Healthy and Sustainable Diets

Finding co-benefits and trade-offs
for the Netherlands

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Healthy and Sustainable Diets

Finding co-benefits and trade-offs for the Netherlands

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“We did not inherit the earth from our parents,
we borrow it from our children”

Chief Seattle

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MILK

CHAPTER I

General introduction

The need for healthier diets

Unhealthy diets have been identified as one of the most important risk factors for non-communicable diseases (NCDs) in Western countries [1, 2]. Diets high in animal-based foods and low in fruit and vegetables, such as a typical Western diet, have been associated with an increased risk of coronary heart disease (CHD), type II diabetes, and several types of cancer [3-5]. Apart from dietary quality, which is defined as a healthy diet in this thesis, also quantity is an important issue. Caloric intake that exceeds energy expenditure leads to weight gain. This is an increasing problem in Europe, where 52% of the adult population is now overweight or obese [6].

The Dutch Health Council has formulated guidelines for a healthy diet. In their latest 2015 dietary guideline, the overarching recommendation is that the current diet should move away from animal-based foods towards plant-based foods to become healthier [7]. However, only 1 in 10 Dutch adults consumes the recommended amount of fruit and vegetables per day [8]. In addition, the current alcohol, meat, sugar-sweetened beverages, and salt consumption are above and consumption of legumes, nuts, and total fiber are below recommended levels. Also in the Netherlands around 50% of the adult population is currently overweight or obese [9].

Diets for public and planetary health

Diets do not only affect health, but also have a large impact on the environment [10]. Food production systems affect the quantity and intensity of greenhouse gas (GHG) emissions, land use, and eutrophication of water [11]. Food production systems are associated with approximately 25% of the worldwide GHG emissions [12], 80% of the loss of biodiversity [13], 70% of water withdrawals for irrigation [13], and 40% of land use [13]. Therefore, dealing with global warming and other environmental changes is also a major food system challenge [14]. Willett *et al.* recently described the necessity of a transformation of the current dietary patterns [13]. They also introduced the term 'The Great Food Transformation': an urgent call for a transformation of the whole food system, from production to consumption. Changes in dietary consumption patterns are identified as the main priority in decreasing the total environmental impact of our current and future food system [13].

Diet and nutrition are already important themes within the Sustainable Development Goals (SDGs), from a health as well as from an environmental perspective, for example in 'Zero hunger' (SDG 2), 'Good health and well-being' (SDG 3), 'Responsible consumption and production' (SDG 12), and 'Life below water' (SDG 14) [15]. These actions are urgently needed since the total world population is estimated to surpass 9 billion people by 2050 and in combination with the current dietary changes such as increased meat consumption in developing countries a projected 60% increase in food and feed production will be needed [16]. Consequently, an increase in the environmental impact of the food system is foreseen. The 'Great Food Transformation' and the SDGs are urgent calls for the development of more sustainable diets. In 2010, the Food and Agriculture Organization (FAO) proposed a definition of what sustainable diets are [17]:

"*Sustainable diets are those diets with low environmental impacts, which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources*".
FAO (2010)

This definition clearly goes beyond health and environment alone and includes economic and socio-cultural dimensions of the diet as well. This shows the complexity of the healthy and sustainable diet topic.

Future and recommended diets

Willett *et al.* describe what a new 'healthy reference diet' could look like in order to obtain healthier people in their recent EAT-Lancet publication [13]. This proposed 'healthy reference diet' differs from the current Dutch dietary guidelines [7]. In general, the Dutch guidelines and the 'healthy reference diet' are in accordance on which foods should be consumed more (e.g. fruits, vegetables, legumes, and nuts) or less (e.g. meat), but the recommended amounts differ substantially (**Table 1.1**). When comparing the 'healthy reference diet' with the average consumption in the Netherlands between 2012-2016 there are several notable differences [18]. For example, total meat consumption is twice the recommend quantity, whereas legumes and nuts consumption are far below both recommendations. Since the average Dutch diet is even far from the recommendations of the Dutch dietary guidelines, the diet proposed by Willett *et al.* can be seen as the next step, beyond the current guidelines, and as a future aim to strive for. It will take time to make the required major modifications to the current diet and to achieve such a healthy and sustainable diet.

Table 1.1 Comparing the mean Dutch dietary consumption (2012-2016) to the recommended intake by the Dutch dietary guidelines and the 'healthy reference diet' proposed by Willett *et al.* [7, 13, 18].

Food group (g/day)	**Healthy reference diet** [13]	**Dutch Healthy Diet guidelines** [7][a]	**Dutch National Food Consumption Survey** [18]
Whole grains	232	≥90	199
Potatoes	50 (0-100)	-	72
Vegetables	300 (200-600)	≥200	143
Fruit	200 (100-300)	≥200	113
Dairy	250 (0-500)	300-450	333
Meat	43 (0-86)	<45 (red meat) 0 (processed meat)	98
Eggs	13 (0-25)	-	13
Fish	28 (0-100)	15	16
Legumes	75 (0-100)	10	5
Nuts	50 (0-75)	≥15	9

a: When the Dutch dietary guidelines do not quantify a recommendation the cut-off values were based on those defined for the Dutch Healthy Diet index 2015 (DHD15-index) [19], which is based on the Dutch dietary guidelines and the Wheel of Five [20].

Currently, most research on healthy and sustainable diets has used cross-sectional data to study the environmental impact of actual and improved diets (e.g. less meat or other replacements) [21-24]. In addition to a cross-sectional approach, cohort studies can be used as a tool to assess actual observed dietary patterns and their variations, changes over time, and how this might influence the environmental impact as well as long-term health. Such an approach is used in this thesis. As stated in the FAO definition of a sustainable diet, acceptability of diets is also important [17]. In this thesis, we measure dietary consumption patterns as presented in our population, therefore these diets can be considered acceptable. Several indices can be employed that have been developed to assess to what extent people adhere to dietary guidelines. For example the Dutch Healthy Diet 2015 index (DHD15-index, [19]) or Dietary Approaches to Stop Hypertension score (DASH score, [25]). In epidemiological cohort studies, these indices can be applied to link dietary quality, environmental impact, and long-term health outcomes to improve dietary patterns towards healthier and more sustainable diets.

Finding the co-benefits and trade-offs

From decades of advice on healthy diets, we know that it is not easy to implement change. Adding a sustainability component will complicate the public health message. Healthier diets and sustainable diets are not necessarily similar diets [26, 27]. Therefore, it is important to identify where health and sustainability go hand in hand (co-benefits) and where there is friction (trade-offs). Finding dietary components that are both healthy and sustainable will help formulate dietary guidelines that benefit both health and the environment. For example, the current Dutch dietary guidelines recommend a fruit intake of at least 200 gram. When sustainability is taken into account this recommendation becomes more complicated, because selecting specific foods within a food group can affect environmental impact. For instance, although comparable in healthiness, imported exotic fruits have a higher environmental impact than local apples, and the same is true for rice versus local potatoes [26]. Another example is sugar-sweetened beverages: they are unhealthy, but from an environmental perspective, they have a small footprint per millilitre. These trade-offs add to the difficult task of defining diets that are both healthy and sustainable, and recommending these diets to the general public in understandable ways [10]. Insights in co-benefits as well as trade-offs can help include sustainability aspects in new dietary guidelines.

The largest environmental impact of the diet is associated with the production of meat and dairy foods, with an estimated 50% contribution to dietary GHG emissions and 80% to farmland use [21, 28, 29]. From a health perspective, red and processed meat consumption is associated with increased risk for several NCDs such as colorectal cancer [7, 30], while dairy consumption is associated with a decreased risk for type II diabetes and colorectal cancer [7]. Because of the co-benefits, reduced meat consumption is considered a priority for policies on healthy and sustainable diets [31], while for dairy there might be a trade-off between health and environmental impacts.

Changing dietary behaviours

Price measures, such as taxation or subsidies, have an effect on food consumption [32, 33]. Currently, environmental effects of food production, such as GHG emission or water usage, are not reflected in the price of foods [28]. Including a tax on unhealthy and unsustainable foods would incorporate some of these currently unpaid factors in the price of the foods and may potentially guide consumers to make better choices [34]. However, taxing or subsidising foods can have several societal side effects; one stakeholder may bear the costs while another stakeholder benefits from these measures. More insight into these societal side effects is needed to guide decisions on implementing such intrusive price polices. A Social Cost-Benefit Analysis (SCBA) can provide these insights because it estimates and monetizes all effects of a policy and gives a clear view of how costs and benefits are distributed over the various stakeholders [35].

Aim and outline of this thesis

The overall aim of this PhD thesis was to provide insight into how the healthiness of the Dutch diet may be increased while simultaneously lowering its environmental impact with the current observed diet as starting point. We study which co-benefits exist for health on the one hand and sustainability on the other based on observed and recommended diets. In addition, we examine where there are trade-offs between these two, i.e. where these two perspectives create tensions. We investigate the following research questions: 1) What do sustainable and healthy diets look like?, 2) Are health and sustainability associated?, 3) To what extent is adhering to dietary guidelines both healthy and sustainable?, 4) What are the estimated effects of a meat tax or a subsidy on fruit and vegetables in the Netherlands?

To answer most of these research questions, we used data from the Dutch contribution to the European Prospective Investigation into Cancer and Nutrition (EPIC-NL) cohort. The environmental impacts of foods are calculated using Life Cycle Analysis (LCA) (**Appendix Chapter 1**). In this thesis, GHG emissions are the main indicator of environmental sustainability.

This thesis is divided into three parts. In the first part, the focus is on the health and sustainability impact of actual observed diets whereas in the second part adherence to several recommended diets, such as the Dutch dietary guidelines, is assessed. In the third part, the societal effects of food pricing policies for meat or fruit and vegetables in the Netherlands are presented.

Part I: Health and environmental impacts of observed Dutch diets

Chapter 2 describes the overall environmental impact of the Dutch diet as observed in the mid-90s based on data from EPIC-NL. It compares the contribution of food groups to total food consumption and to environmental impact expressed in GHG emissions per day and land use. The associations between GHG emissions of the diet and all-cause and cause-specific mortality risk are presented in order to evaluate whether or not sustainable diets are associated with long-term health. In addition, modelled effects of substitutions of meat by other food groups are presented to investigate whether this could result in a healthier and more sustainable diet for the EPIC-NL population. In **Chapter 3**, dietary change over the course of 20-years in the EPIC-NL cohort is presented to study if during these 20 years diets of participants changed with respect to healthiness and sustainability.

Part II: Health and environmental impacts of recommended dietary patterns

In **Chapter 4** several dietary indices are calculated to assess to what extent participants in the EPIC-NL cohort adhere to guidelines for a healthy diet. The guidelines considered are the Dutch dietary guidelines, those from the World Health Organization, and the diet from the Dietary Approaches to Stop Hypertension trial. Adherence to these guidelines is then associated with health (all-cause mortality) and the environment (GHG emissions). To gain insight into the question to what extent healthy and sustainable diets go together, in **Chapter 5** a data-driven technique is applied to derive dietary patterns in the EPIC-NL cohort that are based on both a dietary quality index (DHD15-index) as well as the GHG emissions of the diet.

Part III: Societal effects of food pricing policies in the Netherlands

In **Chapter 6**, the social costs and benefits of a 15% or 30% meat tax as well as the effects of a subsidy of 10% on fruit and vegetables are estimated in a Social Cost-Benefit Analysis. These costs and benefits include, amongst others, health and healthcare costs, policy revenues, environmental impact, productivity at work, and labour participation. The framework for the Social Cost-Benefit Analysis is used to present all modelled outcomes in monetary values calculated over the next 30 years. This broad approach provides evidence for the benefits as well as the costs of implementing such policies in the Netherlands.

In the general discussion (**Chapter 7**), the main findings of this PhD thesis and their implications are discussed and recommendations for future research are given.

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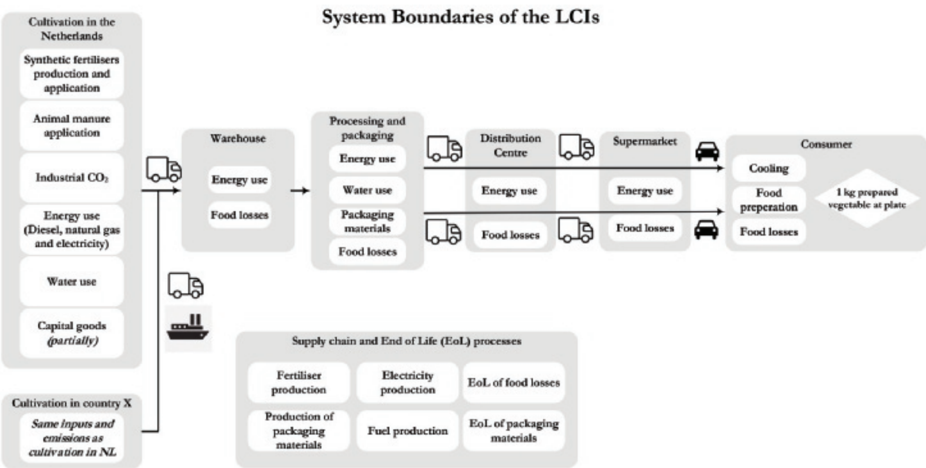
Appendix Chapter I

Calculating the environmental impact of foods

The environmental impact of the Dutch food consumption was estimated with Life Cycle Analysis (LCA), a methodological tool to assess the environmental load throughout the life cycle of a product [1, 2]. The LCA system boundaries were from cradle till plate, indicating all phases from primary production, processing, primary packaging, distribution, supermarket and transport through all phases (except from supermarket to consumer), storage, preparing, cooking and incineration of waste products were used (**Supplemental figure 1.1**). Blonk Consultants provided supporting Life Cycle Inventories (LCI) data representative for Dutch situation. LCIs are all the in and out flows of a product system, including raw resources or materials, energy by type, water, and emissions to air, water and land. The LCIs are combined in the LCA to obtain the environmental impact for a whole diet. These LCA data are then linked to the dietary assessment method used in EPIC-NL (food frequency questionnaires, Chapter 2-5) or Dutch National Food Consumption Survey (24-hour recalls, Chapter 7).



Supplemental figure 1.1. System boundaries of Life Cycle Inventories (Example of vegetables by Blonk Consultants).

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PART I

Health and environmental impacts of observed Dutch diets

CHAPTER II

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.

Sander Biesbroek, H. Bas Bueno-de-Mesquita, Petra H.M. Peeters, W.M. Monique Verschuren, Yvonne T. van der Schouw, Gerard F.H. Kramer, Marcelo Tyszler, Elisabeth H.M. Temme.

Environmental Health, 2014.

Abstract

Background

Food choices influence health status, but also have a great impact on the environment. The production of animal-derived foods has a high environmental burden, whereas the burden of refined carbohydrates, vegetables and fruit is low. The aim of this study was to investigate the associations of greenhouse gas (GHG) emissions and land use of usual diet with mortality risk, and to estimate the effect of a modelled meat substitution scenario on health and the environment.

Methods

The usual diet of 40,011 subjects in the EPIC-NL cohort was assessed using a food frequency questionnaire. GHG emissions and land use of food products were based on life cycle analysis. Cox proportional hazard ratios (HR) were calculated to determine relative mortality risk. In the modelled meat-substitution scenario, one-third (35 gram) of the usual daily meat intake (105 gram) was substituted by other foods.

Results

During a follow-up of 15.9 years, 2,563 deaths were registered. GHG emissions and land use of the usual diet were not associated with all-cause or with cause-specific mortality. Highest vs. lowest quartile of GHG emissions and land use adjusted hazard ratios for all-cause mortality were respectively 1.00 (95% CI: 0.86-1.17) and 1.05 (95% CI: 0.89-1.23). Modelled substitution of 35 g/d of meat with vegetables, fruit-nuts-seeds, pasta-rice-couscous, or fish significantly increased survival rates (6-19%), reduced GHG emissions (4-11%), and land use (10-12%).

