EDITORIAL

Reducing the environmental footprint of food

Despite the considerable achievements of science and agriculture in feeding more people with more food, we are now more concerned than ever that global demand for food is still on the increase. It is unlikely that world population will peak until it is higher than 10 billion or perhaps even 11 billion. Our society, and not-least the operation of the global food system, is putting considerable pressure on our planetary systems. One dramatic example of this is that apparent climate change or the “climate emergency” as it is now known is never out of the headlines for long. While climate change is causing great problems for agriculture in many parts of the world, it is also clear that the operation of our current food system is responsible for significant degradation of terrestrial and aquatic ecosystems. Consequently, there is much interest in the greening of world food production known in China as Agriculture Green Development (AGD).

There is growing awareness that the current food system is responsible for a broad range of environmental degradation which is causing concern in many parts of the world. These problems include excessive water and fertilizer use resulting in falling ground water levels, desertification, pollution of ground water and surface water bodies, soil degradation, and wide-scale reductions in biodiversity. These problems mean that the challenge of modifying current food production and farming methods must take top priority in order to limit further development of the climate emergency and related challenges. This issue highlights the nature of this challenge and reviews some means of addressing the developing problems of our global food system.

In addition to the environmental problems noted above, the Intergovernmental Panel on Climate Change (IPCC) has recently released a major report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems[1]. This has highlighted some of the problems that agriculture, forestry and other land use (AFOLU) activities are creating for our planet. The panel concluded with moderate confidence that these activities accounted for around 13% of CO2, 44% of methane, and 82% of nitrous oxide emissions from human activities globally during 2007–2016, representing 23% (123 Gt$yr–1 CO2-e) of total net anthropogenic emissions of greenhouse gasses.

Despite the considerable achievement of the Paris Accords of 2015[2] and more recent UN Climate Change Conferences, pledges to reduce our carbon emissions are still only enough to hold temperature increases at around 3.3°C. A business-as-usual approach will result in global temperature increases of more than 4°C, with significant consequences for many. Whatever our success in limiting greenhouse gas emissions, feeding the world in the future will certainly not get any easier.

Different countries and regions of the world are starting to develop policies to address a broad range of planetary degradation and many of the changes necessary to bring about change are encapsulated in the UN Sustainability Goals (SDGs), which will provide much-needed targets for societal change. People and governments from many regions are demanding change and asking for development of national strategies and China has been prominent in this regard. Much of the stimulus for this issue has come from developments at China Agricultural University where to

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support the implementation of interdisciplinary research innovations necessary for AGD, the National Academy of Agriculture Green Development and the International School of Agriculture Green Development were launched in July 2018. These centers of excellence have been established in line with strong developing government policies for green development and rural revitalization in this area of concern in China and many other countries.

Shen et al. (this issue) note that as a result of a green revolution in China which resulted in startling increases in agricultural productivity, China has succeeded in producing 25% of the world grain harvest and feeding 20% of the global population while using less than 10% of world arable land (https://doi.org/10.15302/J-FASE-2019300). Currently, China is the largest producer of cereals, cotton, fruit, vegetables, meat, poultry, eggs and fishery products. However, this advance in food production has not been without its problems. One example of this is a doubling of grain production since 1978, accompanied by a threefold increase in nitrogen (N) fertilizer use, an eleven-fold increase in phosphorus (P) fertilizer use, and a 1.5-fold increase in irrigation water use. Shen and coauthors outline the measures proposed in the National Academy program that will address a broad range of China’s land use as well as AGD challenges and note that the approaches taken will be relevant also in a number of developing countries in the region. The major objective of AGD is to coordinate “green” with “development”, and realize the transformation of current agriculture with high resource consumption and high environmental costs towards a green agriculture and countryside with high productivity, high resource use efficiency and low environmental impact. Three key aspects for AGD involve interdisciplinary innovations, whole food chain improvement and regional solutions, with four themes of green crop production system, integrated animal-crop production systems, green food products and industry, and rural environment and ecosystem services. Such a broad approach is critical for realizing AGD and even delivery of progress on achieving the SDGs (https://doi.org/10.15302/J-FASE-2019300). Importantly and in agreement with the proposals of Willet et al., the focus of change should be on planetary health and human health as affected by food

quality[3].

In a related paper, Liu et al. (this issue) define a green eco-environment as including four key elements or measures (https://doi.org/10.15302/J-FASE-2019297): (1) a green eco-environmental indicator system, (2) environmental monitoring and warning networks, (3) emission standards and environmental thresholds for key pollutants, and (4) emission controls and pollution remediation technologies. They describe how Quzhou County (a typical county in the central North China Plain) has been developed as a demonstration area to show how detailed air, water and soil monitoring networks as well as improved farmer practices and pollution control measures (especially ammonia emission mitigation and PM2.5 pollution reduction) can begin to create a green ecoenvironment in China.

One of the foci in the National Academy program is recoupling of livestock and feed production systems. This is a focus of the paper by Chadwick et al. (this issue) who highlights the challenge of reducing nutrient accumulation in regions with little available land bank, while minimizing the risk of pollution swapping from one region to another (https://doi.org/10.15302/J-FASE-2019293). In China, increasing quantities of manure must be managed as diets change and demand for animal protein increases. Chadwick et al. review strategies to improve management at each stage of the manure management chain, and at different scales. These authors stress that a range of stakeholders are needed to support the step change and innovation required to improve manure management, reduce reliance on inorganic fertilizers, and generate new business opportunities (https://doi.org/10.15302/J-FASE-2019297).

