Public Health Nutrition: 24(12), 3916–3921 doi:10.1017/S1368980020004073

Public Health Nutrition

Short Communication

Secular trends in diet-related greenhouse gas emission estimates since 2000 – a shift towards sustainable diets in Sweden

Kirsten Mehlig[1,*,†], Irene Blomqvist[1,†], Sofia Klingberg[1,2], Marta Bianchi[3], Josefin Sjons[3], Monica Hunsberger[1] and Lauren Lissner[1]
[1]University of Gothenburg, School of Public Health and Community Medicine, Institute of Medicine, Gothenburg, Sweden: [2]University of Gothenburg, Department of Internal Medicine and Clinical Nutrition, Institute of Medicine, Gothenburg, Sweden: [3]Research Institutes of Sweden (RISE), Gothenburg, Sweden

Submitted 15 April 2020: Final revision received 2 September 2020: Accepted 28 September 2020: First published online 16 October 2020

Abstract
Objective: This study examines secular changes in diet-related greenhouse gas emissions (GHGE) in younger and older Swedish adults, since the turn of this century.
Design: Two cross-sectional health examination surveys were conducted in 2001–2004 (T_1) and 2014–2018 (T_2). At both times, an eighty-six-item FFQ was embedded in the survey. From the food frequencies and age-standardised portion sizes, GHGE estimates (kg CO_2e/year) were calculated. GHGE was modelled as a function of time period and covariates, for five distinct age groups.
Setting: The municipality of Gothenburg, in western Sweden.
Participants: Women and men aged 25–34, 35–44, 45–54, 55–64 and 65–75 years were randomly selected from the population registry and recruited for examinations. After exclusion of participants with incomplete dietary data, the analytic sample consisted of 2569 individuals at T_1 and 2119 at T_2.
Results: Lower dietary GHGE scores were observed at T_2 compared with T_1, in each age group, adjusting for sex, BMI and education. The largest differences in GHGE were observed in the youngest age group (approximately 30 % reduction). Decreasing trends in GHGE from animal-based foods were observed at all ages and were accompanied by smaller increases from plant-based sources in younger groups only. At all ages, GHGE from discretionary foods decreased, and prevalence of overweight remained stable.
Conclusions: Optimal dietary trends should support both human health and planetary health. Our results suggest that Swedish adults have moved in this direction, e.g. through less intake of red meat products and stable weight status.

Keywords
Animal-based food
Plant-based food
Secular trends
Greenhouse gas emissions
Sustainable diets
Climate change

In recent years, growing concerns regarding climate change, animal welfare and personal health have influenced the population's dietary patterns[1,2]. For instance, exclusion of animal-based foods such as meat is likely to have various health and planetary benefits although potential negative health consequences have been pointed out[2–5], including compensatory intake of discretionary food items with high sugar content[4,6]. Nevertheless, diets based on nutritional recommendations are in general lower in greenhouse gas emissions (GHGE) than average consumption patterns in the population[7–9]. Despite increasing knowledge about diet-related climate impact, future improvements may be hindered by issues of affordability, lack of knowledge and resistance to change[10–13]. The present study describes trends in diet-related GHGE that have occurred during the millennium in western Sweden, with focus on potential characteristics of the population that may be associated with adoption of low-GHGE diets.

†These authors contributed equally to this work.

*Corresponding author: Email Kirsten.mehlig@gu.se

Methods

Two cross-sectional health examination surveys were conducted in 2001–2004 (T_1) and 2014–2018 (T_2). The average time between the two surveys was 13·7 years. Women and men aged 25–34, 35–44, 45–54, 55–64 and 65–75 years were randomly selected from the population. The examinations included physical measurements and self-administered questionnaires on health and lifestyle[14]. The majority of participants in the two youngest groups were newly recruited at T_2, while the older participants had participated in the first survey and moved to a higher age group at T_2. The oldest group at T_1 was not included at T_2 because the participants exceeded the age limit for secular comparisons (see online supplementary material, Supplemental Fig. 1). Participation rates were comparable (approximately 40 %) at T_1 and T_2[14].

