	Poultry/pork & game
	Deli meat
	Offal
	Meat protein alternatives
Mixed dishes and sandwiches	
	Animal-based mixed dishes
	Vegetable-based mixed dishes
Dairy products and alternatives	
	Dairy products alternatives
	Cheese
	Milk
	Yogurt
Sweet products	
	Dairy dessert
	Cakes & pastries
	Biscuits and sweets
Water & other drinks	
	Sweet drinks
	Water

	Fruit juices 100%
	Tea & coffee
Fat products	
	Spices & sauces
	Animal fats
	Vegetal fats

Table S2. Nutritional recommendations[1] applied in constraints

				Women				Men			
Nutrient[2]		**Unit**	**age**	**AR[2]**	**PRI[2]**	**AI[3]**	**MRV**	**AR[2]**	**PRI[2]**	**AI[2]**	**MRV**
Total saturated fatty acids[4]		% energy	all				12				12
DHA EPA fatty acids		g/d	all			0.5				0.5	
Lauric myristic palmitic fatty acids		% energy	all				8				8
Linoleic fatty acid		% energy	all			0.04				0.04	
Linolenic fatty acid		% energy	all			0.01				0.01	
Oleic fatty acid		% energy	all			15	20			15	20
Water		g/d	all			1900				2375	
Fibers		g/d	all			30				30	
Macronutrients	**Carbohydrates**	% energy	all			40	55			40	55
	Lipids	% energy	all			35	40			35	40
	Proteins	% energy	all			10	20			10	20
Total sugars (without lactose)		g/d	all				100				100
Minerals	**Cu**	mg/d	all	0.8	1		5	1	1.3		5
	I	µg/d	all			150	600			150	600
	Mg	mg/d	all			360				420	
	Na	mg/d	all				2273				2994
	P	mg/d	all			700				700	
	Se	µg/d	all			70	300			70	300
	Zn	mg/d	all	6.2	7.5		25	7.5	9.4		25
	Ca	mg/d	<25	860	1000		2500	860	1000		2500
		mg/d	>25	750	950		2500	750	950		2500
	Fe	mg/d	<56	6	16			6	11		
		mg/d	>56	6	11			6	11		
Vitamins	**A**	mg/d	all	490	650		3000	570	750		3000
	B1	mg/kcal/d	all			0.00058				0.00058	
	B12	µg/d	all			4				4	
	B2	mg/kcal/d	all			0.00071				0.00071	
	B3	mg/kcal/d	all	0.0054	0.0067		900 mg/d	0.0054	0.0067		900 mg/d
	B5	mg/d	all			4.7				5.8	
	B6	mg/d	all			1.5	25			1.8	25
	B9	µg/d	all	250	330			250	330		
	C	mg/d	all	90	110			90	110		
	D	mg/d	all			5				5	
	E	mg/d	all			9.9				10.5	
Molar ratio K/Na		.	all				1.7				1.7

MRV: maximum recommended value; AR: average requirement; PRI: population reference intake; AI: adequate intake

[1] Nutritional recommended values, from Agence Nationale de SEcurité Sanitaire de l'alimentation, de l'environnement et du travail (ANSES) Actualisation des repères du PNNS : élaboration des références nutritionnelles; 2016., available online: https://www.anses.fr/fr/system/files/NUT2012SA0103Ra-2.pdf

[2] Minimum intake was imposed as follows: at least AR when observed intake was lower than AR, at least PRI when observed intake was greater than PRI and at least observed intake when observed intake was between PRI and AR

[3] For nutrients with an AI, minimum intake was imposed at AI, except for vitamin D. If observed vitamin D intake was lower than recommended intake (5µg/d), minimum intake was imposed at observed intake.

[4] If observed saturated fatty acid intake was lower than MRV, the maximal intake was imposed at observed intake

Material S3. Principle of IBDO and INDIGOO objective function

Both in IBDO and INDIGOO, the aim was to find the modeled diet that comes as close as possible to the corresponding observed diet. The objective function was mainly inspired from Maillot et al. (2010) [7], where, for each individual, the objective function was aimed at *1*) preferentially choosing foods from his or her food-repertoire (the set of foods declared as consumed by the individual); *2*) minimizing only the decrease in the quantity of each repertoire-food, and, if necessary, *3*) introducing non-repertoire-foods and *4*) preferentially selecting the most frequently consumed foods by the French population. In this study, the increase of repertoire-food were also minimized. IBDO's objective function minimized individual dietary deviations separately for each individual. INDIGOO's objective function minimized sum of individual dietary deviations.