Another innovative approach for increasing nutrient use efficiencies in agriculture is described by Cui et al. (this issue), namely an integrated soil-crop system management (ISSM), a strategy designed to deliver more grain production with greater nutrient use efficiencies and less environmental pollution (https://doi.org/10.15302/J-FASE2019295). The ISSM approach has been used in China on thousands of farms, to substantially increase the yields of maize, rice and wheat while simultaneously increasing nitrogen efficiency and reducing environmental footprints. The paper reports successes at local and regional levels across the nation.

As noted above, greenhouse gas emissions from agricultural systems have a disturbingly large effect on global warming. In this issue, Rees et al. note that nitrous oxide emissions make up a significant part of the agricultural contribution to greenhouse gas emissions (https://doi.org/10.15302/J-FASE-2019294). There is an urgent need to identify new approaches to the mitigation of these emissions. Rees et al. suggest that precision management of agricultural systems offers the opportunity for nitrous oxide mitigation without any reduction in productivity. These approaches depend upon new sensor technology, modeling and spatial information on which to make management decisions and interventions that can improve both agricultural productivity and environmental protection.

Importantly most of the options assessed by the National Academy as means to reduce the environmental footprint of agriculture contribute positively to sustainable development and other more general societal goals and often provide multiple co-benefits. These are points also made in the IPCC report discussed above[1]. The IPCC panel notes that sustainable land management can prevent and reduce land degradation, maintain productivity, and sometimes reverse the adverse impacts of climate change. They stress that reducing and reversing land

William J. DAVIES & Jianbo SHEN. Reducing the environmental footprint of food and farming with Agriculture Green Development 3

degradation, at scales from individual farms to entire watersheds, can provide cost effective, immediate and longterm benefits to communities and support several SDGs. Davies et al. (this issue) have also stressed the importance of setting goals not just for climate change remediation but more generally for societal development (https://doi.org/ 10.15302/J-FASE-2019299), as exemplified by the SDGs. These authors note the importance of the production of nutritious food (not just more food) as diet-related health problems are now increasingly common in many countries. Hassan et al. (this issue) summarize the developmental history of green food in China and current achievements, analyze major challenges that may hamper further development of the industry, and propose strategies to address these challenges, i.e., optimization of food supply chain, deep food processing, and reutilization of food wastes (https://doi.org/10.15302/J-FASE-2019296). Davies et al. also highlights developments in crop science (genetics and agronomy) and engineering science that can help develop a revolution in food and farming (https://doi.org/ 10.15302/J-FASE-2019299).

The focus of the paper by Firbank (this issue) is on the sustainable intensification of agriculture as a component of AGD (https://doi.org/10.15302/J-FASE-2019291). Other authors in this issue highlight the importance of developments in this area, as do Willett et al. in a very important paper where they propose a diet for the planet[3]. Munier-Jolain and Lechenet (this issue) has stressed the importance of redesigning cropping systems for improving agricultural sustainability and focusses attention on participatory research based on farm networks as a way of revolutionizing agricultural practice (https://doi.org/10.15302/J-FASE-2019292).

There is also general consensus through this issue on the key role of effective knowledge exchange (KE) mechanisms in ensuring that appropriate innovations are brought to the attention of practitioners and that researchers properly appreciate the food production practice in different societies. It is equally important that the general public is involved in conversations about an agricultural revolution. The paper by Smith (this issue) analyzes the public policy challenge of agricultural green development and makes the case for a location-sensitive policy mix made up of regulation, advice provision, voluntarism and targeted incentives (https://doi.org/10.15302/J-FASE2019290). Smith notes that the public agricultural extension service in China is a key resource, but one that requires reorientation and reform with the aim of better balancing high farm productivity with environmental protection. In a further policy-focused paper, Lu et al. (this issue) examines how the negative environmental consequences of intensive agriculture have driven China and the UK to shift away from narrowly focused farm output policies and adopt more holistic green development pathways (https://doi.org/10.15302/J-FASE-2019298). He then explores the policy objectives they have in common and assesses the numerous opportunities for joint research and knowledge sharing through the Sustainable Agriculture Innovation Network (SAIN) and other existing institutional mechanisms.

The IPCC report introduced above makes several important policy recommendations, points which are also emphasized by authors in this issue. We highlight several of the key IPCC points relevant to the focus of this issue and to the establishment of a broad-scope National Academy of Agriculture Green Development:

1. Appropriate design of policies, institutions and governance systems.
2. Policies that operate across the whole food system, including those that reduce food loss and waste and influence dietary choices.
3. The adoption of sustainable land management and poverty eradication can be enabled by improving access to markets, securing land tenure, factoring environmental costs into food, making payments for ecosystem services, and enhancing local and community collective action.
4. The effectiveness of decision-making and governance is enhanced by the involvement of local stakeholders.

We hope that the breadth and coverage of AGD in this issue will be of value to those who have a commitment to revolutionizing food and farming to the benefit of human and planetary health.