At each time period, an eighty-six-item FFQ was embedded in the health survey. The FFQ was developed and validated at Karolinska Institute in Stockholm[15–17]. Food frequencies were combined with age- and sex-standardised portion-size estimates to calculate food specific and total food intake in kg/d[17]. Incomplete FFQ with more than eight missing items were excluded (129 at T_1 and 19 at T_2), and the final analytic sample included 2569 individuals at T_1 and 2119 at T_2.

GHGE estimates in units of kg CO_2 equivalents (CO_2e) per kg consumed food were extracted from the RISE Food Climate Database[18], which is based on life cycle analyses of foods representing Swedish consumption patterns. Estimates were collected from consecutively updated studies, with the latest being the most reliable, and valid for both time points in this study. Around 70 % of the GHGE estimates applied in this study were based on production in Sweden and included GHGE from primary production to industry gate. GHGE values included transport to but not within Sweden and generally refer to the edible parts of foods. Specific GHGE estimates were derived for the eighty-six individual food items from the FFQ. The individual food items were then pooled into nineteen food groups (Fig. 1), and an average GHGE estimate was derived for each food group weighting estimates for individual items based on national consumption patterns. These nineteen food groups combined food items of the same origin (e.g. meat, vegetables and dairy), and with similar climate impact distinguishing for instance ruminants from other types of meat, and regular from low-fat dairy products.

Statistical analyses

For each individual, we calculated the intake f_j in kg/year for each food group ($j = 1$–19). These food intakes were multiplied with the conversion factor c_j (= estimated kg CO_2e per kg consumed food), which gives the yearly GHGE due to consumption of foods from group j,