Conclusions

There were no significant associations observed between dietary-derived GHG emissions and land use and mortality in this Dutch cohort. However, the scenario-study showed that substitution of meat with other major food groups was associated with a lower mortality risk and a reduced environmental burden. Especially when vegetables, fruit-nuts-seeds, fish, or pasta-rice-couscous replaced meat.

Background

Current climate changes and the increased need for food underlines the importance of a sustainable food system [1]. Food choices influence health status, but also have a great impact on the environment through food production. Currently, the contribution of food production and consumption to the European Union's total greenhouse gas (GHG) emissions is approximately 20-30% [2]. Individuals can directly influence this share via their own choice of food.

The largest environmental impact from food comes from the production and consumption of meat and dairy products; the estimated GHG emissions are 50% and use of total farmlands is 80% [3-5]. Meat and dairy products also supply about one-third of the dietary energy intake and are major sources of saturated fatty acids in the diet. Diets high in animal products and low in vegetables and fruits, like the Western diet, are associated with a higher risk of major chronic diseases [6-8]. A comparison between a meat-based and a lactoovovegetarian diet also showed that the typical Western diet is less sustainable [9].

A diet according to the Dutch national dietary guidelines would result in a 8% reduction in GHG emissions (men 13%, women 3%) when compared to the actual dietary pattern as observed in the Dutch national food consumption survey [3]. The dietary guidelines, established in 2006, promote a varied diet with plenty of fruit, vegetables and whole-grain cereal products [10]. A study from the UK modelled the health effects of three diets with a different carbon footprint reduction [11]. The results showed that a modelled 50% reduction of meat and dairy products iso-calorically replaced by vegetables, fruit, and cereals resulted in the highest GHG emissions reduction and most deaths delayed or averted per year. Another recent UK study investigated how consumer's food choice could reduce food-derived GHG emissions [12]. Results showed a potential GHG emissions reduction of 35% if meat products were completely eliminated from the diet and 12% when avoidable food waste was cut out. Not eating foods grown in greenhouses or airfreighted to the UK could lead to another 5% reduction. Vieux et al showed that when total caloric intake is reduced to meet the average individual's energy needs, the diet-associated

GHG emissions decreased between 2-11% [13]. In addition, when meat was iso-calorically substituted by fruit and vegetables either null or even positive diet-associated GHG emissions variations occurred. A modelled substitution of animal-derived food products by plant-derived food products resulted in substantial reductions of GHG emissions and land use [14, 15] and a lower risk for all-cause mortality and coronary heart disease [16, 17].

Although it is expected that a diet which is environmental friendlier also reduces mortality of chronic diseases, this has never been investigated in a real-life setting. Therefore, the aim of this study was to investigate to what extent an environmental friendlier diet is also a healthier diet by increasing survival rates in the EPIC-NL cohort study. The effects of food weight-based modelled substitution scenarios, in which part of the total meat intake was replaced by other food groups, on mortality and environmental impact were also investigated.

Methods

Study population

EPIC-NL is the Dutch contribution to European Prospective Investigation into Cancer and Nutrition [18]. EPIC-NL consists of 40,011 subjects of PROSPECT and MORGEN. The PROSPECT cohort included 17,357 women aged 49–70 years, participating in the national breast cancer screening program and living in the city of Utrecht and its surroundings [19]. The MORGEN cohort included 22,654 men and women aged 20–59 years, selected from random samples of the Dutch population in Amsterdam, Doetinchem, and Maastricht [20, 21]. Both cohorts comply with the Declaration of Helsinki.

Exclusion criteria for the present analyses were no informed consent for follow-up of vital status (n=956) and missing follow-up data (n=16). Participants with a history of cancer (n=1,640), diabetes (n=781), myocardial infarction (n=536), stroke (n=458), or a combination of these diseases (n=249) were excluded because the usual diet reported by these persons may not reflect their diet 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. GHG emissions covers carbon dioxide (CO_2) emissions through the use of fossil fuels, methane (CH_4) released during the rearing of cattle and the cultivation of certain crops, and nitrous oxide (N_2O) released from fertilizers, manure and ploughing of grassland [24, 25]. GHG emissions are expressed as kg CO_2-equivalents per day. Land use covers the surface needed for the production of food [24, 25] and is expressed as m^2*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 GHG emissions 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 GHG emissions 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 GHG emissions and land use divided by total energy intake, GHG emissions/kJ and m^2/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 2.1 and 2.2**), 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 on environmental impact were based on the food group average GHG emissions 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, 2,563 deaths were registered. The observed EPIC-NL cohort median value of GHG emissions was 3.87 kg CO_2-equivalents per day and for land use 3.61 m^2*year per day. 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 GHG emissions and land use (**Table 2.1**). The impact of dairy and beverage consumption on the environment is substantial (dairy: 25% of GHG emissions and 17% of land use; beverages: 13% of GHG emissions 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 GHG emissions and land use (**Table 2.2**).

Table 2.1. Contribution of different food groups to daily intake and environmental impact in EPIC-NL.

Food group	Gram/d (%)	GHG emissions (%)	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
Milk[a]	9.4	9.5	6.5
Milk-based desserts[b]	3.5	4.1	2.6
Meat			
Non-processed meat[c]	2.5	25.7	28.1
Processed meat[d]	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

a: consists of milk, milk beverages (chocolate milk), and coffee milk; b: consists of (fruit-) yoghurt, cream desserts, and milk-based puddings; c: non-processed meat: beef, pork, and chicken; d: processed meat: liver-containing items, ham, and miscellaneous types.

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 GHG emissions was 0.76 (0.68-0.85) (**Table 2.3**). 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 GHG emissions 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 2.4**). 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 (0.75-1.54) for CVD, 1.19 (0.58-2.46) for respiratory diseases, and 0.88 (0.61-1.27) for deaths by remaining causes.

Table 2.2. Baseline characteristics by dietary greenhouse gas emission and land use in EPIC-NL.

	Greenhouse gas emission (CO_2-eq/d)		Land use (m^2*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 deaths[a]	736 (8.4)	570 (6.5)	741 (8.5)	558 (6.4)
Person-years[b]	15.8 (14.6-17.0)	16.0 (14.7-17.2)	15.8 (14.6-16.9)	16.0 (14.7-17.2)
GHG emissions[b, 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 use[b, 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 gender[a]	896 (10.2)	4521 (51.6)	766 (8.7)	4727 (53.9)
BMI (kg/m^2)[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[a, e]	1601 (18.4)	2025 (23.3)	1640 (18.8)	2141 (24.6)
Current smokers[a]	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 circum. (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 / BMR[b, 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 intake[b]				
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 meat[h]	41 (23-58)	99 (84-125)	36 (21-51)	101 (87-126)
Processed meat[i]	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)

Table 2.2. Baseline characteristics by dietary greenhouse gas emission and land use in EPIC-NL. (continued)

Characteristic	Greenhouse gas emission (CO_2-eq/d)		Land use (m^2*year/d)	
	Quartile 1 <3.26	**Quartile 4 >4.56**	**Quartile 1 <2.99**	**Quartile 4 >4.28**
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: Values displayed as frequency (percentage); b: Values displayed as median with interquartile range (25-75th percentile); c: GHG emissions: greenhouse gas emissions (CO_2-eq/d); d: Land use (m^2*year/d); e: college or university degree; f: Cambridge Physical Activity Score (inactive, moderately inactive, moderately active, active); g: Ratio of energy intake (EI) and basal metabolic rate (BMR); h: non-processed meat: beef, pork, and chicken; i: processed meat: liver-containing items, ham, and miscellaneous types.

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 2.5**). 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 milk-based 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%) 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 all-cause 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.

Table 2.3. 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 HR[a] (95% CI)	1 (REF)	0.90 (0.81-1.00)	0.79 (0.71-0.88)	0.76 (0.68-0.85)	*P* < 0.0001[d]
Model 1[b] HR	1	0.97 (0.84-1.12)	0.90 (0.77-1.05)	1.00 (0.86-1.17)	*P* = 0.7959
Model 2[b,c] HR	1	0.96 (0.82-1.11)	0.87 (0.74-1.03)	0.95 (0.77-1.15)	*P* = 0.4266
Cause-specific mortality					
Cancer					
No. of deaths	327	324	274	268	
Crude HR[a] (95% CI)	1 (REF)	0.99 (0.85-1.15)	0.83 (0.71-0.98)	0.81 (0.69-0.96)	*P* = 0.0031[d]
Model 1[b] HR	1	1.01 (0.89-1.33)	0.93 (0.75-1.16)	1.01 (0.86-1.34)	*P* = 0.7654
CVD					
No. of deaths	164	146	115	120	
Crude HR[a] (95% CI)	1 (REF)	0.89 (0.71-1.11)	0.70 (0.55-0.89)	0.73 (0.57-0.92)	*P* = 0.0023[d]
Model 1[b] HR	1	0.92 (0.67-1.26)	0.83 (0.59-1.17)	0.90 (0.63-1.28)	*P* = 0.4681
Respiratory Diseases					
No. of deaths	41	37	32	27	
Crude HR[a] (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 1[b] HR	1	1.01 (0.53-1.91)	0.76 (0.39-1.49)	1.12 (0.52-2.39)	*P* = 0.9945
Other Causes					
No. of deaths	157	124	128	120	
Crude HR[a] (95% CI)	1 (REF)	0.79 (0.62-0.99)	0.81 (0.64-1.02)	0.76 (0.60-0.96)	*P* = 0.0334[d]
Model 1[b] HR	1	0.83 (0.59-1.15)	0.96 (0.68-1.35)	0.91 (0.64-1.30)	*P* = 0.7902

a: HR: hazard ratio; b: Cox stratified for age (continuous) and adjusted for sex; c: Additional adjusted for energy intake; d: p value for linear trend significant (p<0.05).

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Table 2.4. Data for mortality risks according to total land use of usual diet in EPIC-NL.

	Land use (m²*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 HR[a] (95% CI)	1 (REF)	0.89 (0.80-0.99)	0.79 (0.71-0.88)	0.74 (0.66-0.82)	*P* < 0.0001[d]
Model 1[b] HR	1	0.99 (0.86-1.15)	0.99 (0.85-1.14)	1.05 (0.89-1.23)	*P* = 0.6190
Model 2[b,c] HR	1	0.99 (0.85-1.14)	0.97 (0.82-1.15)	1.03 (0.84-1.25)	*P* = 0.8534
Cause-specific mortality					
Cancer					
No. of deaths	326	317	282	268	
Crude HR[a] (95% CI)	1 (REF)	0.97 (0.83-1.13)	0.86 (0.73-1.01)	0.82 (0.69-0.96)	*P* = 0.0057[d]
Model 1[b] HR	1	1.05 (0.86-1.29)	0.99 (0.80-1.22)	1.10 (0.88-1.37)	*P* = 0.5291
CVD					
No. of deaths	164	151	112	118	
Crude HR[a] (95% CI)	1 (REF)	0.91 (0.73-1.14)	0.68 (0.53-0.86)	0.71 (0.56-0.90)	*P* = 0.0010[d]
Model 1[b] HR	1	1.03 (0.75-1.41)	0.97 (0.68-1.37)	1.07 (0.75-1.54)	*P* = 0.7666
Respiratory Diseases					
No. of deaths	44	30	34	29	
Crude HR[a] (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 1[b] HR	1	0.81 (0.42-1.56)	0.97 (0.49-1.90)	1.19 (0.58-2.46)	*P* = 0.5950
Other Causes					
No. of deaths	162	133	122	112	
Crude HR[a] (95% CI)	1 (REF)	0.81 (0.65-1.02)	0.75 (0.59-0.95)	0.68 (0.54-0.87)	*P* = 0.0016[d]
Model 1[b] HR	1	0.83 (0.60-1.16)	0.98 (0.70-1.36)	0.88 (0.61-1.27)	*P* = 0.6518

a: HR: hazard ratio; b: Cox stratified for age (continuous) and adjusted for sex; c: Additional adjusted for energy intake; d: p value for linear trend significant (p<0.05).

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. 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 GHG emissions (4-12%), and land use (10-12%).

In this study, the environmental burden of the usual diet was divided into quartiles of total GHG emissions 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 GHG emissions 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 GHG emissions, rice instead of pasta or potatoes and more meat has twice the GHG emissions compared to an equally healthy low-GHG emissions 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 low GHG emissions. 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 lower GHG emissions or less land use.

Table 2.5. Environmental impact of 35 gram modelled meat substitution by predefined food groups and all-cause mortality.

Substitute	Reduction GHG emissions (%)[a]	Reduction Land use (%)[a]	Reduction Mortality risk (%, 95% CI)[b]
Potatoes	10.8	11.3	0 (-6 – 7)
Pasta-rice-couscous	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)

a: Based on the average greenhouse gas (GHG) emissions and land use in EPIC-NL; b: Cox 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.

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 GHG emissions and land use and mortality. Although total GHG emissions and land use were not associated with mortality, modelling a one-third reduction of total meat, a major contributor to dietary GHG emissions and land use, resulted in both reduced mortality risk as well as reduced environmental impact. 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-GHG emissions with low-GHG emissions 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 GHG emissions 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 GHG emissions into the price of foods [33]. A scenario in which a higher taxation rate is calculated for foods above GHG emissions average shows that this could save 7,770 lives in the UK each year, reduce GHG emissions and generate tax revenue. These studies highlight the potential benefits of such policy measures on health and environment impact of the diet.

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 GHG emissions 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 GHG emissions 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 food-labelling system that indicates GHG emissions 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.

In conclusion, 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 population-based cohort, there were no significant associations between overall daily dietary-derived GHG emissions 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 GHG emissions 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.

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CHAPTER III

Are our diets getting healthier and more sustainable? Insights from the EPIC-NL cohort.

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Abstract

Objective

To identify differences in dietary quality, dietary greenhouse gas (GHG) emissions and food consumption over 20 years in a Dutch cohort.

Design

8,932 participants of the EPIC-NL cohort filled out a food-frequency-questionnaire in 1993-1997 and in 2015. The Dutch Healthy Diet index 2015 (DHD15-index) score, GHG emissions, and consumption of food groups (gram/1000 kcal) were compared between the time points with paired t-tests.

Setting

The Netherlands.

Participants

EPIC-NL cohort, aged 18-65 at baseline.

Results

Total energy intake decreased by -162 kcal (95% confidence interval (CI): -1173 kcal; 807 kcal) per day for men and -89 kcal (95% CI:-913 kcal; 748 kcal) per day for women. DHD15-index scores increased 11% (from 64.8 to 71.9 points) and 13% (from 65.2 to 73.6 points) in men and women respectively ($p<0.0001$), mainly due to an increased (shell) fish and nuts/seeds/nut paste consumption. After energy intake adjustment, dietary-related GHG emissions increased by 5% in men (2.48 to 2.61 kg CO_2-eq/1000 kcal, $p<0.0001$)) and were similar in women (0.4%, 2.70 to 2.71 kg CO_2-eq/1000 kcal, $p=0.3930$) due to the increased consumption of (shell)fish, nuts/seeds/nut paste, poultry, and higher GHG intensive red meats such as beef.

Conclusions

This Dutch cohort analyses showed more healthy diets without mitigated GHG emissions over a 20-year period, at similar energy intakes. Higher consumption of (shell) fish and poultry was not yet at the expense of red and processed meat. Lower consumption of animal-based foods is needed to achieve healthier as well as environmentally friendly diets.