Reducing our environmental footprint

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before diagnosis. In addition, these participants have a higher risk of death. Subjects without dietary information (n = 154) were excluded. To exclude implausible values, participants in the highest and lowest 0.5% of the ratio of reported energy intake (based on the food frequency questionnaire (FFQ)) on energy requirement (estimated on the basis of basal metabolic rate (BMR)) were also excluded (n = 662). After these exclusions, 35 057 participants remained for the all-cause mortality survival analysis.

Diet and environmental impact assessment

Usual daily dietary intake was estimated by a 178-item FFQ that has been validated against twelve 24-h recalls, and biomarkers in 24-h urine and blood [22,23]. Spearman rank correlation coefficients based on estimates of the FFQ and 24-h recalls were 0.51 for potatoes, 0.36 for vegetables, 0.68 for fruits, 0.39 for meat, 0.69 for dairy, 0.76 for sugar and sweet products, and 0.52 for biscuits and pastry in men. Results for women were similar.

Blonk Consultants assessed the environmental impact of the Dutch dietary habits [3]. To estimate sustainability scores, life cycle assessments (LCA) were performed for 254 food items. The LCA’s were cradle to grave and included production, processing, packaging, transport, storage, preparation, cooking, avoidable and unavoidable food waste (inedible parts) at home, and waste incineration. GHGE covers carbon dioxide (C02) emissions through the use of fossil fuels, methane (CH4) released during the rearing of cattle and the cultivation of certain crops, and nitrous oxide (N20) released from fertilizers, manure and ploughing of grassland [24,25]. GHGE is expressed as kg CO2-equivalents per day. Land use covers the surface needed for the production of food [24,25] and is expressed as m2\*year per day. These LCA data were combined with the EPIC-NL FFQ data to calculate individual daily greenhouse gas emission and land use for each of our participants. The LCA scores were based on current production practices and assumed equal in the nineties when the FFQ was assessed.

Participants characteristics

At baseline, study participants completed a questionnaire on the presence of chronic diseases and related potential risk factors, and medical and lifestyle factors [18]. Body mass index (BMI) was calculated by dividing weight by height squared. Educational level was coded in low (lower vocational training or primary school), medium (intermediate vocational training or secondary school), or high (higher vocational training or university). The smoking of cigarettes, pipe, or cigars was categorized as current, former, and never. Physical activity was assessed with the validated Cambridge Physical Activity Score (CPAI) [26].

Mortality assessment

Vital status of all EPIC-NL participants was obtained through linkage with the municipal population registries. The information on vital status for the EPIC-NL cohort is complete until 11 April 2011 for MORGEN and until 4 July 2011 for PROSPECT. These data were retrieved from the GBA (Dutch Municipality Basic Administration).

Participants were followed for the occurrence of cancer, cardiovascular disease, respiratory disease and other causes by linkage to several disease registries (Dutch Cancer Registry and Dutch Hospital Discharge Diagnosis Database). Primary cause of death was coded according to the International Classification of Diseases (ICD). Incidence of cancer deaths was coded as 140–239 (ICD-9) or C00-D48 (ICD-10), incidence of cardiovascular disease (CVD) deaths as 390–459 (ICD-9) or I00-I99 (ICD-10), incidence of respiratory system disease mortality as 460–519 (ICD-9) or J00-J99 (ICD-10). The remaining causes of death were merged into the category ‘other causes’. Cause-specific mortality data were available until 31 December 2010. This is the most recent linkage to the database of Statistics Netherlands.

Statistical analysis

Participants were followed over time until death from any cause, loss to follow-up, or were censored on 11 April 2011 for MORGEN and 4 July 2011 for PROSPECT. In the cause-specific mortality analysis, the censor date was 31 December 2010 for both cohorts.

Cox proportional hazard models were used to estimate crude and adjusted hazard ratios (HRs) with 95% confidence intervals (CI) for GHGE and land use in association with mortality. Using manual backward selection, covariates were excluded from the final model when the HR did not change ≥10% [27]. This manual selection was performed because no other prospective studies investigated the effect of the environmental impact of the diet, and therefore, there are no established confounders. The covariates BMI, educational level, smoking habits, physical activity, alcohol intake, and waist circumference were omitted from the final model whereas age and gender were retained. The covariate age failed to meet the proportional hazards assumption according to the Schoenfeld residuals test (p < 0.0001). Adjusted models were Cox stratified by age (continuous) to correct for this. To test for linear trends across categories, we modelled GHGE and land use by including the median value of each quartile as a continuous variable. By adding interaction terms to the model, we assessed deviation from multiplicative interaction for age, sex, BMI, smoking, and waist circumference. None of these factors modified the studied association. A test model in which quartiles of exposure were created from total GHGE and land use divided by total energy intake, GHGE/kJ and m2/kJ, showed very similar results (results not shown).