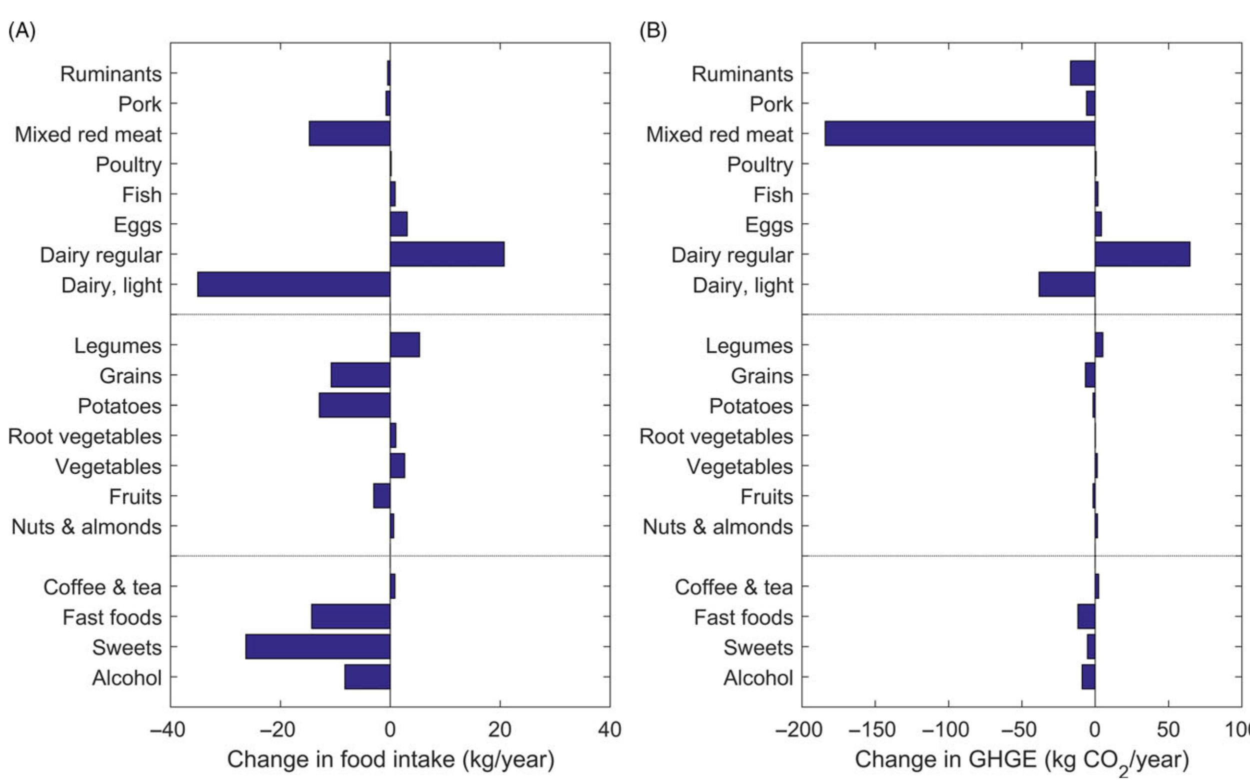

Fig. 1 (colour online) Absolute changes in food intake (A) and in greenhouse gas emissions (GHGE) score (B) on food group level. Food groups are further divided into three categories: animal-based (top), plant-based (middle) and discretionary foods (bottom)

$GHGE_j = c_j \times f_j$ (kg CO_2e/year). Total CO_2 emission is given by $GHGE_{total} = \Sigma \ GHGE_j = \Sigma \ c_j \times f_j$. The ratio of total CO_2 emission over total food intake $\Sigma \ f_j$,

$$ratio = \frac{\sum_{j=1}^{19} c_j f_j}{\sum_{j=1}^{19} f_j}$$

gives an estimate for the climate impact in kg CO_2e/kg consumed food in an individual. The mean value of individual ratios gives the diet-related climate impact per kg consumed food in this population. In addition, source-specific climate scores (animal-based, plant-based, discretionary foods) were divided by total food intake in order to investigate whether changes in source-specific climate scores were explained by secular changes in total food intake.

Dietary information was studied in relation to time period. Because some participants were measured at both T_1 and T_2, the main analyses were stratified into five age bands between ages 25 and 75 years. In this way, statistical comparisons between time periods were performed between independent samples, and no longitudinal changes were considered at the individual level (see online supplementary material, Supplemental Fig. 1). Non-parametric tests examined time period differences in dietary and background characteristics (χ^2 test for categorical variables and Wilcoxon rank sum test for continuous variables). Linear regression was used to analyse the logarithmically transformed GHGE score as a function of time, with adjustment for sex, exact age, BMI and education, giving the relative difference in GHGE score at T_2 relative to T_1 in percent. Effect modification by sex, overweight (BMI $\geq$ 25 kg/m^2) and university education was examined by introducing product terms with time period into the age-specific regression models (see online supplementary material, Supplemental Fig. 2). Analyses were performed using SAS (version 9·4; SAS Institute) and MATLAB (R2016b; The Math Works, Inc.). Statistical significance was set at P-value < 0·05 (two-sided tests).

Results

Descriptive background data on the population are shown in Table 1. The prevalence of overweight was stable between time periods, whereas significant period differences in university education were observed. These increases may be attributed to secular trends in educational standards in the underlying population and to self-selection among both newly recruited and returning participants. Additional analyses (not shown) confirmed that the lack of trend in overweight was independent of increasing educational attainment.

Dietary characteristics within each 10-year age band were compared at T_2 *v.* T_1. Significant decreases in total climate scores were observed in all five age groups and were largest (−374 kg CO_2e/year) in the youngest group (Table 1). Comparing source-specific scores, the largest differences in GHGE were seen for animal-based foods suggesting that improvements in total GHGE were mostly due to lower consumption of animal products. This trend was accompanied by some increases in plant-based food consumption in the two younger age groups. Finally, GHGE from the discretionary category decreased significantly in all age groups. Time period differences in absolute GHGE score were generally confirmed when considering its ratio to the total amount of food consumed, an indicator of changed dietary GHGE pattern rather than amount, adjusting for period differences in total food intakes.