Background

Diet is a major contributor to both global warming and health. On a global scale, the current food production is estimated to be responsible for 20-30% of total greenhouse gas (GHG) emissions, and thus has a major impact on the environment [1-3]. In addition, the global food system faces the major challenge producing food for the ever-growing world population while dealing with limited available resources [4]. The Paris Climate Agreement and the United Nations Sustainable Development Goals stress the urgency of implementing new strategies towards a more sustainable future [5, 6].

Both the current consumer awareness of the environmental impact of the diet is still low and willingness to adapt to a new type of diet are proven to be low [7, 8]. The current Western diet is considered environmentally unsustainable and unhealthy due to the high quantities of animal-based foods consumed [9, 10]. Shifts in dietary patterns towards less animal- and more plant-based foods can therefore potentially provide benefits for both the environment and health, as has been described by previous review studies [11-14].

In the last decades, the food production and consumption landscape in the Netherlands have changed considerably. The area of agricultural land decreased by 6% between 2000 and 2011, while food production increased by 9% [15]. In two representative Dutch samples several dietary trends were identified between 2007-2010 and 2012-2014, such as lower consumption of meat and potatoes but stable consumption of vegetables [16].

Recognizing and understanding trends in food consumption is important to accurately design policy measures (such as information strategies, food based dietary guidelines, tax or subsidy on certain foods and other measures) aiming at a combined environmentally sustainable and healthy food consumption and to evaluate their effectiveness. Since a changed food consumption pattern may affect the dietary quality as well as its environmental impact, it is important to identify these trends. Therefore, our current study was set up to (1) identify the differences in food consumption and dietary quality over the course of 20 years using the European Prospective Investigation into Cancer and Nutrition - Netherlands (EPIC-NL) cohort and (2) to calculate the environmental impact in terms of GHG emissions of the observed differences in both men and women.

Subjects and Methods

Study population

EPIC-NL [17] consists of 40,011 participants of the two Dutch contributors to the European-wide EPIC project, being EPIC-Prospect [18] and EPIC-MORGEN [19, 20], both carried out between 1993 and 1997. The EPIC-Prospect cohort included 17,357 women aged 49–70 years living in the city of Utrecht and its vicinity. The EPIC-MORGEN cohort included 22,654 men and women aged 20–65 years, living in Amsterdam, Maastricht and Doetinchem. These cohort studies were conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving human participants were approved by the Institutional Review Board of the University Medical Centre Utrecht and the Medical Ethical Committee of TNO Nutrition and Food Research. Written informed consent was obtained from all participants. The design and rationale of EPIC-NL are described elsewhere by Beulens *et al* [17].

In 2015, respondents to the 2011 follow-up questionnaire on electromagnetic radiation (EMV) [21] who were still alive, living in the Netherlands and who gave informed consent (n=13,421) were invited to fill out a food-frequency questionnaire (FFQ). In addition, participants from Doetinchem, who at that time already had participated in the sixth round of the Doetinchem cohort study (n=1,528) were invited. Participants from Doetinchem did not receive the EMV questionnaire. The response rate to the 2015 FFQ was 62.9% (9,399 out of 14,949).

For the current study, participants without dietary information at baseline were excluded (n=27). Participants with implausible dietary intake at either FFQ, i.e. those with a reported energy intake of less than 500 kcal/day or greater than 3,500 kcal/day [22], were also excluded (n=440) resulting in a total population of 8,932 participants (**Supplemental figure 3.1**).

Dietary assessment

At baseline, usual daily dietary intake was estimated by a 178-item FFQ, which has been validated against twelve 24-hour dietary recalls and biomarkers in 24-hour urine and blood [23, 24]. Spearman rank correlation coefficients based on estimates of the FFQ and 24-hour recalls were 0.58 for potatoes, 0.38 for vegetables, 0.68 for fruits, 0.47 for meat, 0.32 for fish, 0.64 for cheese, 0.71 for dairy, 0.78 for sweet products, and 0.56 for biscuits and pastry. Energy intake was estimated using the 1996 Dutch Food Composition table [25].

At follow-up, a new standardized 160-item FFQ developed for Dutch epidemiological studies was used [26]. This FFQ was validated against on average 2.7 (range 1-5) telephone-based 24 hour recalls as well as biomarkers in 24 hour urine and blood samples. Spearman rank correlation coefficients based on estimates of the FFQ and 24 hour recalls were 0.28 for potatoes, 0.53 for vegetables, 0.67 for fruits, 0.38 for meat, 0.28 for fish, 0.16 for cheese, 0.61 for dairy, 0.38 for sweet products, and 0.33 for biscuits and pastry. Energy intake was estimated using the 2011 Dutch Food Composition table [27].

In order to assess differences in dietary quality between baseline and follow-up a modification of the Dutch Healthy Diet index 2015 (DHD15-index) was calculated [28]. The DHD15-index estimates the level of adherence to the most recent 2015 Dutch dietary guidelines from the Dutch Health Council [29]. We were able to calculate twelve of the fifteen original components (see **Supplemental table 3.1**). For each component, a score between 0 and 10 was calculated. Consequently, the DHD15-index score in our study could range from 0-120 points, with higher scores indicating a healthier diet. We excluded the components for coffee and salt consumption, because the type of coffee (filtered or unfiltered) and salt consumption was not available in both FFQ's. Two components needed to be adapted to our data. First, the wholegrain components originally had two components (both 5 points), one for total wholegrain product intake and one for the ratio between wholegrain and refined grain products. Our follow-up questionnaire did not differentiate between types of cereals (wholegrain or not). Therefore, the wholegrain component was based on wholegrain bread only. Consumption equal to or above 90 grams of wholegrain bread per day received the maximum score of 10 points, gradually decreasing to 0 points at a consumption of 0 grams per day. Second, separate variables for red and processed meat were not available for the follow-up questionnaire, so these two components were combined. Consumption below 45 grams of red and processed meats per day received the maximum score of 10 points, gradually decreasing to 0 points at consumption of 150 grams or more per day.

Additionally, the food groups were classified by source category: animal-based, plant-based, beverages, and miscellaneous. Animal-based foods included red and processed meat, poultry, (shell) fish, eggs and dairy (including cheese). Plant-based foods contained potatoes, fries, bread and cereals, fruit, vegetables, vegetarian meat replacers, and nuts/seeds/nut-paste. Beverages included coffee, tea, (light) soft drinks, fruit and vegetable drinks, and alcoholic beverages. Miscellaneous contained savoury snacks, cakes/cookies, soups, sauces, oils and fats, and sweets. The twelve DHD15-index components can also be divided in these categories. Animal-based were the components dairy, (shell) fish, and red and processed meat with a combined maximum score of 30 points on the DHD15-index. Plant-based components were vegetables, fruit, wholegrain bread, legumes, and nuts/seeds/nut paste with a combined maximum score of 50 points. In the beverages category the components tea, sweetened beverages and fruit juices, and alcoholic beverages were included with a maximum total score of 30 points. The last category, miscellaneous, included component for replacing butter and hard fats with oils and margarines for a maximum of 10 points.

Environmental impact assessment

To estimate the greenhouse gas emissions (GHG) associated with foods in the Netherlands, the methodology of life cycle assessment (LCA) was applied. The LCA was performed using Life Cycle Inventory (LCI) data (Blonk Consultants, dataset version 2016) from Agri-Footprint [30, 31]. These LCI data were representative for the Dutch situation. These LCIs were used as input for life cycle impact assessments (LCIAs) using ReCiPe version 2008 and carried out by the Dutch National Institute for Public Health and the Environment (RIVM). The LCIAs were cradle to plate and included all life cycle stages from production, transport, preparation, and including waste/losses at all stages. The preparation of foods by consumers was based on the average cooking time for each product and an energy mix representative for the Dutch market. Food waste was included by using food group specific percentages for avoidable and unavoidable food losses at all stages of the life cycle. The time horizon for the effects of GHG emission calculations was 100 years and economic allocation was used for production processes that led to more than one food product. GHG emissions were expressed as kg CO_2-equivalents per kg food prepared at plate. The environmental data used were previously presented by Van de Kamp *et al.* [31]. The LCA data were combined with the EPIC-NL FFQ data both at baseline and at follow-up to calculate daily GHG emissions associated with the usual diet in kg CO_2-equivalents (kg CO_2-eq) per person per day. Although improvements in production over time may most likely have decreased the environmental impact, we applied the same LCA data to both the baseline and follow-up FFQ because then the observed differences in environmental impact are directly related to the dietary changes.

Lifestyle and anthropometric variables

For the description of our research population at baseline, several lifestyle and anthropometric variables were measured. The study participants completed a standardised structured general questionnaire on the presence of chronic diseases, related potential risk factors and lifestyle factors. Blood pressure, weight and height were measured by trained staff according to standardised protocols [17]. Body mass index (BMI) was calculated by dividing weight by height squared (kg/m^2). Physical activity was assessed with a validated questionnaire [32] and classified according to the Cambridge Physical Activity Index (CPAI) with imputed data for missing values (n=693) [33]. The CPAI was categorised into inactive, moderately inactive, moderately active and active. Smoking was operationalised as current, former, and never smoker. Educational level was coded as low (lower vocational training or primary school), medium (intermediate vocational training or secondary school) or high (higher vocational training or university).

Statistical analysis

All analyses were stratified by sex. First, the DHD15-index score was calculated. Second, the environmental impact of the diet at baseline and follow-up was calculated. We analysed the GHG emissions absolute (total) and relative per 1000 kcal. Third, the differences in food group consumption and food source over time were calculated. In order to get insight in the differences in consumption of food groups independently from differences in energy intake over time, consumption was standardized by energy intake (gram per 1000 kcal). Mean and standard deviation values at baseline and follow-up were calculated for each indicator (the DHD15-index score, GHG emissions (kg CO_2-eq/1000 kcal), and food groups (gram/1000 kcal)). A paired sample t-test was used to test the observed differences for significance. A p-value below 0.05 was considered statistically significant and all analyses were performed with SAS 9.4.

Results

Mean age at baseline was 51 years for women and 44 years for men in our cohort. At baseline, the majority of the participants were at least moderately physically active, moderately to highly educated and most often either never smokers or former smokers (**Table 3.1**). Fifty-five percent of men were overweight (BMI >= 25 kg/m^2) whereas 39% of the women were overweight. At follow-up, both among men and women a higher prevalence of obesity (BMI >= 30 kg/m^2) as well as underweight (BMI <18 kg/m^2) was observed. Men and women reported a decreased caloric intake (-162 kcal (95% Confidence Interval (CI): -1173; 807) for men and -89 kcal (95% CI:-913; 748) for women) between baseline and follow-up (**Table 3.2**).

Table 3.1. Study population characteristics of EPIC-NL expressed as % (n).

	1993-1997		2015	
Characteristics	**Men** (n=1,844)	**Women** (n=7,088)	**Men** (n=1,844)	**Women** (n=7,088)
Age at baseline				
20-35 year	16.7% (308)	8.7% (619)	23.9% (441)	8.2% (584)
35-50 year	49.3% (910)	22.7% (1,612)	7.2% (132)	4.1% (293)
50-65 year	33.9% (626)	64.4% (4,561)	29.1% (536)	11.5% (818)
65-80 year	0.1% (2)	4.2% (296)	39.1% (722)	62.2% (4,408)
>80 year	-	-	0.7% (13)	13.9% (985)
Education level				
Low	22.6% (416)	29.6% (2,096)	NA	
Moderate	38.1% (702)	42.3% (2,998)		
High	39.3% (726)	29.1% (1,994)		
Physical activity				
Inactive	6.5% (120)	3.9% (274)	NA	
Moderately inactive	24.4% (449)	24.6% (1,741)		
Moderately active	28.0% (517)	27.1% (1,926)		
Active	41.1% (758)	44.4% (3,147)		
Smoking status				
Yes	28.0% (517)	20.6% (1,455)	12.2% (165)	7.3% (445)
No	35.1% (645)	43.2% (3,055)	36.5% (492)	46.5% (2,864)
Former	36.9% (678)[a]	36.2% (2,561)[b]	51.3% (692)[c]	46.3% (2,850)[d]
Body mass index				
<18 kg/m^2	0.3% (5)	0.7% (51)	15.1% (279)	11.0% (780)
18-25 kg/m^2	44.7% (824)	60.6% (4,296)	40.7% (751)	43.3% (3,071)
25-30 kg/m^2	46.2% (853)	30.8% (2,181)	33.6% (619)	31.6% (2,238)
>30 kg/m^2	8.8% (162)	7.9% (560)	10.6% (195)	14.1% (999)

NA: not available. a: 4 missing. b: 17 missing. c: 495 missing. d: 929 missing.

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Table 3.2. Mean (standard deviation) baseline and follow-up food consumption and dietary greenhouse gas emissions in EPIC-NL[a].

Food groups	Men (n=1,844)							
	gram/1000 kcal				kg CO_2-eq/1000 kcal			
	Baseline		Follow-up		Baseline		Follow-up	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Total energy intake (kcal/day)	2,416	491	2,254*	577				
Animal-based foods								
(Shell)Fish	4.2	4.5	13.6*	14.9	0.04	0.04	0.13*	0.14
Red and processed meat	49.5	22.0	48.5	28.9	0.95	0.47	1.07*	0.76
Poultry	5.6	5.8	12.5*	14.8	0.07	0.07	0.15*	0.18
Cheese	15.1	11.3	7.1*	7.6	0.15	0.11	0.07*	0.07
Low-fat dairy	92.6	82.2	96.6	95.9	0.17	0.15	0.19*	0.19
High-fat dairy	59.6	51.4	21.0*	33.0	0.13	0.11	0.04*	0.06
Eggs	7.2	5.7	10.3*	9.6	0.04	0.03	0.05*	0.05
Plant-based foods								
Fries	11.4	9.5	7.8*	11.2	0.04	0.03	0.03*	0.04
Potatoes	42.6	26.9	36.9*	27.7	0.03	0.02	0.05*	0.03
Low-fiber bread	15.9	19.1	25.8*	28.6	0.03	0.03	0.03	0.03
High-fiber bread	58.2	30.8	38.2*	32.2	0.06	0.03	0.04*	0.03
Fruit	68.8	55.3	64.9*	57.0	0.06	0.05	0.06	0.06
Cereals and cereal products	30.5	24.4	34.8*	29.7	0.04	0.04	0.05*	0.05
Vegetables and legumes	54.0	23.7	63.1*	41.1	0.07	0.03	0.08*	0.06
Nuts, seeds, and nut-paste	4.7	5.5	7.1*	7.8	0.01	0.01	0.02*	0.02
Vegetarian meat replacers and soy products	0.9	2.9	4.2*	19.1	0.001	0.005	0.01*	0.02
Beverages								
Coffee	273.7	167.9	212.5*	154.3	0.08	0.05	0.07*	0.05
Tea	94.8	123.8	120.1*	145.6	0.02	0.02	0.02*	0.03
Light soft drinks	13.1	27.8	34.8*	82.0	0.01	0.02	0.02*	0.05
Soft drinks, fruit and vegetable juices	59.8	54.5	65.1*	78.3	0.05	0.05	0.06*	0.06
Alcoholic beverages	127.2	132.7	128.3	129.0	0.13	0.13	0.15*	0.14
Miscellaneous								
Savoury snacks	10.4	9.1	8.9*	9.6	0.03	0.04	0.04*	0.05
Cakes/cookies	11.4	9.0	14.8*	13.2	0.02	0.02	0.04*	0.03
Soups	33.5	36.4	23.9***	30.6	0.11	0.12	0.04*	0.06
Sweets	18.5	12.5	19.5*	16.6	0.02	0.02	0.05*	0.06
Savoury sauces	9.9	8.3	5.7*	5.9	0.02	0.01	0.01*	0.01
Oils, diet margarine, liquid cooking fats	5.0	4.8	11.7*	11.1	0.01	0.01	0.03*	0.02
Butter and solid cooking fats	7.3	5.7	2.3*	5.3	0.04	0.04	0.02*	0.06