To study the effect of a modelled substitution of meat by other food components, both meat and the replacement component were added as continuous variables in the same multivariate model. Similar to previous studies, the difference in the parameter estimates and covariance was used to estimate HR and 95% CI [16,17]. The models were adjusted for major dietary and lifestyle factors (age, gender, BMI, smoking status, physical activity, energy intake, and alcohol intake). The investigated substitution component sources were potatoes, total vegetables, total fruit-nuts-seeds, pasta-rice-couscous, cheese, milk-based desserts, or fish. These food groups were selected because they can replace meat in a hot meal. In addition, they represent highly acceptable food products that are consumed in significant amounts in the current Dutch diet (Tables 1 and 2), and thus represent acceptable substitutions for meat. The modelled substitution was a one-third reduction (35-gram) of the average (105-gram, standard deviation of 55-gram) total daily meat intake in EPIC-NL. For realistic scenarios, we substituted by equal food weight and not the same amount of dietary energy. For example, in case of applying iso-caloric substitutions, an additional 300 gram of vegetables is needed to compensate for the energy intake of 35 gram of meat and this was assumed not to be realistic. Another argument for substitution based on food weight is that a large part of the adult Dutch population is overweight. This suggests that energy intake is high compared with energy requirements. Effects

Table 1 Contribution of different food groups to daily intake and environmental impact in EPIC-NL

|  |  |  |  |
| --- | --- | --- | --- |
| Food group | Gram/d (%) | C02–eq (%) | Land use (%) |
| Potatoes | 3.5 | 1.9 | 1.2 |
| Vegetables | 4.4 | 5.5 | 3.6 |
| Legumes | 0.3 | 0.3 | 0.3 |
| Fruit, nuts and seeds | 6.9 | 5.6 | 4.4 |
| Dairy  Cheese | 1.3 | 11.6 | 7.7 |
| Milka | 9.4 | 9.5 | 6.5 |
| Milk-based dessertsb | 3.5 | 4.1 | 2.6 |
| Meat  Non-processed meatc | 2.5 | 25.7 | 28.1 |
| Processed meatd | 1.1 | 5.6 | 6.1 |
| Cereals  Bread products | 5.0 | 3.4 | 4.8 |
| Pasta, rice and couscous | 1.6 | 1.5 | 2.6 |
| Fish | 0.4 | 2.1 | 0.8 |
| Egg | 0.5 | 1.2 | 1.8 |
| Fat | 0.9 | 2.3 | 5.0 |
| Sugar and confectionary | 1.5 | 2.5 | 1.7 |
| Cake and biscuits | 1.0 | 2.1 | 3.6 |
| Beverages  Non-alcoholic | 48.0 | 9.4 | 10.9 |
| Alcoholic | 4.8 | 3.4 | 5.1 |
| Condiments and sauces | 0.7 | 0.8 | 1.2 |
| Soups | 2.4 | 0.6 | 0.2 |
| Miscellaneous | 0.3 | 2.1 | 2.0 |

aconsists of milk, milk beverages (chocolate milk), and coffee milk; bconsists of (fruit)yoghurt, cream desserts, and milk-based puddings; cnon-processed meat: beef, pork, and chicken; dprocessed meat: liver-containing items, ham, and miscellaneous types.

on environmental impact were based on the food group average GHGE and land use. The average environmental impact of meat was based on the proportional daily intake, i.e. non-processed meat accounts for 80% of total gram per day intake of meat.

All statistical analyses were performed using SAS software (version 9.3, SAS Institute Inc., Cary, NC, USA). A two-sided p-value of <0.05 was considered statistically significant.

Results

During a median follow-up of 15.9 years, 2563 deaths were registered. The observed EPIC-NL cohort median value of GHGE was 3.87 kg CO2-equivalents/d and for land use 3.61 m2\*year/d. While contributing 3.6% of daily intake weight (and 11% of daily energy intake), total meat intake accounts for approximately 30% of total dietary-derived GHGE and land use (Table 1). The impact of dairy and beverage consumption on the environment is substantial (dairy: 25% of GHGE and 17% of land use; beverages: 13% of GHGE and 16% of land use).

A higher energy, vegetables, fruits, dairy, meat, cereals, fat, soups, and alcohol intake, a lower age, an increased proportion of men, smokers, and higher activity level were associated with a higher environmental impact of usual diet. Educational level, waist to hip ratio, and body mass index (BMI) differed only slightly between the highest and lowest quartiles of GHGE and land use

(Table 2).

In the crude Cox proportional hazards analyses, we observed an inverse association of total greenhouse gas emission of usual diet with all-cause mortality. The HR (95% confidence interval) of highest versus lowest quartile of GHGE was 0.76 (0.68-0.85) (Table 3). After multivariable adjustment, model 1, no association with risk was seen (HR of 1.00 (0.86-1.17)). Additional adjustment for energy intake, model 2, did not change the association. The findings from the fully adjusted model, all possible confounders included, were essentially similar to the sparsely adjusted model (model 1). Hazard ratios of highest versus lowest quartile of GHGE for adjusted cause-specific mortality models were for cancer 1.01 (0.86-1.34), CVD 0.90 (0.63-1.28), 1.12 (0.52-2.39) for respiratory diseases, and 0.91 (0.64-1.30) for other causes of death.