Multivariable regression models (Table 2) confirmed the significant reductions in GHGE in all five age groups. The largest differences were consistently seen in the youngest age group and the smallest differences in the 45–54-year-old group. The magnitude of the crude effects (model A) hardly changed after adjustments for age, sex, education and BMI (models B and C). The secular differences were slightly attenuated but remained statistically significant in all age groups after further adjustment for total food intake (model D). Results from models C and D also implied that decreases in GHGE could not be attributed to the increasing educational level between the two periods. Considering education *per se*, no differences in GHGE were observed between individuals with university *v.* lesser education, at either time period (not shown). In contrast, BMI was positively associated with GHGE scores at T_2, with and without adjustment for the total amount of food consumed: GHGE in overweight individuals was 3 % higher compared with those with lower BMI (P = 0·01, adjusted for age, sex, education and total intake, not shown). Furthermore, the magnitude of GHGE differences over time tended to be smaller in overweight individuals, with significant time by overweight interaction in age group 35–44 (see online supplementary material, Supplemental Fig. 2 middle panel). There were no interactions of time period with education or sex (see online supplementary material, Supplemental Fig. 2).

Finally, Fig. 1 shows the secular trends for specific food groups within the broader categories of animal, plant and other sources. Contrasting patterns may be observed regarding the two measures of secular change, i.e. period differences in foods consumed and in food-related GHGE scores. For instance, an apparent replacement of light dairy products with a smaller amount of full fat ones (panel A) produced a net pattern of increasing GHGE for these two items considered together (panel B). Moreover, trends in consumption of the mixed red meat group (mainly processed meat items) dominate the decrease in GHGE scores compared with all other items (panel B). Much smaller changes were observed in both food intake and GHGE from ruminant animals (beef, veal and lamb).

Table 1 Age-specific characteristics of the population including background covariates as percentage, followed by dietary outcomes as median and interquartile range. Dietary characteristics are divided into total, animal-based, plant-based and discretionary foods. Statistically significant period differences are indicated (ref = T_1)

	25–34 years				35–44 years				45–54 years				55–64 years				65–75 years			
	T_1 (n 350)		T_2 (n 584)		T_1 (n 556)		T_2 (n 519)		T_1 (n 544)		T_2 (n 272)		T_1 (n 585)		T_2 (n 297)		T_1 (n 405)		T_2 (n 447)	
	%		%		%		%		%		%		%		%		%		%	
Description of sample†																				
Female sex	55		55		53		52		51		56		49		49		52		51	
University education	48		74***		43		67***		36		55***		29		43***		15		36***	
Overweight	34		34		47		44		56		53		61		61		71		66	
	Median	IQR	Median	IQR	Median	IQR	Median	IQR	Median	IQR	Median	IQR	Median	IQR	Median	IQR	Median	IQR	Median	IQR
Dietary characteristics‡																				
All foods																				
Food intake (kg/year)	866	415	749***	348	943	403	819***	318	951	454	905*	331	922	396	874*	374	868	356	783***	334
GHGE score (kg CO_2e/year)	1251	705	877***	585	1228	684	976***	595	1199	726	1094**	591	1166	662	1053***	642	1066	587	922***	566
Ratio (kg CO_2e/kg food)§	1·42		1·21***		1·34		1·26***		1·28		1·21*		1·27		1·21**		1·25		1·21*	
Animal-based foods: ruminants, pork, mixed red meat, poultry, fish and shellfish, eggs, regular dairy products, reduced fat dairy products																				
Food intake (kg/year)	214	153	146***	135	196	138	179**	121	187	129	184	133	197	126	175*	131	195	117	179*	126
GHGE score (kg CO_2e/year)	906	582	579***	529	860	538	668***	516	826	571	743***	480	818	539	730***	489	725	489	652***	461
Ratio (kg CO_2e/kg food)§	1·02		0·80***		0·96		0·88***		0·89		0·84		0·90		0·83*		0·87		0·85	
Plant-based foods: legumes, grains, potatoes, root vegetables and onions, vegetables, fruits, berries, nuts																				
Food intake (kg/year)	266	139	273	140	281	148	282	141	307	142	279**	130	300	155	281*	156	296	144	280**	129
GHGE score (kg CO_2e/year)	141	73	154**	88	146	78	156**	87	160	76	151	72	152	82	151	89	144	72	144	67
Ratio (kg CO_2e/kg food)§	0·16		0·20***		0·16		0·19***		0·17		0·17		0·17		0·18		0·17		0·18**	
Discretionary foods: fast foods and snacks, sweets, coffee and tea, alcoholic beverages																				
Food intake (kg/year)	356	263	299***	208	414	278	328***	205	417	285	402*	213	386	269	363	251	348	215	293**	206
GHGE score (kg CO_2e/year)	173	136	140***	97	190	144	142***	95	177	155	153**	83	160	139	138***	105	150	139	117***	98
Ratio (kg CO_2e/kg food)§	0·21		0·18***		0·21		0·18***		0·19		0·17**		0·18		0·16**		0·18		0·16***	