Table 3.2. Mean (standard deviation) baseline and follow-up food consumption and dietary greenhouse gas emissions in EPIC-NL[a]. (continued)

Food groups	**Women** (n=7,088)							
	gram/1000 kcal				**kg CO_2-eq/1000 kcal**			
	Baseline		**Follow-up**		**Baseline**		**Follow-up**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Total energy intake (kcal/day)	1,860	424	1,770*	521				
Animal-based foods								
(Shell)Fish	5.8	6.2	16.8*	19.1	0.05	0.06	0.16*	0.19
Red and processed meat	42.7	22.3	42.2	29.2	0.88	0.51	0.97*	0.78
Poultry	6.3	6.7	13.0*	15.6	0.08	0.08	0.16*	0.19
Cheese	20.1	13.0	9.0*	9.5	0.20	0.13	0.09*	0.09
Low-fat dairy	145.8	108.6	149.2*	120.0	0.28	0.20	0.30*	0.24
High-fat dairy	70.3	56.3	19.1*	33.7	0.16	0.13	0.04*	0.07
Eggs	8.0	6.3	12.4*	11.3	0.04	0.03	0.06*	0.06
Plant-based foods								
Fries	3.6	7.2	3.9*	8.5	0.01	0.03	0.01*	0.03
Potatoes	39.4	25.8	37.2*	28.4	0.03	0.02	0.04*	0.03
Low-fiber bread	12.7	13.4	17.4*	24.2	0.02	0.02	0.02	0.03
High-fiber bread	54.0	24.5	39.0*	30.4	0.05	0.02	0.04*	0.03
Fruit	125.9	83.3	104.8*	77.7	0.11	0.08	0.10*	0.08
Cereals and cereal products	24.6	21.2	30.5*	25.9	0.03	0.03	0.04*	0.04
Vegetables and legumes	81.4	35.5	83.4*	56.3	0.10	0.04	0.11*	0.08
Nuts, seeds, and nut-paste	4.2	5.3	6.6*	8.1	0.01	0.01	0.02*	0.02
Vegetarian meat replacers and soy products	1.4	4.2	7.8*	31.4	0.002	0.01	0.01*	0.03
Beverages								
Coffee	294.9	180.5	234.3**	160.6	0.09	0.06	0.08*	0.06
Tea	207.4	188.4	255.9*	227.9	0.04	0.03	0.05*	0.04
Light soft drinks	16.3	32.1	21.1*	68.9	0.01	0.02	0.01*	0.04
Soft drinks, fruit and vegetable juices	66.2	60.1	65.6	85.7	0.06	0.06	0.06	0.08
Alcoholic beverages	54.5	71.2	65.2*	82.1	0.08	0.09	0.10*	0.12
Miscellaneous								
Savoury snacks	6.0	5.9	5.9	7.7	0.02	0.03	0.03*	0.04
Cakes/cookies	17.2	11.5	17.3	13.8	0.03	0.02	0.04*	0.03
Soups	36.8	39.5	27.2*	37.8	0.13	0.13	0.05*	0.07
Sweets	15.9	11.9	19.0*	16.2	0.02	0.02	0.05*	0.05
Savoury sauces	9.7	8.0	5.9*	6.8	0.01	0.01	0.01*	0.01
Oils, diet margarine, liquid cooking fats	5.1	4.2	9.7*	9.8	0.01	0.01	0.02*	0.02
Butter and solid cooking fats	6.6	5.1	3.2*	5.9	0.04	0.04	0.03*	0.07

a: Significance level paired t-test *<0.05.

For both men and women, a statistically significant increase of about 12% in the DHD15-index score was observed at follow-up compared to baseline, indicating an improved dietary quality between 2015 and 1993-1997 (**Figure 3.1**). At follow-up, men had on average a score of 71.9 points (95% CI: 41.9; 97.8) and women 73.6 points (95% CI: 45.3; 99.8). The increase in DHD15-index score was mostly due to a higher consumption of (shell) fish and nuts/seeds/nut paste (see **Supplemental table 3.1**). The two component scores of the DHD15-index that had the largest decreases in score were wholegrain bread and vegetables.

Total daily GHG emissions of the diet were respectively 2% and 4% lower in men (5.82 versus 5.92 kg CO_2-eq per day, p=0.052) and in women (4.74 versus 4.94 kg CO_2-eq per day, p<0.0001) in 2015 compared to 1993-1997 (**Figure 3.2**). After adjusting for energy intake, diets of men were associated with a statistically significant 5% higher GHG emissions in 2015 compared with diets at baseline when expressed per 1000 kcal (2.61 versus 2.48 kg CO_2-eq per 1000 kcal per day, p<0.0001), while diets of women had similar relative dietary GHG emissions (p=0.3930).

Animal-based foods consumption was healthier according to the DHD15 index score for animal-based foods but less environmentally friendly according to the GHG emissions per 1000 kcal. A potential 30 points could be scored on the DHD15-index for animal-based foods, on which both men (15.4 to 17.6 points) and women (15.5 to 18.8 points) had increased scores (**Figure 3.3A**). The associated GHG emissions of the animal-based foods statistically significantly increased from 1.54 to 1.70 and 1.69 to 1.78 kg CO_2-eq/1000 kcal in men and women respectively (**Figure 3.3B**), mainly because of the higher (shell)fish, poultry, and type of red meat consumption (**Table 3.2**). Total red and processed meat consumption per 1000 kcal (48.5 gram/1000 kcal at follow-up for men, and 42.2 gram/1000 kcal for women) was similar thus meats with relative higher GHG emissions were more often consumed.

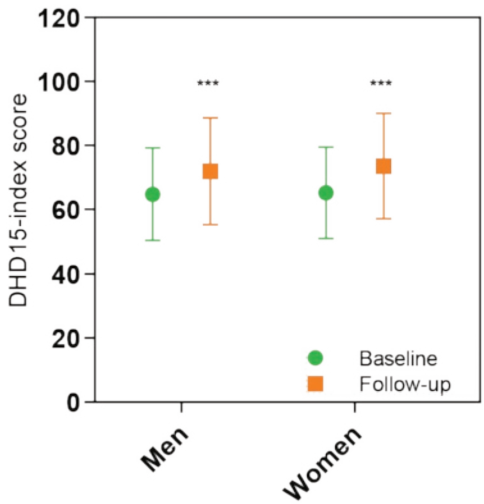

Figure 3.1. Mean (standard deviation) score on the Dutch Healthy Diet index 2015 (DHD15-index) at baseline and follow-up in EPIC-NL. Significance level paired t-test *<0.05, **<0.001, ***<0.0001.

For the plant-based foods, at similar energy intakes, healthiness of diets and GHG emissions was almost similar. A potential 50 points could be scored on the DHD15-index for plant-based foods, on which men scored similar but women decreased their score. The GHG emissions of total plant-based foods increased only slightly but statistically significantly in men and women. Within the plant-based foods, an increased consumption (gram/1000 kcal) of low-fiber bread, cereals, vegetables and legumes, nuts/seeds/nut paste, and vegetarian meat replacers was observed whereas the consumption of potatoes, fruit, and fries (men only) decreased.

The difference in consumption of miscellaneous foods resulted in slightly lower relative GHG emissions and (men and women) and higher DHD15-index scores (only women). Miscellaneous food groups of which the consumption increased at follow-up were cakes/cookies, sweets, and oils, diet margarines and liquid cooking fats whereas a decreased consumption of savoury snacks and sauces, soups, and butter and solid cooking fats was reported. Within the category beverages, our participants reported a decreased coffee consumption (~60 gram/1000 kcal less) and increased consumption of tea, light soft drinks, soft drinks (men only), and alcoholic beverages (women only) (**Table 3.2**) resulting in somewhat higher GHG emissions/1000 kcal but also higher DHD15-index scores.

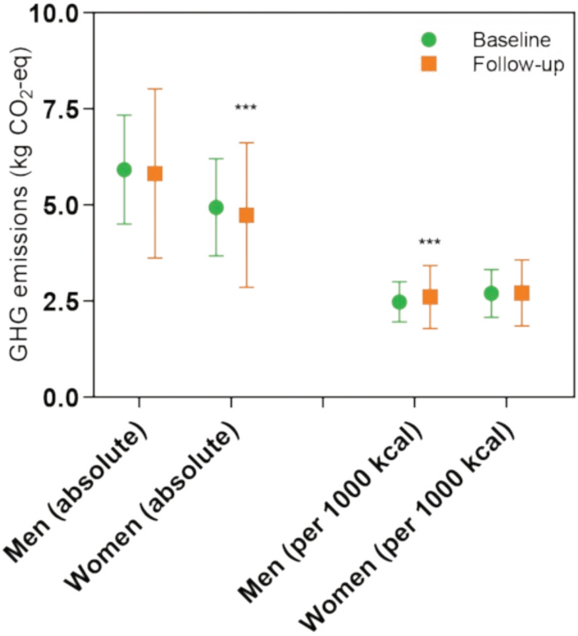

Figure 3.2. Mean (standard deviation) greenhouse gas (GHG) emissions at baseline and follow-up in EPIC-NL. Significance level paired t-test *<0.05, **<0.001, ***<0.0001.

Discussion

Overall, energy intake decreased by 162 kcal per day for men and 89 for women. The observed dietary changes resulted in a healthier diet, as measured by the DHD15-index score. The average score was 12% higher at follow-up, mainly due to increased consumption of fish and nuts/seeds/nut paste. Absolute GHG emissions of the diet were slightly lower in women (-4%) only. Expressed per 1000 kcal, the GHG emissions of the diet were higher in men (+5% $p<0.0001$) and remained similar in women (+0.4%), indicating no mitigation of GHG emissions. Higher consumption of (shell) fish and poultry was not yet at the expense of red and processed meats.

The Dutch National food consumption surveys between 1987 and 2010, showed similar meat, cheese, dairy and bread consumption. Rice, pasta, and non-alcoholic beverages consumption increased and potatoes, fruit and vegetable consumption decreased [34]. In 2012, the consumption of potatoes was even lower, while similar amount vegetables were consumed and slightly less cheese, dairy, and meat [35]. Comparing a similar timeframe (between 1987 and 2010), red and processed meat consumption remained similar in our cohort as well, while the type of red meat changed from beef to pork. Total meat and fish consumption increased because of the increased poultry and fish consumption. On the other hand and not in line with results of the Dutch National food consumption survey [34], we observed an increased cereal and vegetables consumption, decreased bread (especially high-fiber bread) and cheese consumption.

For all of the differences noted in our analyses, we did not investigate yet whether it is an effect of the ageing of our cohort or a difference between time points. Especially the reduction in calorie intake would likely be an ageing effect. A new study could also stratify the data by age group to compare both ageing as well as time effects simultaneously. This was, however, beyond the scope of our current study. Since most of the observed changes in diet in our cohort were comparable to other Dutch cross-sectional studies over time [34, 35], we hypothesize that they are a time effect and not necessarily an ageing effect.

A Canadian study identified 10-year dietary changes and its related GHG emissions between two cross-sectional surveys (in 2004 and 2015) using two 24-hour recalls [36]. Overall, total amount of calories consumed were 20% lower in 2015 compared to 2004. The authors observed a lower consumption of beef (-29%), dairy (-22%) pork (-11%), sausages (-31%), fruit and vegetables (-16%). In addition, a higher consumption of poultry (+18%), fish (+11%) and nuts (+43%) was observed. The total dietary GHG emissions in the Canadian study were 28% lower in 2015 than in 2004, which could be attributed mainly to the lower caloric intake and to the lower beef consumption. Although the observed differences in GHG emission and consumption of food groups were in the same or similar direction as in our study, much larger differences were found, especially for the consumption of red and processed meats. Similar to our study, consumption and GHG emission due to poultry and fish consumption increased over time.

Some changes in the diet might be linked to increased awareness of consumers of what a healthy diet constitutes. Over the years, the Dutch

Health Council and the Netherlands Nutrition Centre have been presenting guidelines for a healthy diet. In 2006, they highlighted the benefits of a higher consumption of fish, vegetables and fruits, and risks of a high solid fats, alcohol and salt consumption [37]. The updated guidelines, issued in 2015 after our measurements, included more food groups and had a focus on a plant-based instead of an animal-based diet (more vegetables, fruit, and nuts, less red meat, no processed meat, dairy within a range) [29]. The observed increased consumption of (shell) fish, nuts/seeds/nut paste, legumes, meat replacers and the decreased consumption of fries and snacks in our population are in line with these new recommendations. The consumption of (red and processed) meats and dairy within a range needs further attention and additionally may lead to diets with lower GHG emissions.

Our results showed improvements on the dietary quality of the diets, as measured by the DHD15-index, but not more environmentally friendly diets, as measured via GHG emission. Considering the minimal reduction in absolute consumption of red and processed meat, the higher GHG emissions from animal-based food consumption (meat, poultry, fish, dairy (including cheese) combined), and the below recommendation consumption of fruit and vegetables (290 versus 400 gram per day) these parts are key in new food policies and communication targeting both health as well as environmental aspects. The observed increase in DHD15-index score (men scored 7 points higher and women 8.5), is relevant for public health. In a previous study with baseline data of EPIC-NL we observed that per 1 SD increase in the DHD15-index score (16 points) the overall risk of mortality was 12% (95% CI: 5-18%) lower in men and 8% (95% CI: 4-12%) lower in women [38].

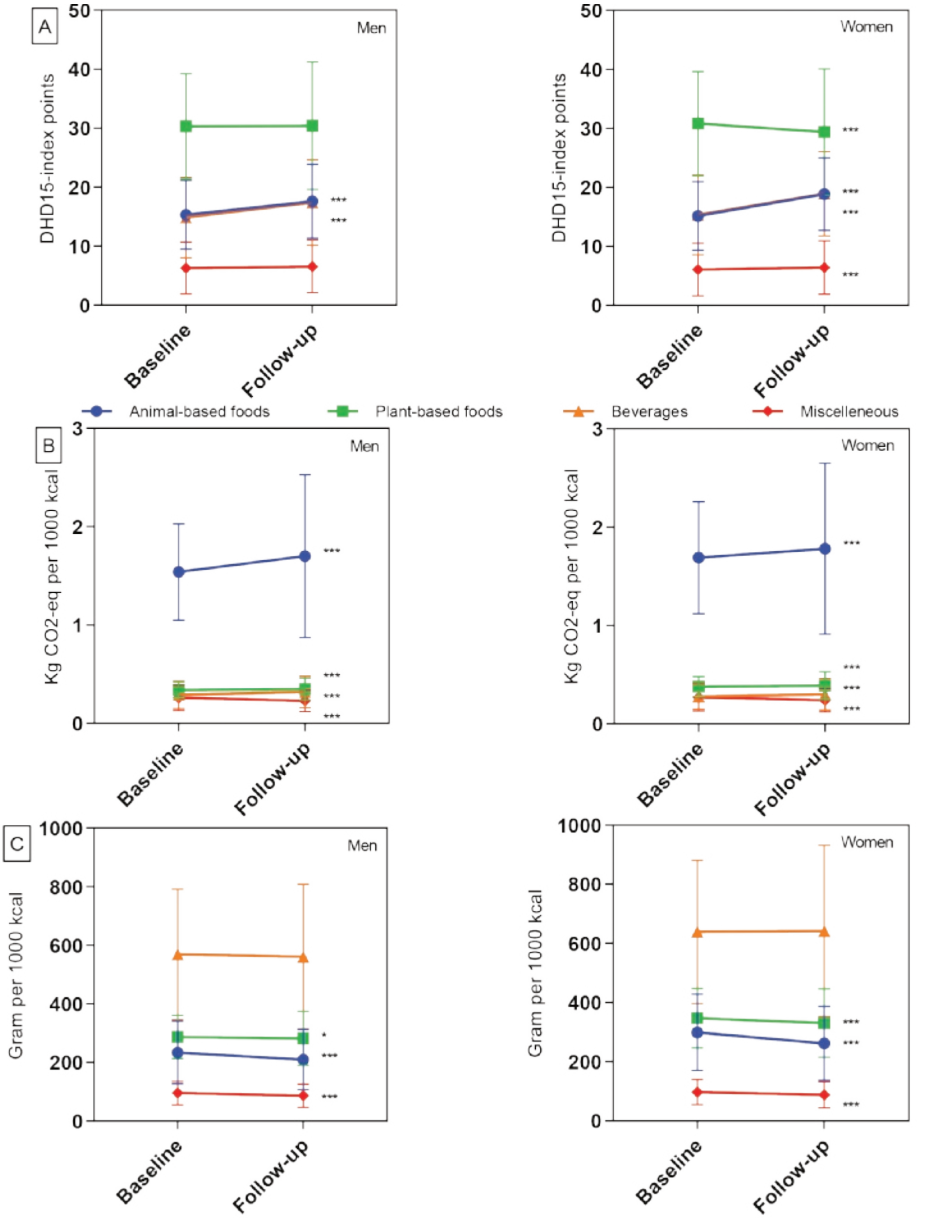

Figure 3.3. Mean (standard deviation) Dutch Healthy Diet 2015 index score (A), greenhouse gas emissions (B), and food consumption (C),) per food type at baseline and follow-up[a]. Significance level paired t-test *<0.05, **<0.001, ***<0.0001.

a: Animal-based foods include red and processed meat, poultry, (shell) fish, eggs and dairy. Plant-based foods contain potatoes, fries, bread and cereals, fruit, vegetables, vegetarian meat replacers, nuts, seeds and nut-paste. Beverages include coffee, tea, (light) soft drinks, fruit and vegetable drinks, and alcoholic beverages. Miscellaneous contain savoury snacks, cakes/cookies, soups, sauces, oils and fats, and sweets.