In crude analysis, total land use of usual diet was inversely associated with all-cause mortality (HR of highest versus lowest quartile: 0.74 (0.66-0.82)) (Table 4). However, after multivariable adjustment, we found a statistically non-significant HR of 1.05 (0.89-1.23). Correction for energy intake did not alter the association. Cause-specific adjusted HR’s were 1.10 (0.88-1.37) for cancer, 1.07 (0.751.54) for CVD, 1.19 (0.58-2.46) for respiratory diseases, and 0.88 (0.61-1.27) for deaths by remaining causes.

Modelling a substitution of 35 g/d of total meat intake by an equal amount of potatoes, pasta-rice-couscous, vegetables, fruit-nuts-seeds, milk-based desserts, fish, or cheese has environmental or health benefits (table 5). Reductions in total daily greenhouse gas emissions were 10.8% for potatoes, 10.1% for pasta-rice-couscous, 10.0% for vegetables, 10.0% for fruits-nuts-seeds, 10.0% for milkbased desserts, 4.5% for fish, 0.6% for cheese, and 11.5% for reducing meat intake by 35 gram without replacements based on the average carbon footprint of the usual diet in EPIC-NL. Reductions in land use were 11.3% for potatoes,

9.7% for pasta-rice-couscous, 10.8% for vegetables, and

10.3% for fruit-nuts-seeds, 10.9% for milk-based desserts, 9.8% for fish, 4.5% for cheese, and 11.7% without any replacement. In addition, favourable health effects of the substitutions were observed. When compared, 35 gram of pasta-rice-couscous instead of meat was associated with an 11% (95% CI, 4% to 16%) lower risk. A substitution by vegetables was associated with a 9% (95% CI, 3% to 15%)

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| Table 2 Baseline characteristics by dietary greenhouse gas emission and land use in EPIC-NL  Greenhouse gas emission (CO2-eq/d) Land use (m2\*year/d)   |  |  |  |  |  | | --- | --- | --- | --- | --- | | Characteristic | Quartile 1 <3.26 | Quartile 4 >4.56 | Quartile 1 <2.99 | Quartile 4 >4.28 | | No. of subjects | 8770 | 8769 | 8769 | 8769 | | No. of deathsa | 736 (8.4) | 570 (6.5) | 741 (8.5) | 558 (6.4) | | Person-yearsb | 15.8 (14.6-17.0) | 16.0 (14.7-17.2) | 15.8 (14.6-16.9) | 16.0 (14.7-17.2) | | GHGEb,c | 2.86 (2.56-3.07) | 5.12 (4.79-5.62) | 2.84 (2.55-3.14) | 5.10 (4.71-5.62) | | Land useb, d | 2.62 (2.31-2.88) | 4.78 (4.42-5.28) | 2.61 (2.31-2.82) | 4.80 (4.51-5.28) | | Age (years)b | 52 (44–59) | 48 (37–54) | 53 (44–60) | 48 (37–54) | | Male gendera | 896 (10.2) | 4521 (51.6) | 766 (8.7) | 4727 (53.9) | | BMI (kg/m2)b | 24.8 (22.4-27.1) | 25.5 (23.2-28.0) | 24.7 (22.3-27.0) | 25.5 (23.2-28.0) | | High education levela,e | 1601 (18.4) | 2025 (23.3) | 1640 (18.8) | 2141 (24.6) | | Current smokersa | 2466 (28.2) | 3086 (35.3) | 2179 (25.0) | 2607 (29.8) | | CPAI-‘active’a,f | 3249 (37.1) | 2488 (48.2) | 3379 (38.5) | 4070 (46.4) | | Waist circumference (cm)b | 81.0 (74.3-89.0) | 87.3 (80.0-95.8) | 81.0 (74.0-89.0) | 87.8 (80.0-96.0) | | Energy intake (MJ)b | 6.4 (5.6-7.3) | 11.0 (9.4-12.8) | 6.4 (5.6-7.4) | 10.9 (9.43-12.8) | | Ratio EI/BMRb,g | 1.1 (1.0-1.3) | 1.6 (1.4-1.9) | 1.1 (1.0-1.3) | 1.6 (1.4-1.9) | | Alcohol use (g)b | 2.1 (0.2-9.1) | 10.3 (2.2-24.0) | 1.5 (0.1-6.6) | 12.9 (3.5-28.0) | | Dietary intakeb  Potatoes | 69 (41–105) | 122 (75–179) | 66 (41–101) | 123 (76–180) | | Vegetables | 108 (82–140) | 138 (107–175) | 111 (84–145) | 134 (105–171) | | Legumes | 5 (2–11) | 8 (3–15) | 5 (2–11) | 8 (3–15) | | Fruit, nuts & seeds | 142 (92–250) | 192 (118–300) | 171 (109–262) | 170 (104–274) | | Dairy | 261 (143–402) | 533 (321–763) | 308 (171–466) | 453 (258–683) | | Non-processed meath | 41 (23–58) | 99 (84–125) | 36 (21–51) | 101 (87–126) | | Processed meati | 15 (6–27) | 40 (22–48) | 14 (5–23) | 43 (25–67) | | Cereals | 148 (11–193) | 233 (171–311) | 147 (111–191) | 238 (174–315) | | Fish | 6 (2–14) | 10 (−17) | 7 (2–14) | 9 (4–16) | | Egg | 11 (5–18) | 16 (9–29) | 11 (5–18) | 17 (10–29) | | Fat | 20 (13–28) | 34 (23–48) | 19 (12–27) | 36 (24–49) | | Sugar & confectionary | 31 (17–50) | 48 (27–76) | 31 (18–50) | 47 (25–76) | | Cake & biscuits | 22 (11–37) | 27 (14–45) | 22 (11–37) | 26 (13–44) | | Beverages | 1325 (1041–1670) | 1717 (1368–2140) | 1327 (1038–1678) | 1726 (1395–2135) | | Condiments & sauces | 12 (5–22) | 22 (11–33) | 11 (5–22) | 23 (12–34) | | Soups | 36 (17–72) | 72 (33–107) | 36 (17–72) | 72 (33–107) | | Miscellaneous | 5 (2–11) | 7 (3–15) | 6 (2–11) | 8 (4–15) |   a b th c  Values displayed as frequency (percentage); Values displayed as median with interquartile range (25-75 percentile); GHGE: greenhouse gas emission (C02-eq/d);  d 2 e f g  Land use (m \*year/d); college or university degree; Cambridge Physical Activity Score (inactive, moderately inactive, moderately active, active); Ratio of energy intake (EI) and basal metabolic rate (BMR); hnon-processed meat: beef, pork, and chicken; iprocessed meat: liver-containing items, ham, and miscellaneous types. |