GHGE, greenhouse gas emissions.
***$P < 0·001$; **$P < 0·01$; *$P < 0·05$.
†Period differences by χ^2 test.
‡Period differences by Wilcoxon rank sum test.
§Climate score divided by total food intake.

Table 2 Secular trends in climate impact by age group, with effect sizes expressed as percent change in greenhouse gas emissions (GHGE) score in T_2 *v.* T_1†

	Age groups									
	25–34 (*n* 934)		35–44 (*n* 1075)		45–54 (*n* 816)		55–64 (*n* 882)		65–75 (*n* 852)	
	% change	95 % CI	% change	95 % CI	% change	95 % CI	% change	95 % CI	% change	95 % CI
A: Unadjusted results										
T_2–T_1	−28·3***	−32·4, −23·9	−20·1***	−24·0, −16·0	−9·0**	−14·2, −3·5	−10·9***	−16·0, −5·4	−14·8***	−19·5, −9·9
B: Adjusted for age, sex										
T_2–T_1	−28·0***	−31·6, −24·1	−20·0***	−23·5, −16·2	−7·3**	−11·8, −2·5	−10·9***	−15·3, −6·3	−15·2***	−19·3, −10·9
C: Adjusted for age, sex, education and BMI										
T_2–T_1	−28·2***	−32·0, −24·2	−19·9***	−23·6, −16·1	−7·3**	−12·0, −2·4	−10·5***	−15·0, −5·7	−16·1***	−20·3, −11·6
D: Adjusted for age, sex, education, BMI and total food intake										
T_2–T_1	−19·4***	−22·8, −15·8	−12·9***	−16·1, −9·6	−3·9*	−7·5, 0·0	−6·9***	−10·5, −3·1	−6·8***	−10·5, −3·0

†Regression of log (GHGE) on time point and covariates, with results expressed as (exp (b)–1) × 100 = % GHGE change in T_2 *v.* T_1.

Discussion

The current study showed that Swedish men and women in all age groups decreased their dietary GHGE over approximately 14 years. In particular, the younger age groups (25–44 years) consumed less animal-based and more plant-based foods. Decreases in discretionary foods were seen in all age groups. There was no accompanying difference in overweight prevalence over time, in contrast to earlier trends of increasing BMI and waist-to-hip ratio in this population in the late 20th century[19]. However, the most recent examination (2014–2018) showed that participants with overweight had higher diet-related GHGE than non-overweight participants, independent of amount of food consumed. In this context, it is noted that total food consumption may be considered a proxy for energy consumption. Although energy intake was not estimated for the second time period, the high correlation between total food and energy intake in 2001–2004 (Pearson's correlation coefficient 0·79, $P < 0·001$) motivated our decision to treat food intake as an indicator of energy intake.