INDIGOO's optimization was run in two phases. In the first phase, diet optimization was conducted on the whole sample (n = 1 918) in order to identify infeasible diets (Figure 1, equation INDIGOO A). Diet was infeasible when optimization required to give up at least one constraint of the model. In the second phase, diet optimization was run on feasible diets only (Figure 1, equation INDIGOO B).

IBDO

$$Min\ F_i = \sum_{j \in R_i} D_{i,j} + \sum_{j \notin R_i} W_j Q_{i,j}^{opt}$$

INDIGOO

A) $Min\ F_{init} = \sum_{i=1}^{i=Ntot} (\sum_{j \in R_i} D_{i,j} + \sum_{j \notin R_i} W_j Q_{i,j}^{opt} + 10\,000\,000 * \sum_{c=1}^{c=n} E_{i,c})$

B) $Min\ F = \sum_{i=1}^{i=Ntot} (\sum_{j \in R_i} D_{i,j} + \sum_{j \notin R_i} W_j Q_{i,j}^{opt})$

With:

F_i, the objective function of one IBDO model, representing the individual deviations for individual *i*

F_{init}, the objective function of the initial INDIGOO optimization, including infeasible diets

F, the objective function of the final INDIGOO, representing the sum of each individual deviations among the sample

R_i, the food repertoire of the individual *i*

$D_{i,j} = \frac{|Q_{i,j}^{opt} - Q_{i,j}^{obs}|}{Q_{i,j}^{obs}}$, the relative deviation between the optimized and observed intake of repertoire's food *j* for the individual *i*

$Q_{i,j}^{opt}$, the quantity in grams of the food *j* in the optimized diet of individual *i*

$Q_{i,j}^{obs}$, the quantity in grams of the food *j* in the observed diet of individual *i*

$W_j = \frac{(1 + \frac{0,1 * Ntot}{Nb_{cons\,j}})}{Q_j^{med}}$, the weight of the food *j* to preferentially select the most consumed foods among additional foods

Q_j^{med}, the median observed quantity of food *j* in the sample

$Ntot$, the total number of individuals in the sample

$Nb_{cons\,j}$, the number of consumers of food *j*

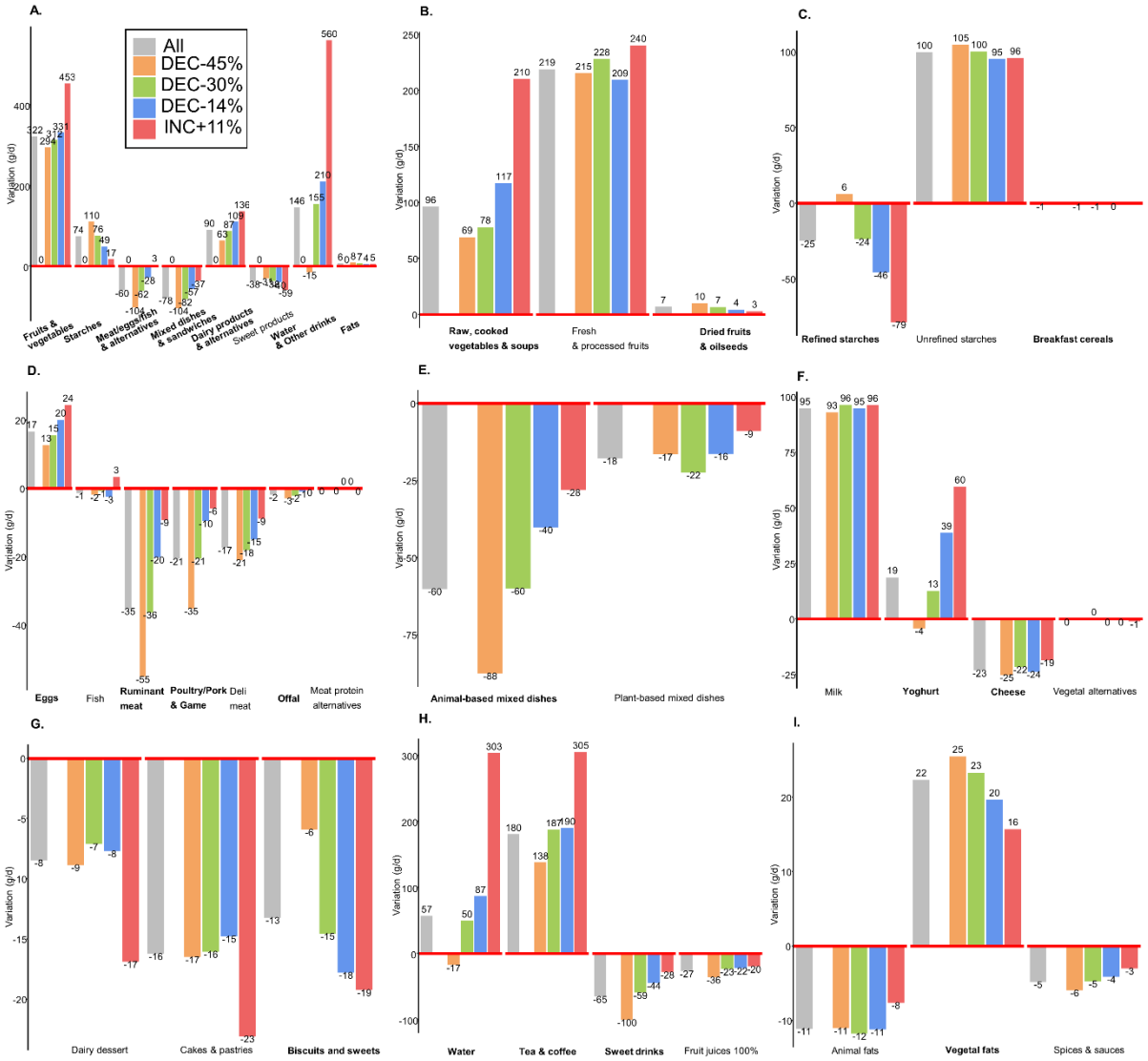
$E_{i,c}$, the elastic variable, representing the deviation from the minimal or maximal value applied for the constraint *c* of individual *i*