lower risk of all-cause mortality and by fruit-nuts-seeds with a 6% (95% CI, 1% to 10%) lower risk. A shift to 35 gram more milk-based dessert was associated with a borderline non-significant 4% (95% CI, 0% to 9%) lower risk. Substitution by fish was associated with a 19% (95% CI, 3% to 33%) lower risk. 35 gram more cheese instead of meat (HR: 6% (95% CI, −4% to 14%)) or potatoes (HR: 0% (95% CI, −6% to 7%)) was not associated with a lower allcause mortality risk. Reducing intake of total meat by 35

gram without replacement was associated with a 4% (95% CI, 2% to 7%) lower mortality risk.

Discussion

In this large prospective cohort of Dutch men and women, we observed that the total environmental impact of usual diet was not associated with all-cause or cause-specific mortality. This indicates that an environmental friendlier diet is not necessarily a healthier diet.

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| Table 3 Data for mortality risks according to greenhouse gas emissions of usual diet in EPIC-NL  Greenhouse gas emission (CO  2  -  eq/d  )  P  for  linear trend  <3.26  3.26 - 3.87  3.87 - 4.56  >4.56  All-cause mortality   |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | | No. of participants | 8770 | 8769 | 8771 | 8769 |  | | No. of deaths | 736 | 671 | 586 | 570 |  | | Person-years, median | 15.8 | 15.9 | 15.8 | 16.0 |  | | Crude HRa (95% CI) | 1 (REF) | 0.90 (0.81-1.00) | 0.79 (0.71-0.88) | 0.76 (0.68-0.85) | P < 0.0001d | | Model 1b HR | 1 | 0.97 (0.84-1.12) | 0.90 (0.77-1.05) | 1.00 (0.86-1.17) | P = 0.7959 | | Model 2b,c HR  Cause-specific mortality  Cancer | 1 | 0.96 (0.82-1.11) | 0.87 (0.74-1.03) | 0.95 (0.77-1.15) | P = 0.4266 | | No. of deaths | 327 | 324 | 274 | 268 |  | | Crude HRa (95% CI) | 1 (REF) | 0.99 (0.85-1.15) | 0.83 (0.71-0.98) | 0.81 (0.69-0.96) | P = 0.0031d | | Model 1b HR  CVD | 1 | 1.01 (0.89-1.33) | 0.93 (0.75-1.16) | 1.01 (0.86-1.34) | P = 0.7654 | | No. of deaths | 164 | 146 | 115 | 120 |  | | Crude HRa (95% CI) | 1 (REF) | 0.89 (0.71-1.11) | 0.70 (0.55-0.89) | 0.73 (0.57-0.92) | P = 0.0023d | | Model 1b HR  Respiratory diseases | 1 | 0.92 (0.67-1.26) | 0.83 (0.59-1.17) | 0.90 (0.63-1.28) | P = 0.4681 | | No. of deaths | 41 | 37 | 32 | 27 |  | | Crude HRa (95% CI) | 1 (REF) | 0.90 (0.58-1.40) | 0.78 (0.79-1.23) | 0.65 (0.40-1.06) | P = 0.0687 | | Model 1b HR  Other causes | 1 | 1.01 (0.53-1.91) | 0.76 (0.39-1.49) | 1.12 (0.52-2.39) | P = 0.9945 | | No. of deaths | 157 | 124 | 128 | 120 |  | | Crude HRa (95% CI) | 1 (REF) | 0.79 (0.62-0.99) | 0.81 (0.64-1.02) | 0.76 (0.60-0.96) | P = 0.0334d | | Model 1b HR | 1 | 0.83 (0.59-1.15) | 0.96 (0.68-1.35) | 0.91 (0.64-1.30) | P = 0.7902 |   a b c  HR: hazard ratio; Cox stratified for age (continuous) and adjusted for sex; Additional adjusted for energy intake. |

dp value for linear trend significant (p < 0.05).