The applied FFQs were validated against 24-hour recalls but showed some differences in measurement error for several food groups [23, 24, 26]. The validation studies indicate similar correlations between both FFQs with 24-hour recalls for meat, dairy, and fish consumption. A higher correlation was observed for potatoes (0.58 vs 0.28), cheese (0.64 vs 0.16), sweets (0.78 vs 0.38), and cakes/cookies (0.56 vs 0.33) for the baseline compared to the follow-up FFQ. The correlation between vegetable consumption and 24-hour recalls was higher in the follow-up FFQ (0.52 versus 0.38). Therefore, the observed differences between baseline and follow-up of these food groups must be interpreted with caution since the measurement error is larger when the correlation coefficient is lower. The drop in cheese consumption (50% less), for example, might be due to the large difference in correlation error of the FFQs to the 24-hour recalls (baseline: 0.64 vs follow-up: 0.16). Furthermore, FFQs are designed to rank individuals and not to calculate absolute food consumption or energy intake. Although most observed changes in diet in our cohort were comparable to other Dutch cross-sectional studies based on 24-hr recalls [34, 35], the absolute intakes should be interpreted carefully. The food composition tables used in our study have changed with regard to the calculation of energy [25, 27]. Fiber content was used for energy calculations (2 kcal/gram) only in the table of 2011. Since we used energy-adjusted consumption (gram/1000 kcal) in our analyses, we will slightly overestimate the gram/1000 grams of all food groups and kg GHG emissions per 1000 kcal in 1996 compared to 2015. The recommended amount of fiber consumption in the Netherlands is 40 gram per day [39], so this would add approximately 80 kcal per day to the mean caloric intake at baseline. For example, the red meat consumption in men would then be estimated to be 47.9 gram/1000 kcal instead of 49.5 gram/1000 kcal, decreasing the already non-significant difference between baseline and follow-up. Since most Dutch people do not meet the recommendation for fiber (median habitual consumption 20 gram per day [40], this actual difference between the with and without fiber calculation at baseline will be even smaller. The number of total food items per FFQ also differ, 178 in the baseline questionnaire and 160 at follow-up, but the used food groups were similar. Excluding the several sub questions on brands present in the baseline FFQ, both FFQs had a similar total number of foods. In addition, by aggregating food items to overarching food groups in our study, potential differences in specific food items within food groups likely have not played a major role.

Although the time span of 20 years between the two FFQs, we applied the same data on GHG emissions of foods as available in the Netherlands. Consequently, differences in the GHG emissions between the two time points can be directly related to differences in dietary consumption and not to possible changes in production methods or efficiency gains in certain processes. Because of these technological improvements in production over time, we are likely underestimating the GHG emissions at baseline, since the GHG emissions were based on the 2016 data. In our study, the environmental impact is an average for foods available in the Netherlands, such as imported and domestic foods. For example, for tomatoes a percentage is grown in greenhouses in the Netherlands and a percentage is field grown in Spain and imported. Because the FFQ does not provide information on country of origin and production method, such variations in GHG emissions could not be considered. The small differences in the GHG emissions associated with the observed changes in the diet should therefore be interpreted cautiously. In addition, food production not only affects GHG emission, but also eutrophication, water use, and acidification. However, data on GHG emissions are available most and are therefore used by us, and other recent studies [41-45].

In conclusion, this Dutch cohort analyses showed more healthy diets without mitigated GHG emissions over a 20-year period, at similar energy intakes. Higher consumption of (shell) fish and poultry was not yet at the expense of red and processed meats. Lower consumption of animal-based foods is needed to achieve healthier as well as environmentally friendly diets.

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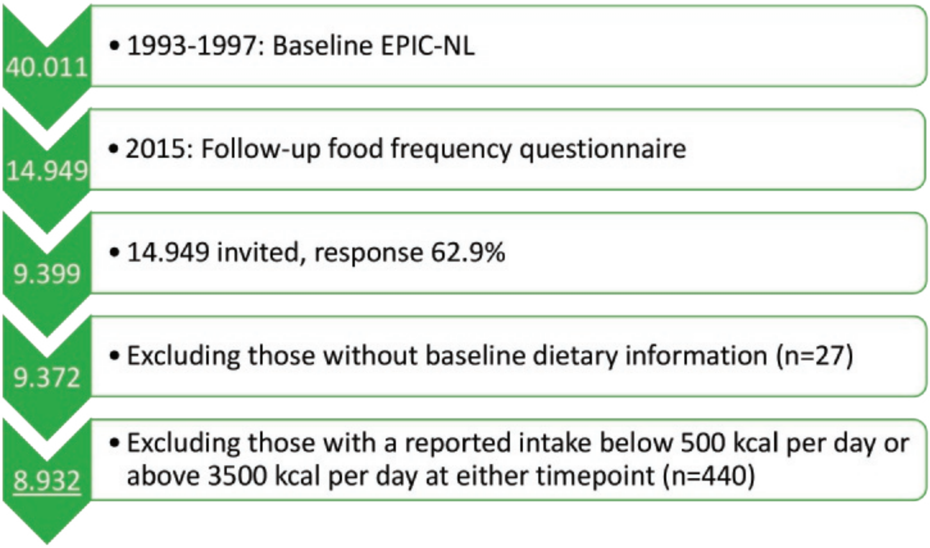
Appendix Chapter III



Supplemental figure 3.1. Flow chart of participants in the present study.

Supplemental table 3.1. Mean score and standard deviation on the subcomponents of the Dutch Healthy Diet index 2015 (DHD15-index) at baseline and follow-up stratified by sex[a].

Food groups	**Men** (n=1,844)				**Women** (n=7,088)			
	Baseline		**Follow-up**		**Baseline**		**Follow-up**	
Vegetables	6.4	2.4	6.0*	3.1	6.4	2.3	5.8*	3.1
Fruit	6.4	3.2	6.2	3.7	6.6	3.2	6.7*	3.6
Wholegrain bread	7.4	3.5	6.5*	3.9	7.6	3.5	6.2*	3.9
Legumes	6.0	3.9	6.5	4.5	6.2	3.8	6.7*	4.5
Nuts/seeds/nut paste	4.0	3.6	5.7*	4.0	3.9	3.6	5.0*	4.1
Dairy products	5.8	3.6	5.7	3.4	5.8	3.6	6.3*	3.4
Fish	4.0	2.6	6.3*	3.6	3.8	2.6	6.1*	3.7
Tea	5.3	3.8	5.4	4.0	5.2	3.7	6.3*	3.9
Replace butter and hard fats with margarines and oils	6.3	4.4	6.5	4.5	6.1	4.5	6.4*	4.5
Red meat and processed meat	5.9	3.6	5.6*	3.9	5.9	3.5	6.4*	3.7
Sweetened beverages and fruit juices	4.6	3.4	5.8*	3.9	4.8	3.4	6.1*	3.8
Alcohol	6.4	4.2	6.3	4.3	6.4	4.2	6.6	4.3

a: Significance level paired t-test *<0.05.

3

PART II

Health and environmental impacts of recommended dietary patterns


MILK

CHAPTER IV

Does a better adherence to dietary guidelines reduce mortality risk and environmental impact in the Dutch sub-cohort of the European Prospective Investigation into Cancer and Nutrition?

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British Journal of Nutrition, 2017.

Abstract

Background

Guidelines for a healthy diet aim to decrease the risk of chronic diseases. It is unclear to what extent a healthy diet is also an environmentally friendly diet.

Methods

In EPIC-NL, diet was assessed with a 178-item food frequency questionnaire of 40,011 participants aged 20–70 years between 1993 and 1997. The WHO's Healthy Diet Indicator (HDI), the Dietary Approaches to Stop Hypertension (DASH) score and the Dutch Healthy Diet index 2015 (DHD15-index) were investigated in relation to greenhouse gas (GHG) emissions, land use and all-cause mortality risk.

Results

GHG emissions were associated with HDI scores (-3.7% per standard deviation (SD) increase (95% confidence interval (CI): -3.4%; -4.0%) for men and -1.9% (-0.4%; -3.4%) for women), with DASH scores in women only (1.1% per SD increase, 95% CI: 0.9%; 1.3%) and with DHD15-index scores (-2.5% per SD increase (95% CI: -2.2; -2.8) for men and -2.0% (95% CI: -1.9; -2.2) for women). For all indices, higher scores were associated with less land use (ranging from -1.3 to -3.1%). Mortality risk decreased with increasing scores for all indices. Per SD increase of the indices, hazard ratios for mortality ranged from 0.88 (95% CI: 0.82; 0.95) to 0.96 (95% CI: 0.92; 0.99).

Conclusions

Our results showed that adhering to the WHO and Dutch dietary guidelines will lower the risk of all-cause mortality and moderately lower environmental impact. The DASH diet was associated with lower mortality and land use, but because of high dairy consumption in the Netherlands, it was also associated with higher GHG emissions.

Background

Global warming has led to an increased interest in environmentally friendly dietary patterns. At the end of 2015, the Paris Climate Agreement and the United Nations Sustainable Development Goals were initiated [1, 2]. Both agreements reflect the world's recognition that action is needed. In the European Union, the food sector is responsible for 20–30% of the total greenhouse gas (GHG) emissions [3]. A typical Western dietary pattern high in animal products, soft drinks and processed foods is reported to have a large environmental impact [4] and is associated with a higher risk of diseases compared to diets rich in vegetables, fruit and fibre-rich cereals [5-7]. Correspondingly, a Mediterranean dietary pattern high in fruit and vegetables, legumes, wine, fish and oils and low in meats, dairy and processed foods is found to be healthier [8] and adherence to the Mediterranean guidelines is more environmentally friendly [9]. In a Dutch setting, substituting meat with vegetables, fruit-nuts-seeds, fish, or pasta-rice-couscous was associated with both a lower mortality risk (6 to 19%) and a reduced environmental burden, measured as GHG emissions (4 to 11%) and land use (10 to 12%) [10]. Shifts in dietary patterns can therefore potentially benefit both the environment and health.

As early as 1986, Gussow and Clancy proposed that dietary guidelines should take into account the impact of dietary patterns on global natural resources [11]. Yet current guidelines are still primarily based on health outcomes. Examples of such guidelines are the World Health Organisation (WHO) [12] and Dutch [13] dietary guidelines and the Dietary Approaches to Stop Hypertension (DASH) diet [14]. For research purposes, the levels of adherence to the WHO and DASH dietary guidelines have been operationalised in the Healthy Diet Indicator (HDI) and DASH score, respectively [15, 16]. Recently, the dietary guidelines of the Netherlands were reviewed [13] and therefore the Dutch Healthy Diet (DHD) index, reflecting adherence to the Dutch dietary guidelines of 2006 [17], was updated to measure adherence to these new guidelines: the Dutch Healthy Diet index 2015 (DHD15-index [18].

Greater adherence to the WHO guidelines for a healthy diet (HDI) has been associated with increased longevity in European and American elderly [19] while the DASH diet but not the HDI was significantly associated with a lower risk of developing cardiovascular disease (CVD), coronary heart disease (CHD) and stroke in the EPIC-NL study [20]. The previous DHD-index was not associated with disease burden (disability-adjusted life years (DALYs)) or CVD risk in one Dutch cohort [20, 21] but was associated with decreased risk of all-cause mortality and CVD mortality in another [22].

To the best of our knowledge, no prospective study has compared the effect of adherence to dietary guidelines on indicators of environmental impact and health outcomes. Therefore, in this study we first quantified the association between better adherence to these guidelines and dietary environmental impact. Second, we studied the association between adherence to the dietary guidelines and risk of all-cause mortality. We used data from the Dutch contribution to the European Prospective Investigation into Cancer and Nutrition cohort study (EPIC-NL).

Subjects and Methods

Study population

EPIC-NL [23] consists of 40,011 subjects of EPIC-Prospect [24] and EPIC-MORGEN [25, 26], both carried out between 1993 and 1997. The EPIC-Prospect cohort included 17,357 women aged 49-70 years living in the city of Utrecht and its vicinity. The EPIC-MORGEN cohort included 22,654 men and women aged 20-65 years, living in Amsterdam, Maastricht and Doetinchem. This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving human participants were approved by the Institutional Review Board of the University Medical Centre Utrecht and the Medical Ethical Committee of TNO Nutrition and Food Research. Written informed consent was obtained from all participants. The design, cohort profile and rationale of EPIC-NL are described elsewhere [23]. On average, the EPIC-NL cohort had a participation rate of 40% (35% in EPIC-Prospect and 45% in EPIC-MORGEN). The non-response was previously found to impact on prevalence estimates of, for example, smoking but not examined associations [27].

Table 4.1. Components and scoring criteria of the indices measuring adherence to dietary guidelines.