Food production causes around one-third of global GHGE, and dietary changes hold great potential for reducing these emissions[20]. Changes in dietary patterns of the younger age groups studied here, with major shifts in both animal- and plant-based foods, are promising, but improvements appear to be smaller in all other age groups, particularly in 45–54-year-olds. Decreases in GHGE from discretionary foods occurred in parallel with a stable prevalence of overweight and obesity. The association between overweight status and higher dietary GHGE in this study is consistent with results from a less urbanised Northern Swedish cohort[21]. Our observation that the youngest age groups showed highest GHGE in 2001–2004 (3·4 kg CO_2e/d) and lowest levels in 2014–2018 (2·4 kg CO_2e/d) may be an indication that food products with lower carbon footprint have become more socially desirable, available and affordable, especially to younger adults.

While longitudinal decrease in dietary GHGE was reported for cohort studies in the Netherlands[22] and Northern Sweden[23], to our knowledge, this is the first study to document decreasing secular trends of dietary GHGE in same-aged adults compared 2001–2004 and 2014–2018. Strengths of this study include the population-based recruitment and the repeated cross-sectional design based on similar survey methodologies, together with derivation of GHGE estimates specific to the Swedish diet. Among the limitations are consistently low participation rates, probable dietary reporting biases and numerous assumptions involved in GHGE estimation. Moreover, the FFQ method does not reflect complete dietary intake, but relatively broad-ranged definitions allowed to aggregate few items newly introduced at T_2 into existing food item categories, which were comprehensive regarding, e.g. seasonal variations.

Conclusion

In conclusion, the magnitude of the secular differences in the younger age groups was promising, but the lesser effects in other age groups underscore the need for effective policies to improve climate impact of diets. The consistent decreases in discretionary foods indicate a healthy trend with a small but favourable climate impact, whereas lack of changes in consumption of meat from ruminant animals suggests a potential for greater improvements. Finally, the positive association between BMI and GHGE in the recent survey is consistent with potential health benefits of a dietary shift, while at the same time suggesting that the climate message might not be reaching individuals with overweight.

Acknowledgements

Acknowledgements: Not applicable. *Financial support:* This study was supported by grants from the Swedish

Council for Health, Working Life, and Welfare (Forte) and the Swedish Research Council for Environment, Agricultural Sciences, and Spatial Planning (Formas) and by grants from the Swedish state under the agreement between the Swedish government and the country councils, the ALF-agreement (30411). *Conflict of interest:* There are no conflicts of interest. *Authorship:* I.B., K.M. and L.L. formulated the research question and prepared the manuscript; K.M. and I.B. conducted the data analysis; S.K., L.L., K.M. and M.H. supervised the research; M.B. and J.S. assisted with methods pertaining to the use of the RISE Food Climate Database. All authors have participated in writing the manuscript and approved the final version. None of the authors has any commercial association that would pose a conflict of interest. There have been no previous publications of this work. *Ethics of human subject participation:* This study was conducted according to the guidelines laid down in the Declaration of Helsinki, and all procedures involving research study participants were approved by the regional ethics review board (237/2000). Written informed consent was obtained from all participants.

Supplementary material

For supplementary material accompanying this paper visit https://doi.org/10.1017/S1368980020004073