Even though meat only contributed for 3.6% to the total weight of daily intake in grams, it is responsible for approximately 30% of dietary greenhouse gas emission and land use. A 35 g/d reduction or shift from total meat intake to vegetables, fruit-nuts-seeds, pasta-rice-couscous, or fish would significantly increase survival rates (4-19%), reduce GHGE (4-12%), and land use (10-12%).

In this study, the environmental burden of the usual diet was divided into quartiles of total GHGE and land use to analyse the influence of diets with a higher impact on the relative risk for mortality. For this division no impact on mortality risk was observed in the Cox survival models. Other studies have suggested that a healthier diet may also be more sustainable [3,15]. A diet according to the Dutch Dietary Guidelines would result in 8% less GHGE and decrease land use by 21% compared to the average diet. However, a healthier diet and diet with a lower environmental impact do not necessarily need to be equally sustainable. For example, a healthy diet that includes fruits and vegetables with a high GHGE, rice instead of pasta or potatoes and more meat has twice the GHGE compared to an equally healthy low-GHGE diet [28]. On the other hand, a less healthy diet, with high quantities of sugars and refined carbohydrates, small quantities of meat, fruits and vegetables, can also have a low GHGE. Our modelled substitution scenario resulted in healthier diets with reduced environmental impact. Substitutions of meat lead to a double benefit in both health and reduced environmental impact aspects. However, a healthier diet is not necessarily accompanied by a lower GHGE or less land use.

The Dutch diet is relatively high in animal-derived products and refined carbohydrates and low in fruit and vegetables. Within the dietary range of this cohort, there was no significant association between the overall daily GHGE and land use and mortality. Although total GHGE and land use were not associated with mortality, modelling a one-third reduction of total meat, a major contributor to dietary GHGE and land use, resulted in both reduced mortality risk as well as reduced environmental impact.

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| Table 4 Data for mortality risks according to total land use of usual diet in EPIC-NL  Land use (m  2  \*year/d)  P  for  linear trend  <2.99  2.99 - 3.61  3.61  –  4.28  >4.28  All-cause mortality   |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | | No. of participants | 8769 | 8771 | 8770 | 8769 |  | | No. of deaths | 741 | 669 | 595 | 558 |  | | Person-years, median | 15.8 | 15.9 | 15.8 | 16.0 |  | | Crude HRa (95% CI) | 1 (REF) | 0.89 (0.80-0.99) | 0.79 (0.71-0.88) | 0.74 (0.66-0.82) | P < 0.0001d | | Model 1b HR | 1 | 0.99 (0.86-1.15) | 0.99 (0.85-1.14) | 1.05 (0.89-1.23) | P = 0.6190 | | Model 2b,c HR  Cause-specific mortality  Cancer | 1 | 0.99 (0.85-1.14) | 0.97 (0.82-1.15) | 1.03 (0.84-1.25) | P = 0.8534 | | No. of deaths | 326 | 317 | 282 | 268 |  | | Crude HRa (95% CI) | 1 (REF) | 0.97 (0.83-1.13) | 0.86 (0.73-1.01) | 0.82 (0.69-0.96) | P = 0.0057d | | Model 1b HR  CVD | 1 | 1.05 (0.86-1.29) | 0.99 (0.80-1.22) | 1.10 (0.88-1.37) | P = 0.5291 | | No. of deaths | 164 | 151 | 112 | 118 |  | | Crude HRa (95% CI) | 1 (REF) | 0.91 (0.73-1.14) | 0.68 (0.53-0.86) | 0.71 (0.56-0.90) | P = 0.0010d | | Model 1b HR  Respiratory diseases | 1 | 1.03 (0.75-1.41) | 0.97 (0.68-1.37) | 1.07 (0.75-1.54) | P = 0.7666 | | No. of deaths | 44 | 30 | 34 | 29 |  | | Crude HRa (95% CI) | 1 (REF) | 0.68 (0.42-1.07) | 0.77 (0.49-1.20) | 0.65 (0.41-1.04) | P = 0.1086 | | Model 1b HR  Other causes | 1 | 0.81 (0.42-1.56) | 0.97 (0.49-1.90) | 1.19 (0.58-2.46) | P = 0.5950 | | No. of deaths | 162 | 133 | 122 | 112 |  | | Crude HRa (95% CI) | 1 (REF) | 0.81 (0.65-1.02) | 0.75 (0.59-0.95) | 0.68 (0.54-0.87) | P = 0.0016d | | Model 1b HR | 1 | 0.83 (0.60-1.16) | 0.98 (0.70-1.36) | 0.88 (0.61-1.27) | P = 0.6518 |   a b c  HR: hazard ratio; Cox stratified for age (continuous) and adjusted for sex; Additional adjusted for energy intake. |

dp value for linear trend significant (p < 0.05).

The 35-gram reduction of meat was well within the intake variation (standard deviation) of 55 gram and is thus a realistic scenario. Meat intake has been linked to an increased risk of mortality before [29]. In addition, other meat substitution studies reported reduced mortality [17] or cardiovascular risks [16]. Temme et al. showed that a complete replacement of meat and dairy by a variety of plant-derived foods would not affect total iron intake, reduce saturated fatty acid intake, and reduce land use by around 50% in Dutch female young adults [30].