	Maximum score	Minimum score
Healthy Diet Indicator (HDI)	**1 point**	**0 points**
1. Saturated fatty acids (en%)	<10	≥10
2. Polyunsaturated fatty acids (en%)	6-10	<6 or >10
3. Cholesterol (mg)	<300	≥300
4. Protein (en%)	10-15	<10 or >15
5. Dietary fibre (g)	>25	≤25
6. Fruits and vegetables (g)	≥400	<400
7. Free sugars (en%)	<10	≥10
Dietary Approaches to Stop Hypertension (DASH)score[a]	**5 points**	**1 point**
1. Fruit (g)	Sex-specific quintile 5	Sex-specific quintile 1
2. Vegetables (g)	Sex-specific quintile 5	Sex-specific quintile 1
3. Nuts and legumes (g)	Sex-specific quintile 5	Sex-specific quintile 1
4. Whole grains (g)	Sex-specific quintile 5	Sex-specific quintile 1
5. Low-fat dairy (g)	Sex-specific quintile 5	Sex-specific quintile 1
6. Sodium (mg)	Sex-specific quintile 1	Sex-specific quintile 5
7. Red and processed meat (g)	Sex-specific quintile 1	Sex-specific quintile 5
8. Sweetened beverages (g)	Sex-specific quintile 1	Sex-specific quintile 5
Dutch Healthy Diet index 2015 (DHD15-index)[b]	**10 points**	**0 points**
1. Vegetables (g)	≥200	0
2. Fruit (g)	≥200	0
3a. Wholegrain products (g) 3b. Replace refined with wholegrain products	≥90 (5 points) No consumption of refined products or ratio wholegrain/ refined ≥11 (5 points)	0 No consumption of wholegrain products or ratio wholegrain/refined ≤0.7
4. Legumes (g)	≥10	0
5. Nuts (g)	≥15	0

Table 4.1. Components and scoring criteria of the indices measuring adherence to dietary guidelines. (continued)

	Maximum score	Minimum score
6. Dairy products[c] (g)	300-450	0 or ≥750
7. Fish[d] (g)	≥15	0
8. Tea (g)	≥450	0
9. Replace butter and hard fats with margarines and oils	No consumption of fats or ratio oils/fats ≥13	No consumption of oils or ratio ≤0.6
10. Replace unfiltered coffee with filtered coffee	Consumption of only filtered coffee or no coffee consumption	Any consumption of unfiltered coffee
11. Red meat (g)	<45	≥100
12. Processed meat (g)	0	≥50
13. Sweetened beverages and fruit juices (g)	0	≥250
14. Alcohol (g)	≤10	Men: ≥30 Women: ≥20
15. Sodium (g)	<1.9	≥3.8

En%: the percentage of total energy intake (excluding alcohol). Abbreviations: g - grams
a: Higher quintile represents higher intake. Scoring of the components of the DASH score depends on the sex-specific quintile (1, 2, 3, 4 or 5 points). b: A score above the recommended intake is 10 points, whereas an intake below is given a proportional score between 0 and 10 points. c: A maximum of 40 grams cheese per day could be included. d: A maximum of 4 grams lean fish per day could be included.

Diet and environmental impact assessment

Usual daily dietary intake was estimated by a 178-item food frequency questionnaire (FFQ), which has been validated against twelve 24-hour recalls and biomarkers in 24 hour urine and blood [28, 29]. Spearman rank correlation coefficients based on estimates of the FFQ and 24 hour recalls in men 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. Results for women were similar. Energy intake and daily nutrient intakes were estimated using the 1996 Dutch Food Composition table [30]. Blonk Consultants assessed the environmental impact of food items consumed by the Dutch population [31]. Environmental impact was calculated based on life cycle assessments

(LCA). The LCAs were cradle to grave and included all steps from production, transport, preparation, to waste. The impact value of a food item is a weighted average of different subtypes of the product, e.g. by country of origin, which is based on the Dutch production (for the Dutch market) and Dutch import data. GHG emissions are expressed as kg CO_2-equivalents per day. Land use is expressed as m^2*year per day. These LCA data were combined with the EPIC-NL FFQ data to calculate daily GHG emissions and land use associated with the usual diet. For a more elaborate description of the calculation of the environmental impact of the diet see our previous paper [10].

Dietary indices

HDI

The HDI is based on the 2002 WHO guidelines [12] and has previously been used in other EPIC-NL papers [20, 21, 32, 33]. The HDI score consists of six nutrients (saturated fatty acids, polyunsaturated fatty acids, cholesterol, protein, dietary fibre and free sugars) and one food group (fruits and vegetables), (**Table 4.1**). When the intake was within the recommended range according to WHO's guidelines a score of one was assigned to that component, otherwise zero points were given. The final HDI score was the sum of all these components, ranging from 0 (minimal adherence) to 7 (maximal adherence).

DASH score

The DASH score is based on eight criteria from the DASH clinical trial from 1997 [14] and has been used in other analyses in EPIC-NL [20, 34]. Included components are fruit, vegetables, nuts and legumes, whole grains, low-fat dairy products, sodium, red and processed meats and sweetened beverages. For each of the components, participants were classified into sex-specific quintiles according to their intake. A score ranging from 1 to 5 was given to each quintile. For all components except sodium, red and processed meats and sweetened beverages, higher intakes were given higher scores, whereas for the latter components higher intakes were given lower scores (**Table 4.1**). In our population, only sodium incorporated in food products is accounted for and added salt during cooking or at the table is not included. The overall DASH score is the sum of all components and can range from 8 (lowest adherence) to 40 (highest adherence).

DHD15-index

The DHD15-index is based on the Dutch dietary guidelines of 2015 [13] and is an updated version of the previous DHD-index presented by Van Lee *et al.* [17]. The DHD15-index consists of 15 components (**Table 4.1**). A proportional score between 0 and 10 was assigned to the components. There are five component types included, which are adequacy, moderation, optimum, ratio and quality components. For adequacy components, the recommendation is to consume at least the mentioned quantity. The moderation components represent the foods of which the intake should be lowered. The optimum component has an optimal range of intake. The ratio components are based on replacement of one group by another food group. The quality component is based on the type of food group. The components vegetables, fruit, legumes, nuts, fish and tea are adequacy components, and the components red meat, processed meat, sweetened beverages and fruit juices, alcohol and sodium are moderation components. The component dairy is an optimum component with an optimal range of intake, whereas the fats and oils component is defined as a ratio component. The coffee component is defined as a qualitative component based on type of coffee (filtered or unfiltered). The wholegrain component is scored with two subcomponents: an adequacy component for wholegrain consumption and a ratio component for the ratio wholegrain products and refined grain products.

More detailed information on the calculation of the DHD15-index will be published in another paper [18]. In short, for the adequacy components, a lower limit of intake was given. For example, for fruits it is recommended to eat at least 200 grams per day. This level of intake received the maximum score of 10 points, gradually decreasing to an intake level of 0, which received 0 points. For the moderation components, an upper limit was given in the guidelines. For example, for red meat it was recommended to eat a maximum of 45 grams per day. This level of intake received 10 points, decreasing to a score of 0 points at intakes of 100 grams per day or more. The optimum component (dairy) was calculated by assigning 10 points when the intake was within the optimum range (300–450 grams per day). When intake was below the optimum range, the scores decreased linearly with lower intakes. When intake was above the optimum range, higher intakes were given linearly fewer points with a score of zero points assigned to intakes of 750 grams per day or more. The ratio components were scored by calculating the ratio between the recommended food group and the food group that needed to be replaced and dividing this ratio by the difference between threshold and cut-off value. The maximum score of 10 points was assigned when the ratio was higher than the cut-off value, and gradually decreased to 0 points at the threshold value. For some foods a quality aspect was defined (coffee); the maximum score of 10 points was assigned if all coffee consumed was filtered or if there was no coffee consumption. If all coffee consumed was unfiltered, the score would be 0. The final DHD15-index was the sum of all components and ranged from 0 (minimal adherence) to 140 (maximal adherence).

All-cause mortality assessment

The vital status of all EPIC-NL participants was obtained through linkage with the municipal population registries. Participants were followed over time until death by any cause, loss to follow-up, or were censored on January 1, 2015. During a mean follow-up of 19.2 (SD 3.3) years, 3,845 deaths were documented.

Lifestyle and anthropometric variables

At baseline, study participants completed a standardised structured general questionnaire on the presence of chronic diseases, related potential risk factors and lifestyle factors. Blood pressure, weight and height were measured by trained staff according to standardised protocols [23]. Body mass index (BMI) was calculated by dividing weight by height squared (kg/m^2). Physical activity was assessed with a validated questionnaire [35] and classified according to the Cambridge Physical Activity Index (CPAI) with imputed data for missing values (n=4,930) [36]. The CPAI is categorised into inactive, moderately inactive, moderately active and active. Smoking was operationalised as current, former, and never smoker. Educational level was coded as low (lower vocational training or primary school), medium (intermediate vocational training or secondary school) or high (higher vocational training or university).

Statistical analysis

Participants without dietary information at baseline were excluded (n=218) from this study. Participants with implausible dietary intake, i.e. those in the highest and lowest 0.5% of the ratio of reported energy intake to basal metabolic rate were also excluded (n=400). Participants without informed consent for linkage to municipal registries were excluded (n=1,034). Participants with a self-reported history of cancer (n=1,616), diabetes (n=759), myocardial infarction (n=514) or stroke (n=451) at baseline were excluded because their reported usual diet may not reflect their diet before diagnosis. Participants with missing information on BMI (n=17), educational level (n=191) or smoking status (n=23) were also excluded. After these exclusions, 35,031 participants remained for analysis (EPIC-Prospect=14,770 and EPIC-MORGEN=20,261). Since these are secondary analyses based on an existing large cohort with a long follow-up time, the justification for the sample size is not required.

Because the diets of men and women differ with respect to total energy intake and environmental impact, all analyses were stratified by sex. For the DASH score and DHD15-index, tertiles of adherence were created. Because the HDI ranged from 0-7 only, the HDI was categorised into three groups with a score 0-2, 3 and 4–7, respectively. Tabulations of sociodemographic data by HDI categories and tertiles of the DASH score and DHD15-index were made.

General linear models were used to calculate differences in mean GHG emission and land use in the different categories of dietary indices. The first category/tertile was used as reference. These analyses were adjusted for age at baseline, total energy intake and physical activity to compare the environmental impact based on dietary choices independently of total amount of foods consumed. In addition, we added educational level to the model in a sensitivity analysis. We assessed multicollinearity using the variance inflation factor (VIF), homoscedasticity and independence of the residuals, the mean and normality of the residuals, checked for linearity, and found that all criteria were met.

Cox proportional hazard models were used to estimate hazard ratios (HRs) with 95% confidence intervals (CI) for the associations between dietary indices and all-cause mortality. The first category/tertile was used as reference. The model was pooled for sub-cohort (EPIC-MORGEN or EPIC-Prospect) and adjusted for confounding by age, BMI, educational level, smoking status, total energy intake and physical activity. The HDI and DASH score did not include alcohol consumption; these models were also adjusted for this variable. The proportional hazards assumption was checked using the Schoenfeld residuals test and showed that none of the p-values was significant. P-values for the linear trend across the categories were calculated by including the mean score of each tertile as continuous variable in the model.

All analyses were repeated for a (continuous) change of one standard deviation (SD) in the dietary score to enable a better comparison of the associations between the different dietary scores. All statistical analyses were performed using SAS software (version 9.4, SAS Institute Inc., Cary, NC, USA). A two-sided p-value of <0.05 was considered statistically significant.

Results

Participants with higher DASH and DHD15-index scores tend to be older whereas those with a higher HDI score are younger than participants with lower scores (**Table 4.2**). The BMI and prevalence of current smoking is consistently lower with higher dietary index scores whereas physical activity levels are higher. With higher dietary index scores, energy intake is lower for the DASH score and DHD15-index but higher for the HDI. Alcohol intake is lower with higher dietary index scores, with the exception of women for whom alcohol intake remains constant across tertiles of the DASH score.

Adherence to dietary guidelines and environmental impact

On average, men's diets have a higher total environmental impact than women's do (respectively, 4.6 kg CO_2-eq per day and 4.4 m^2*year per day versus 3.7 kg CO_2-eq per day 3.5 m^2*year per day). However, when expressed per 1000 kcal women's diets have higher GHG emissions and land use (1.8 kg CO_2-eq and 1.7 m^2*year versus 2.0 kg CO_2-eq and 1.9 m^2*year).

Table 4.2. Baseline characteristics of the EPIC-NL cohort according to tertiles of the dietary guidelines.

	Healthy Diet Indicator (HDI)					
	Men			Women		
	Cat 1 0–2 (N=2,369)	Cat 2 = 3 (N=3,092)	Cat 3 4–7 (N=3,723)	Cat 1 0–2 (N=6,409)	Cat 2 = 3 (N=9,258)	Cat 3 4–7 (N=10,180)
Index score	1.8 (0.5)	3.0 (0.0)	4.4 (0.6)	1.9 (0.4)	3.0 (0.0)	4.5 (0.6)
Age (years)	43.5 ± 11.0	43.1 ± 10.9	42.0 ± 11.0	51.2 ± 11.6	50.7 ± 11.4	50.5 ± 11.8
Body mass index (kg/m²)	26.0 ± 3.5	25.8 ± 3.5	25.5 ± 3.4	25.6 ± 4.2	25.6 ± 4.1	25.4 ± 4.0
Energy intake (kcal/day)	2,498 ± 661	2,576 ± 703	2,675 ± 621	1,805 ± 456	1,810 ± 447	1,982 ± 464
Ethanol intake (g/day)	20.4 ± 24.0	18.7 ± 20.1	15.8 ± 17.8	8.9 ± 12.7	9.3 ± 12.7	8.0 ± 11.2
Current smokers (%)	44.9	39.5	33.6	31.7	30.0	23.5
High educational level (%)	23.1	28.0	30.3	14.9	18.2	21.5
Physically active (%)	42.0	43.3	49.5	38.5	39.2	44.4
	Dietary Approaches to Stop Hypertension (DASH)					
	Men			Women		
	Tertile 1 ≤ 22 (N=3,559)	Tertile 2 23 – 26 (N=2,796)	Tertile 3 ≥ 27 (N=2,829)	Tertile 1 ≤ 22 (N=9,786)	Tertile 2 23–26 (N=7,863)	Tertile 3 ≥ 27 (N=8,198)
Index score	19.2 (2.5)	24.5 (1.1)	29.6 (2.4)	19.0 (2.6)	24.5 (1.1)	29.5 (2.3)
Age (years)	40.8 ± 11.1	43.1 ± 10.8	45.0 ± 10.5	47.1 ± 12.3	51.5 ± 11.1	54.4 ± 9.8
Body mass index (kg/m²)	25.9 ± 3.8	25.7 ± 3.4	25.4 ± 3.2	25.7 ± 4.3	25.6 ± 4.0	25.3 ± 3.8
Energy intake (kcal/day)	2,712 ± 670	2,576 ± 683	2,469 ± 609	1,956 ± 488	1,860 ± 466	1,798 ± 413
Ethanol intake (g/day)	19.3 ± 21.7	17.7 ± 20.9	16.6 ± 18.1	8.5 ± 12.8	9.0 ± 12.2	8.5 ± 11.4
Current smokers (%)	44.5	39.3	30.2	36.6	26.1	19.3
High educational level (%)	17.1	27.2	41.6	12.8	19.2	25.3
Physically active (%)	45.0	45.1	46.5	37.5	41.8	44.6

Table 4.2. Baseline characteristics of the EPIC-NL cohort according to tertiles of the dietary guidelines. (continued)

	Dutch Healthy Diet index 2015 (DHD15- index)					
	Men			Women		
	Tertile 1 ≤ 59.9 (N=3,058)	Tertile 2 60.0–74.2 (N=3,607	Tertile 3 ≥ 74.2 (N=3,059)	Tertile 1 ≤ 73.7 (N=8,608)	Tertile 2 73.8–86.7 (N=8,631)	Tertile 3 ≥ 86.7 (N=8,608)
Index score	49.8 (7.7)	66.9 (4.1)	85.6 (9.0)	63.6 (8.1)	80.3 (3.7)	96.1 (7.3)
Age (years)	40.6 ± 11.1	43.0 ± 11.0	44.7 ± 10.5	48.5 ± 11.8	51.4 ± 11.3	52.4 ± 11.4
Body mass index (kg/m^2)	26.0 ± 3.8	25.8 ± 3.4	25.4 ± 3.2	25.9 ± 4.4	25.6 ± 4.0	25.0 ± 3.8
Energy intake (kcal/day)	2,808 ± 667	2,602 ± 657	2,378 ± 594	1,999 ± 507	1,856 ± 448	1,774 ± 402
Ethanol intake (g/day)	23.8 ± 23.4	16.8 ± 19.2	13.4 ± 16.7	11.2 ± 14.6	8.2 ± 11.5	6.7 ± 9.3
Current smokers (%)	47.6	37.5	30.3	40.2	25.4	18.2
High educational level (%)	17.1	26.1	39.9	11.4	17.0	27.7
Physically active (%)	46.4	45.8	44.2	38.3	41.4	43.5

Continuous variables are presented as mean ± SD and categorical variables as percentage.