Table S4. Sociodemographic characteristics (%) by population class

		All	DEC-45%	DEC-30%	DEC-14%	INC+11%	*p*-value*
Socio-occupational category (%)	Low	14.85	19.58	17.17	8.79	11.03	<0.0001
	Intermediate	33.62	31.03	31.45	37.24	38.5	
	High	9.07	10.59	7.69	8.64	10.58	
	Economically inactive	42.46	38.8	43.69	45.32	39.89	
Education level (%)	Low	17.73	16.31	18.07	18.67	18.2	0.3924
	Middle	51.59	51.9	54.43	49.9	44.77	
	High	30.56	31.79	27.38	31.16	37.03	
	Missing value	0.12	.	0.11	0.27	.	
Physical activity (%)	Low	22.43	19.86	22.55	24.85	22.23	0.0981
	Moderate	31.17	29.43	34.67	27.77	39.63	
	High	45.25	49.64	42.03	45.67	37.55	
	Missing value	1.15	1.07	0.75	1.71	0.59	
Sex (%)	Men	48.3	61.85	50.05	37.62	27.72	<0.0001
	Women	51.7	38.15	49.95	62.38	72.28	
Family status (%)	Couples with children	29.95	32.64	27.96	29.17	30.52	0.0172
	Couples without children	41.37	44.48	42.69	39.05	31.54	
	Single parent households	6.42	5.05	7.59	6.6	6.48	
	Single parent without children	22.18	17.82	21.76	24.94	31.45	
	Missing value	0.08	.	.	0.24	.	
Smoking status (%)	Yes	27.37	32.41	29.16	20.98	26.33	<0.0001
	No	70.63	63.68	69.8	77.86	72.09	
	Missing value	2	3.91	1.05	1.16	1.58	

** p-value of Chi-2 test*

Figure S5. Variation of food groups (A) and Fruits & vegetables (B), Starches (C), Meat/eggs/fish & alternatives (D), Mixed dishes (E), Dairy products & alternatives (F), Sweet products (G), Water & other beverages (H) and Fat products (I) and subgroups between observed and optimized diets by population class[1,2]



[1]Optimized amounts were significantly different than the observed amounts, except for meat/eggs/fish and alternatives (for INC+11% population class) and water and other beverages (for DEC-45% population class) food groups, and except for refined starches (for DEC-45% population class), breakfast cereals (for INC+11% population class), fish (for DEC-45%, DEC-30% and INC+11% population classes), meat protein alternatives (for all and each population classes), yoghurt (for DEC-45% population class), vegetal alternatives (for DEC-30%, DEC-14% and INC+11% population classes) and water (for DEC-45% et DEC-30% population classes).

[2] Bold food groups or subgroups indicated significant differences across population classes adjusted on energy intake and dietary GHGE.