Substituting high-GHGE with low-GHGE meats could also contribute to increased survival rates and reduced environmental impact. Replacing red meat with poultry would reduce the environmental impact (data Blonk Consultants ) and is associated with reduced mortality risk [17]. In addition, processed meat intake appears to be stronger associated with several morbidity outcomes than red meat [31]. Replacement of meat by fish can be considered controversial from an ecological point of view, because of sustainability concerns of the current ocean fishing and fish cultivation practices.

A New Zealand study presented findings of scenario development with linear programming that determined several dietary patterns to cover nutrient intake at low cost and low GHGE profiles [32]. The study suggests that these results could provide guidance to governments decisions around the focus of their food policies, i.e. food taxes, healthy food vouchers and subsidies. An UK study investigated the effect of incorporating the societal cost of GHGE into the price of foods [33]. A scenario in which a higher taxation rate is calculated for foods above GHGE average shows that this could save 7770 lives in the UK each year, reduce GHGE and generate tax revenue. These studies highlight the potential benefits of such policy measures on health and environment impact of the diet.

Table 5 Environmental impact of 35 gram modelled meat substitution by predefined food groups and all-cause mortality

|  |  |  |  |
| --- | --- | --- | --- |
| Substitute | Reduction GHGE (%)a | Reduction land use (%)a | Reduction mortality risk  (%, 95% CI)b |
| Potatoes | 10.8 | 11.3 | 0 (−6 – 7) |
| Pasta-ricecouscous | 10.1 | 9.7 | 11 (4 – 16) |
| Vegetables | 10.0 | 10.8 | 9 (3 – 15) |
| Fruit, nuts and seeds | 10.0 | 10.3 | 6 (1 – 10) |
| Milk-based dessertsc | 10.0 | 10.9 | 4 (0 – 9) |
| Fish | 4.5 | 9.8 | 19 (3 – 33) |
| Cheese | 0.6 | 4.5 | 6 (−4 – 14) |
| Remove 35 gram meat  (No replacement) | 11.5 | 11.7 | 4 (2 – 7) |

aBased on the average greenhouse gas emission (GHGE) and land use in EPIC-NL; bCox stratified for age (continuous) and adjusted for gender, BMI (continuous), smoking status, physical activity, energy intake (continuous), and alcohol intake (continuous); c: consists of (fruit)yoghurt, cream desserts, and milk-based puddings.

Our study has some strengths and limitations. The combination of sustainability of the usual diet and health was not previously studied in a large prospective cohort with a follow-up time of 16 years. The participants of this cohort were sampled from four different geographic areas in the Netherlands and therefore the results may be extrapolated to the Dutch population. In addition, mean GHGE and land use in our cohort were similar to the Dutch Consumption Survey of 1998 [3]. The dietary assessment took place only in the nineties, while nowadays people might have different eating patterns and eat foods that are produced differently. A FFQ is designed to rank people according to their diet. Therefore, the modelled substitution of the 35 g/d of meat was not based on actual intake but was estimated with usual intake. However, our outcomes clearly demonstrate health and environmental benefits from a dietary shift towards lower meat consumption.

The scope of this study is limited to substitutions of an equivalent quantity in grams. Future research may include iso-caloric substitutions or nutritional component equivalency of meat substitutions. In addition, within food groups the environmental impact can vary per product due to farming methods, animal feed, use of side products, transport, and growing conditions [24]. Taking the variety of distributions of environmental impact for every stage of the production process would allow for variance estimation of the environmental impact of a food group. This would further improve the GHGE and land use estimates used in our study. Other research may focus on the role of governmental decisions on consumer behaviour and its efficacy. Examples of governmental actions could be a foodlabelling system that indicates GHGE per 100-gram product, food taxes based on a combination of health aspects and environmental impact of a product, or media campaigns to inform consumers of environmental impact of foods.

Conclusions

The Dutch diet is relatively high in animal-derived food products and refined carbohydrates and low in fruit and vegetables. Within the dietary range of this populationbased cohort, there were no significant associations between overall daily dietary-derived GHGE and land use and mortality. However, a modelled reduction of 35 gram meat which was replaced with vegetables, fruits, fish, or cereal-rice-couscous resulted in lower GHGE and land use as well as decreased all-cause mortality risk. The results of our study emphasise that a healthier diet is not necessarily a more sustainable diet, and the other way around. Nevertheless, a reduction of meat consumption can influence both health and environmental aspects.

Abbreviations

BMI: Body mass index; CPAI: Cambridge physical activity index;

EPIC: European Prospective Investigation into Cancer and Nutrition; FFQ: Food frequency questionnaire; GHGE: Greenhouse gas emission; HR: Hazard ratio; 95% CI: 95% confidence interval.

Competing interests

The authors declare that they have no competing interests.

Authors’ contributions

SB carried out the statistical analysis, prepared the tables and figures, and wrote the paper, taking into account comments from all the co-authors. EHMT and HBB-d-M initiated and designed this study. EHMT was the overall project coordinator. HBB-d-M and EHMT were members of the writing group and gave input on the statistical analysis and interpretation of the results. HBB-d-M, PHMP, WMMV, and YTS are members of the EPIC-NL steering committee. All authors provided comments and suggestions on the manuscript and approved the final version.

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