4

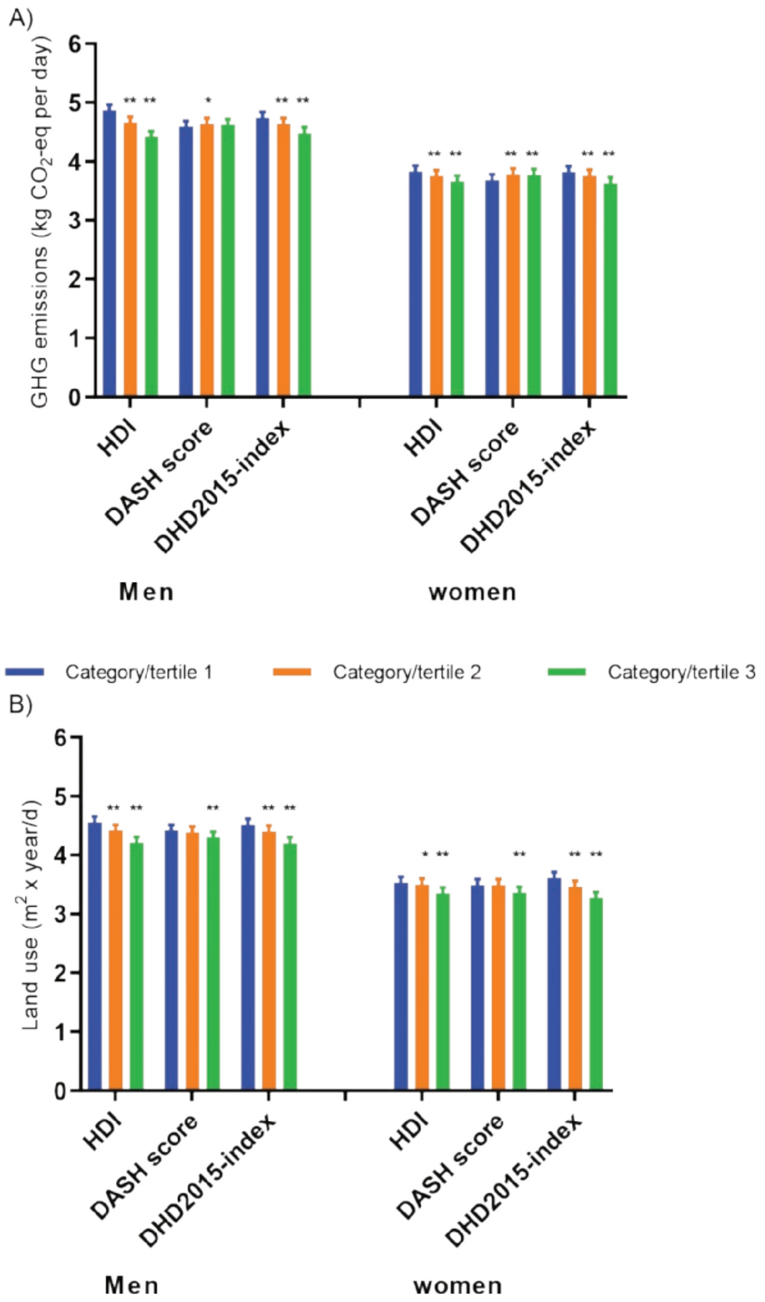

Figure 4.1. Adjusted mean (standard error) greenhouse gas (GHG) emissions (A) and Land Use (B) according to tertiles of the Healthy Diet Indicator (HDI), Dietary Approaches to Stop Hypertension (DASH) diet, and Dutch Healthy Diet index 2015 (DHD15-index).
All values adjusted for age at baseline, energy intake, and physical activity level. Significance compared to category/tertile 1. *= P<0.05, **= p<0.0001.

Table 4.3. Adjusted differences (%) and 95% confidence intervals (CIs) in greenhouse gas (GHG) emissions and land use according to the indices.

	Healthy Diet Indicator (HDI)			
	Cat 1	**Cat 2**	**Cat 3**	**Continuous per SD**
Men				
Index score (mean, SD)	1.8 (0.5)	3.0 (0.0)	4.4 (0.6)	3.3 (1.2)
Difference in GHG emission (%)	REF	-4.3 (-3.5; -5.1)	-9.1 (-8.4; -9.9)	-3.7 (-3.4; -4.0)
Cat 1 = 4.87 kg CO_2-eq/d				
Difference in land use (%)		-3.0 (-2.2; -3.8)	-7.7 (-6.9; -8.5)	-3.3 (-3.0; -3.6)
Cat 1 = 4.56 m^2*year/d				
Women				
Index score (mean, SD)	1.9 (0.4)	3.0 (0.0)	4.5 (0.6)	3.3 (1.3)
Difference in GHG emission (%)	REF	-1.9 (-1.4; -2.1)	-4.2 (-3.7; -4.7)	-1.9 (-0.4; -3.4)
Tertile 1 = 3.83 kg CO_2-eq/d				
Difference in land use (%)		-0.8 (-0.3; -0.5)	-5.0 (-4.5; -5.6)	-1.9 (-1.8; -2.1)
Tertile 1 = 3.53 m^2*year/d				
	Dietary Approaches to Stop Hypertension (DASH) score			
	Tertile 1	**Tertile 2**	**Tertile 3**	**Continuous per SD**
Men				
Index score (mean, SD)	19.2 (2.5)	24.5 (1.1)	29.6 (2.4)	24.0 (4.8)
Difference in GHG emissions (%)	REF	1.1 (0.3; 1.8)	0.6 (-0.2; 1.4)	0.2 (-0.2; 0.5)
Tertile 1 = 4.59 kg CO_2-eq/d				
Difference in land use (%)		-0.7 (-1.5; 0.1)	-2.7 (-1.9; -3.5)	-1.3 (-1.0; -1.6
Tertile 1 = 4.42 m^2*year/d				
Women				
Index score (mean, SD)	19.0 (2.6)	24.5 (1.1)	29.5 (2.3)	24.0 (4.9)
Difference in GHG emissions (%)	REF	2.6 (2.1; 3.1)	2.3 (1.8; 2.9)	1.1 (0.9; 1.3)
Tertile 1 = 3.68 kg CO_2-eq/d				
Difference in land use (%)		0.0 (-0.5; 0.5)	-3.5 (-2.9; -4.0)	-1.3 (-1.1; -1.4)
Tertile 1 = 3.49 m^2*year/d				

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Table 4.3. Adjusted differences (%) and 95% confidence intervals (CIs) in greenhouse gas (GHG) emissions and land use according to the indices. (continued)

	Dutch Healthy Diet index 2015 (DHD15- index)			
	Tertile 1	**Tertile 2**	**Tertile 3**	**Continuous per SD**
Men				
Index score (mean, SD)	49.8 (7.7)	66.9 (4.1)	85.6 (9.0)	67.4 (16.3)
Difference in GHG emissions (%)	REF	-2.0 (-1.3; 2.8)	-5.5 (-4.7; -6.3)	-2.5 (-2.2; -2.8)
Tertile 1 = 4.74 kg CO_2-eq/d				
Difference in land use (%)		-2.7 (-1.9; -3.5)	-7.1 (-6.3; -7.9)	-3.1 (-2.8; -3.4)
Tertile 1 = 4.52 m^2*year/d				
Women				
Index score (mean, SD)	63.6 (8.1)	80.3 (3.7)	96.1 (7.3)	80.0 (14.9)
Difference in GHG emissions (%)	REF	-1.7 (-1.2; -2.2)	-4.9 (-4.4; -5.4)	-2.0 (-1.9; -2.2)
Tertile 1 = 3.82 kg CO_2-eq/d				
Difference in land use (%)		-4.2 (-3.7; -4.7)	-9.6 (-9.1; -10.1)	-3.1 (-3.0; -3.3)
Tertile 1 = 3.61 m^2*year/d				

All values adjusted for age at baseline, energy intake and physical activity level.

Mean GHG emissions and land uses according to the three categories of adherence to the three dietary indices are presented in **Figure 4.1**. In men, comparing the highest category with the lowest, dietary GHG emissions are significantly lower for the HDI (-9.1%, 95% CI: -8.4%; -9.9%) and for the DHD15-index (-5.5%, 95% CI: -4.7%; -6.3%) but not for the DASH score (0.6%, 95% CI: -0.2%; 1.4%) after adjusting for age, energy intake and physical activity levels (**Table 4.3**). In women, better adherence to the guidelines is associated with statistically lower GHG emissions for the HDI and DHD15-index. However, higher scores on the DASH diet were associated with significantly higher GHG emissions (2.3%, 95% CI: 1.8%; 2.9%). Analysing the results continuously per difference of one standard deviation of the score gave very similar results. Including educational level as a possible additional confounder did not change the results (not shown).

All dietary guideline indices showed that an increase in the score is associated with lower land use (**Figure 4.1 and Table 4.3**). For men, comparing category 3 to category 1, land use is significantly lower by -7.7% (95% CI: -6.9; -8.5) for the HDI, -2.7% (95% CI: -1.9; -3.5) for the DASH score and -7.1% (95% CI: -6.3; -7.9) for the DHD15-index. In women, land use of category 3 versus category 1 is -5.0% (95% CI: -4.5; -5.6) lower for the HDI, -3.5% (95% CI: -2.9; -4.0) for the DASH score and -9.6% (95% CI: -9.1; -10.1) for the DHD15-index.

Adherence to dietary guidelines and all-cause mortality

Mortality risk is significantly lower in the highest compared to the lowest category of the HDI for both men (HR_{C3-C1}: 0.82, 95% CI: 0.70; 0.97) and women (HR_{C3-C1}: 0.83, 95% CI: 0.76; 0.91) (**Table 4.4**). Adherence to the DASH diet is not associated with all-cause mortality in men and women when analysed in tertiles. However, analysing the DASH score continuously per standard deviation increase of the score, a better adherence is significantly associated with lower risk of all-cause mortality (**Table 4.4**). Mortality risk is significantly lower with better adherence to the DHD15-index in men (HR_{T3-T1}: 0.84, 95% CI: 0.69; 0.98) and women (0.85, 95% CI: 0.78; 0.96).

Table 4.4. Adjusted[a] hazard ratios (HRs) and 95% confidence intervals (CIs) for the associations between the indices and all-cause mortality among 35,031 EPIC-NL participants.

	Healthy Diet Indicator (HDI)				
All-cause mortality	**Cat 1**	**Cat 2**	**Cat 3**	**P for trend**	**Continuous per SD**
Men					
No. of deaths	292	307	292		
No. of participants	2,369	3,092	3,723		
Person-years (median, SD)	19.2 (3.6)	19.3 (3.7)	19.3 (3.4)		
Index score (mean, SD)	1.8 (0.5)	3.0 (0.0)	4.4 (0.6)		3.3 (1.2)
Mortality risk	1 (REF)	0.90 (0.77;1.06)	0.82 (0.70;0.97)	0.021	0.90 (0.84;0.97)
Women					
No. of deaths	875	1,057	1,022		
No. of participants	6,409	9,258	10,180		
Person-years (median, SD)	19.2 (3.5)	19.2 (3.1)	19.1 (3.2)		
Index score (mean, SD)	1.9 (0.4)	3.0 (0.0)	4.5 (0.6)		3.3 (1.3)
Mortality risk	1	0.89 (0.82;0.98)	0.83 (0.76;0.91)	0.0001	0.93 (0.90;0.97)
	Dietary Approaches to Stop Hypertension (DASH) score				
	Tertile 1	**Tertile 2**	**Tertile 3**	**P for trend**	**Continuous per SD**
Men					
No. of deaths	338	294	259		
No. of participants	3,559	2,796	2,829		
Person-years (median, SD)	19.3 (3.6)	19.2 (3.6)	19.2 (3.5)		
Index score (mean, SD)	19.2 (2.5)	24.5 (1.1)	29.6 (2.4)		24.0 (4.8)
Mortality risk	1	1.04 (0.89;1.22)	0.87 (0.74;1.04)	0.15	0.92 (0.86;0.99)

Table 4.4. Adjusted[a] hazard ratios (HRs) and 95% confidence intervals (CIs) for the associations between the indices and all-cause mortality among 35,031 EPIC-NL participants. (continued)

	Dietary Approaches to Stop Hypertension (DASH) score				
	Tertile 1	**Tertile 2**	**Tertile 3**	**P for trend**	**Continuous per SD**
Women					
No. of deaths	980	900	1,074		
No. of participants	9,786	7,863	8,198		
Person-years (median, SD)	19.2 (3.2)	19.2 (3.2)	19.1 (3.2)		
Index score (mean, SD)	19.0 (2.6)	24.5 (1.1)	29.5 (2.3)		24.0 (4.9)
Mortality risk	1	0.94 (0.85;1.03)	0.94 0.86;1.03)	0.18	0.96 (0.92;0.99)
	Dutch Healthy Diet index 2015 (DHD15-index)				
	Tertile 1	**Tertile 2**	**Tertile 3**	**P for trend**	**Continuous per SD**
Men					
No. of deaths	293	329	269		
No. of participants	3,058	3,067	3,059		
Person-years (median, SD)	19.3 (3.5)	19.3 (3.6)	19.2 (3.6)		
Index score (mean, SD)	49.8 (7.7)	66.9 (4.1)	85.6 (9.0)		67.4 (16.3)
Mortality risk	1	1.04 (0.88;1.21)	0.84 (0.69;0.98)	0.04	0.88 (0.82;0.95)
Women					
No. of deaths	1,000	964	9,90		
No. of participants	8,608	8,631	8,608		
Person-years (median, SD)	19.2 (3.2)	19.2 (3.2)	19.1 (3.2)		
Index score (mean, SD)	63.6 (8.1)	80.3 (3.7)	96.1 (7.3)		80.0 (14.9)
Mortality risk	1	0.86 (0.78;0.93)	0.85 (0.78;0.94)	0.001	0.92 (0.88;0.96)

Model is pooled for cohort (EPIC-Prospect or EPIC-MORGEN).

a. Mortality risk: adjusted for age at baseline, body mass index, educational level, smoking status, total daily energy intake, and physical activity level. In addition, the HDI and DASH models are adjusted for alcohol intake.

Discussion

Our study shows that better adherence to the dietary guidelines from the WHO, DASH (in men only) and Dutch Health Council is associated with lower environmental impact and lower risk of all-cause mortality. In men, the largest difference in environmental impact is observed for higher scores on the HDI (-3.7% per SD for GHG emissions and -3.3% per SD for land use). For women the largest environmental impact differences are observed for the DHD15-index (-2.0% per SD for GHG emission and -3.1% per SD for land use). Higher DHD15-index scores are associated with the lowest relative all-cause mortality risk of the indices (HRSD of 0.88, for men and 0.92, for women).

The different guidelines, and therefore the indices, have conceptual differences. Despite these differences, the HDI, DASH, and DHD15-index have quite comparable associations with all-cause mortality and the HDI and DHD15-index show comparable possible reductions in GHG emissions and land use of the diet in our study.