References

1. Sabate J & Soret S (2014) Sustainability of plant-based diets: back to the future. *Am J Clin Nutr* **100**, 476s–482s.
2. Willett W, Rockstrom J, Loken B *et al.* (2019) Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems. *Lancet* **393**, 447–492.
3. Hallstrom E, Roos E & Borjesson P (2014) Sustainable meat consumption: a quantitative analysis of nutritional intake, greenhouse gas emissions and land use from a Swedish perspective. *Food Policy* **47**, 81–90.
4. Payne CL, Scarborough P & Cobiac L (2016) Do low-carbon-emission diets lead to higher nutritional quality and positive health outcomes? A systematic review of the literature. *Public Health Nutr* **19**, 2654–2661.
5. Green R, Milner J, Dangour AD *et al.* (2015) The potential to reduce greenhouse gas emissions in the UK through healthy and realistic dietary change. *Climatic Change* **129**, 253–265.
6. Hendrie GA, Baird D, Ridoutt B *et al.* (2016) Overconsumption of energy and excessive discretionary food intake inflates dietary greenhouse gas emissions in Australia. *Nutrients* **8**, 690.
7. Sjors C, Hedenus F, Sjolander A *et al.* (2017) Adherence to dietary recommendations for Swedish adults across categories of greenhouse gas emissions from food. *Public Health Nutr* **20**, 3381–3393.
8. Cobiac LJ & Scarborough P (2019) Modelling the health co-benefits of sustainable diets in the UK, France, Finland, Italy and Sweden. *Eur J Clin Nutr* **73**, 624–633.
9. Hyland JJ, Henchion M, McCarthy M *et al.* (2017) The role of meat in strategies to achieve a sustainable diet lower in greenhouse gas emissions: a review. *Meat Sci* **132**, 189–195.
10. Masset G, Vieux F, Verger EO *et al.* (2014) Reducing energy intake and energy density for a sustainable diet: a study based on self-selected diets in French adults. *Am J Clin Nutr* **99**, 1460–1469.
11. Seconda L, Baudry J, Alles B *et al.* (2018) Identification of sustainable dietary patterns by a multicriteria approach in the NutriNet-Sante cohort. *J Clean Prod* **196**, 1256–1265.
12. Donati M, Menozzi D, Zighetti C *et al.* (2016) Towards a sustainable diet combining economic, environmental and nutritional objectives. *Appetite* **106**, 48–57.
13. Macdiarmid JI, Douglas F & Campbell J (2016) Eating like there's no tomorrow: public awareness of the environmental impact of food and reluctance to eat less meat as part of a sustainable diet. *Appetite* **96**, 487–493.
14. Mehlig K, Berg C, Bjorck L *et al.* (2017) Cohort profile: the INTERGENE study. *Int J Epidemiol* **46**, 1742h–1743h.
15. Messerer M, Johansson SE & Wolk A (2004) The validity of questionnaire-based micronutrient intake estimates is increased by including dietary supplement use in Swedish men. *J Nutr* **134**, 1800–18005.
16. Wolk A, Ljung H, Vessby B *et al.* (1998) Effect of additional questions about fat on the validity of fat estimates from a food frequency questionnaire. Study group of MRS SWEA. *Eur J Clin Nutr* **52**, 186–192.
17. Berg C, Lappas G, Wolk A *et al.* (2009) Eating patterns and portion size associated with obesity in a Swedish population. *Appetite* **52** 21–26.
18. Sweden (2018) *RIo. Öppna listan - ett utdrag från RISE klimatdatabas för livsmedel v. 1.5. (Extract from the RISE Climate Database v. 1.5)*. Stockholm, Sweden: Research Institutes of Sweden. https://www.ri.se/en/our-stories/foundation-climate-smarter-food-consumption (accessed November 2020).
19. Berg C, Rosengren A, Aires N *et al.* (2005) Trends in overweight and obesity from 1985–2002 in Goteborg, West Sweden. *Int J Obes (Lond)* **29**, 916–924.
20. Hallstrom E, Carlsson-Kanyama A & Borjesson P (2015) Environmental impact of dietary change: a systematic review. *J Clean Prod* **91**, 1–11.
21. Strid A, Hallstrom E, Hjorth T *et al.* (2019) Climate impact from diet in relation to background and sociodemographic characteristics in the Vasterbotten Intervention Programme. *Public Health Nutr* **22** 3288–3297.
22. Biesbroek S, Bueno-de-Mesquita HB, Peeters PH *et al.* (2014) Reducing our environmental footprint and improving our health: greenhouse gas emission and land use of usual diet and mortality in EPIC-NL: a prospective cohort study. *Environ Health* **13**, 27.
23. Hjorth T, Huseinovic E, Hallstrom E *et al.* (2020) Changes in dietary carbon footprint over 10 years relative to individual characteristics and food intake in the Vasterbotten Intervention Programme. *Sci Rep* **10**, 20.