Governments and health organisations promote dietary patterns linked to a broad range of positive health effects. Considering the significant environmental impact of our current diet, these diets should ideally be accompanied by lower GHG emissions and land use to meet the Food and Agriculture Organisation's definition of a sustainable diet [37]. In a literature review of 16 studies by Payne et al. it is stated that dietary patterns that primarily aim to reduce GHG emissions may not always improve nutritional quality or health outcomes compared to the average dietary patterns [38]. Similarly, in a previous paper we showed that total GHG emissions and land use of the diet were not associated with all-cause mortality [10]. On the other hand, our current results suggest that adhering to some of the dietary guidelines will both improve health and moderately reduce environmental impact. While diets according to guidelines most likely ensure a higher dietary quality, their links with environmental impact are less clear. A review of modelling studies showed that meeting dietary guidelines may reduce GHG emissions by 0–35% and land use by 15–50% compared to the average observed food consumption in a population [39]. However, in 5 of the 14 scenarios the reduction potential was less than 10%. Although the increased consumption of some food groups, such as fruits and vegetables, legumes and nuts, increases environmental impact, this is usually outweighed by the lower consumption of meat and products, such as snacks, sweets and pastries [40]. In addition, fish consumption would have to increase to meet the recommendation, which will not only increase GHG emissions and land use (farmed fish), but it will also put pressure on wild fish stocks. But total GHG emissions will not necessarily increase when fish replaces other protein-rich foods with a higher environmental impact, such as beef [41]. This underlines the importance of looking at dietary patterns from both a health and an environmental perspective together to create environmentally friendly and healthy diets.

Although limited to two studies, environmental impact has been studied for the HDI [42] and the DASH diet [43] before. Green et al. modelled and optimised the current United Kingdom (UK) consumption to completely match the WHO guidelines and showed a possible 17% reduction in GHG emissions [42]. The difference found by the authors was larger than we observed in our study (category 3 (4–7 points) versus category 1 (0–2 points): 4% lower GHG emissions in women and 9% in men), but we compared categories of adherence and did not model the impact when all recommendations are completely met (mean score was 4.5 out of a possible 7 in the highest category). In addition, this was an optimisation study in which specific foods with a low environmental impact were selected to replace unhealthy foods instead of observing actual food intakes as in our study. Monsivais et al. studied the GHG emissions associated with the DASH diet within the UK population of the EPIC cohort [43]. GHG emissions in the highest quintile of adherence were 17% lower than in the lowest quintile. We observed a small increase in GHG emissions (a not significant increase of 0.6% for men and a significant 2.3% increase for women) between the lowest to the highest tertile of the DASH score. There is a noticeable difference between our studies in the calculation of the DASH score. We analyse the foods in grams per day, whereas Monsivais et al. used food groups expressed as energy percentage. Low-fat dairy consumption is promoted in the DASH diet, but the mean consumption and the variation in consumption in the UK cohort are much lower than in our population (174.9 (SD=104.0) [44] versus 250.8 (SD=209.1) grams per day). Since the DASH score is based on quintiles of intake, the difference between the consumption in Q5 and Q1 of low-fat dairy is much larger in our population than in the UK one.

Consequently, the difference in environmental impact of this food group is also much larger because dairy is a major contributor to total GHG emissions. Total dairy is on average responsible for 25% of the diet-related GHG emissions in our population [10]. Also, differences between quintiles of the total DASH score (Monsivais et al. [43]) are expected to be larger than between tertiles (our study). Combined, these factors may account for the small increase in GHG emissions in our cohort compared to the decrease observed in the UK cohort.

Previously, higher levels of adherence to the HDI were inversely associated with all-cause mortality risk in two European population studies with similar risk estimates as we present here [19, 45]. The DASH diet was associated with lower all-cause mortality in older adults [46] and adults with hypertension [47], similar to our results. For the previous DHD-index, based on the Dutch guidelines from 2006, supporting evidence of the overall association with all-cause and cause-specific mortality is inconclusive [20-22] whereas the new DHD15-index is clearly associated with mortality in our population.

Energy intake is correlated with GHG emissions. In a UK population, for every 1000 kcal GHG emissions increased by, on average, 3 kg CO_2-eq [43]. Therefore, we adjusted our analysis for energy intake to independently study the effect of dietary quality on GHG emissions and land use. We can conclude that at equal energy intake adhering to the HDI, DASH (only for land use), and the DHD15-index are better for the environment. Taking the obesity trend in the Netherlands into consideration not only dietary quality should be improved, but also the limiting of energy intake should be crucial. Besides reducing the burden of disease associated with overweight and obesity [48], this would also reduce the environmental impact of our diet by less food being eaten. A modelling scenario in the US in which the caloric intake was reduced to maintain a healthy body weight without changing the actual food mix resulted in an approximate reduction in GHG emissions of 9% [49].

The reductions in GHG emissions that are observed in our study are only moderate, but are accompanied by a clear reduction in mortality risk. The added value of sustainability aspects in nutritional guidelines would be that consumers would learn what the healthy foods are and could combine this with the sustainable choice between food groups and also within each food group

[50]. However, to achieve a more sustainable food system, change should not be limited to the choices made by consumers. Within each food group, producers, retailers and transport businesses may invest in new technologies that retain crop yield while protecting biodiversity, reuse materials, provide better storage and produce less waste to facilitate a more sustainable production of foods. This is why both aspects are combined in the UN Sustainable Development Goals under the header 'responsible consumption and production' [2]. However, if the consumers demand for sustainable and healthy foods becomes more eminent this might force companies to follow.

Major strengths of this study are that we used both dietary and environmental impact data of the same population and have linked these with registered mortality data. In addition, we have a large population-based cohort with a long follow-up of 19 years. We compared three different indices for healthy diets and found similar and thus robust results. Some limitations need to be addressed. Our study assessed dietary intake and its environmental impact only at baseline and only in adults. We assume in our current analyses that both intake and impact are stable. However, a previous study compared the environmental impact of the Dutch diet of 2007/2010 with that of 1997/1998 and observed a 4.9% lower GHG emission in men and 7.0% for women due to changing dietary intakes [31]. According to the Dutch National Food Consumption Survey, between 2012 and 2014 and 2007 and 2010, the average diet of Dutch adults showed a decrease in the consumption of potatoes, fats and oils, alcoholic beverages, dairy products, cakes and biscuits and meat versus an increase in the intake of non-alcoholic drinks and condiments and sauces. Adolescents showed similar dietary changes, but in addition fruit intake increased by 20%. Not considering such dietary changes can result in an under- or overestimation of the association between the dietary patterns and mortality because participants can be misclassified. If we were to apply the Dutch guidelines to the current food consumption data most Dutch people would not meet the guidelines at this moment [51] and thus our message that dietary change is needed to increase sustainability of the diet and health remains a priority.

Under- and over-reporting of dietary energy intake might affect the associations of the dietary patterns with environmental impact. Therefore, we excluded participants in the highest and lowest 0.5% of the ratio of reported energy intake to basal metabolic rate as proxy for over- and under-reporters. The indicators for environmental impact are based on Dutch LCA data and apply to a Dutch setting only. Our results for environmental impact of the dietary patterns may therefore not be directly extrapolated to other countries where production methods, productivity, fossil energy use, import and export and ways of transport may differ.

In conclusion, national and international guidelines for a healthy diet are aimed at decreasing the risk of chronic diseases. If these guidelines were adhered to by a larger proportion of the Dutch population, lower risk of all-cause mortality as well as reductions in GHG emissions and land use could be achieved. The possible reductions in GHG emissions and land use seem to be moderate. Eating more plant-based instead of animal-based products and according to the guidelines for a healthy diet and limiting caloric intake to match energy requirement are all strategies that need to be combined and applied to maximise the health potential while limiting the environmental impact of our diet.

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CHAPTER V

Identification of data-driven Dutch dietary patterns that benefit the environment and are healthy.

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Abstract

Background

More sustainable dietary patterns are needed to mitigate global warming. This study aims to identify data-driven healthy dietary patterns that benefit the environment.

Methods

In EPIC-NL, diet was assessed using a 178-item FFQ in 36,203 participants aged 20-70 years between 1993 and 1997. The Dutch Healthy Diet index 2015 (DHD15-index) was used to score healthiness of the diet. As proxy for environmental impact, greenhouse gas (GHG) emissions were calculated using life-cycle analysis. To determine patterns that are both healthy and environmentally friendly, Reduced Rank Regression was applied.

Results

A "*Plant-based Pattern*" characterized by high consumption of fruits, vegetables and legumes, and low consumption of fries, red meat and processed meat and a "*Dairy-based Pattern*" characterized by high consumption of dairy, and nuts and seeds and low consumption of coffee and tea, sugar-containing sodas, low-fiber bread, and savoury sauces were derived. At equal energy intake, the diet of adherents (highest quartile) to the "Plant-based Pattern" were significantly healthier (89.8 points on the DHD15-index, $p<0.0001$) and more sustainable (3.96 kg CO_2-eq/day, $p<0.0001$) compared to the average diet (76.2 points, 4.06 kg CO_2-eq/day) whereas the "*Dairy-based Pattern*" was somewhat healthier (77.9 points, $p<0.0001$), but less sustainable (4.43 kg CO_2-eq/day, $p<0.0001$).

Conclusion

When deriving dietary patterns based on health and environmental aspects of the diets, a "*Plant-based*" and a "*Dairy-based*" pattern were observed in our study population. Of these, the plant-based diet benefits health as well as the environment.

Background

The Paris Climate Agreement and the United Nations Sustainable Development Goals underline the need to improve the sustainability of our society and limit global warming to less than 2°C [1, 2]. Excessive greenhouse gas (GHG) emissions are an important driver of climate change and new strategies are needed to reduce emissions [3]. Food and beverage consumption is estimated to be responsible for 20-30% of total GHG emissions in the EU, and thus have a major impact on the environment [4].

Many dietary-related factors, such as high blood glucose, overconsumption, high cholesterol, alcohol and low consumption of fruit and vegetables contribute to an increasing global burden of disease [5]. Globally, in 2016 a suboptimal diet accounted for 9.6% of disability adjusted life years (DALYs) and 18.8% of all deaths [6]. That is why, according to the Food and Agriculture Organisation (FAO) a sustainable diet should, among other things, be environmentally friendly and contribute towards health [7]. These criteria should be considered simultaneously since an environmentally friendly diet may not necessarily benefit health and vice versa. For example, dietary scenarios that primarily aim to lower dietary GHG emissions do not always result in improvements in nutritional quality or health outcomes [8]. In addition, no direct association was observed between diet related GHG emissions and mortality risk in a previous study [9]. However, adhering to a vegetarian or Mediterranean-style dietary pattern has been shown to be associated with lower environmental impacts and better health [10-12].

Dietary patterns based on nutritional guidelines from the WHO or national health councils are examples of a priori defined diets [13, 14]. Besides a priori dietary patterns, several statistical models can derive and identify posteriori dietary patterns actually present based on population food intake information [15]. Examples of these models are principle component analysis (PCA) or cluster analysis (CA) [16-18]. Both a priori and a posteriori techniques have been combined in a relatively new method: reduced rank regression (RRR) [19]. When combining dietary information with known biomarkers for a disease, RRR was able to derive dietary patterns that showed stronger associations with a particular disease than PCA based patterns [19-21].

This hybrid approach is partly theoretically driven, by using variables that are relevant to answer the research question, but still identifies dietary patterns based on the data. For our study, we used a priori knowledge on the healthiness of diets and environmental effects of foods to identify dietary patterns that could potentially be more sustainable and healthy. As far as we know, RRR has only been applied with biomarkers of disease or nutrient intake as response variables but not with an overall dietary index based on recommendations for a healthy diet [15], let alone in combination with an indicator of environmental impact.

In this study, we will investigate the association between the current Dutch dietary guidelines and their environmental impact (a priori). Secondly, we will investigate which dietary patterns are present in our study population that might be beneficial for health and the environment (hybrid approach).

Subjects and Methods

Study population

The European Prospective Investigation into Cancer - Netherlands (EPIC-NL) cohort consists of 40,011 subjects of EPIC-Prospect [22] and EPIC-MORGEN [23, 24] both with inclusion of participants from which data were collected between 1993 and 1997. Both studies comply with the Declaration of Helsinki [25].

Participants without dietary information at baseline were excluded (n=218) for the current analysis. To exclude dietary over and under reporters, participants in the highest and lowest 0.5% of the ratio of reported energy intake to basal metabolic rate were also excluded (n=400). Participants with a self-reported history of cancer (n=1,645), diabetes (n=793), myocardial infarction (n=531) or stroke (n=463) at baseline were excluded to include the same population as our previous publications [9, 26]. After these exclusions, 36,209 participants remained for analysis.

Dietary assessment

Usual daily dietary intake was estimated by a 178-item food frequency questionnaire that has been validated against twelve 24-h recalls and biomarkers in 24-h urine and blood samples [27, 28]. 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. Similar results were obtained for women. Energy intake and daily nutrient intakes were estimated using the Dutch Food Composition Table [29]. We grouped the food items into 35 food groups (**Supplemental table 5.1**). For each of the 35 food groups, intakes were presented as the percentage energy they contributed to total energy intake.

Assessment of healthiness of diets

We calculated the Dutch Healthy Diet index 2015 score as an indicator of the healthiness of the diet [30] in our study population. A proportional score between 0 and 10 was assigned to each of the 15 recommendations (**Supplemental table 5.2**). Some recommendations require a minimal level of intake. For example for fruit, it is recommended to eat at least 200 grams per day. An intake equal to or above this level received the maximum score of 10 points, gradually decreasing to an intake level of zero, which received 0 points. For other foods, the guidelines recommend a maximum intake. For example, for salt it is recommended to consume a maximum of 6 grams per day (2.4 grams sodium). An intake below this level received the maximum score of 10 points, gradually decreasing to a score of 0 points at the reference value (twice the recommended level of intake) and above. In our FFQ added salt was not included. Previously, added salt was estimated to be 20% [31], and subsequently the upper limit was set at 4.8 grams of salt (1.9 grams of sodium). For dairy, an optimal intake is recommended (2-3 portions per day). Consumption of 2-3 portions received 10 points, gradually decreasing to an intake level of zero, which received 0 points. When intake was higher than 3 portions, the score also gradually decreased to a score of 0 points at 5 portions per day or more. For some food groups, it is recommended to replace one type of food with another. For example, it is recommended to replace butter and hard fats with margarines and oils. For this type of recommendation we created a ratio by dividing the intake of the recommended food by the intake of the replaced food. When the oils/fats ratio was higher than 13 a score of 10 points was received, gradually decreasing to 0 points when the ratio was lower than 0.6 [30]. For coffee the recommendation is to consume filtered instead of unfiltered coffee. However, in our population, information was not available on the type of coffee consumed so this item was omitted from our calculation of the DHD15-index.

Assessment of the environmental impact of diets

Blonk Consultants assessed the environmental impact of food items consumed by the Dutch population [32]. As a proxy for environmental impact, greenhouse gas (GHG) emissions were calculated using life cycle assessments (LCA) and expressed as kg CO_2-equivalents per day. These LCAs included all steps from production, transport and preparation. Food losses during production, retail, transportation and consumption are taken into account in the LCA models. The impacts of processing this waste (composting, by-products, etc.) are allocated to the products the products that benefit from this compost and other by-products. We use weighted averages per food group, which considers the proportion of imported/Dutch products and different production methods. The LCA data, version 2014, was linked to the EPIC-NL FFQ data to calculate daily GHG emissions associated with the usual diet. A more extensive description of the calculation of environmental impact of the diet in EPIC-NL has been published previously [9].

Table 5.1. Characteristics (mean (SE)) of adherent of the Reduced Rank Regression derived "Prudent" and "Dairy-based" dietary patterns.

	Mean EPIC-NL	"Plant-based Pattern"		"Dairy-based Pattern"	
		Quartile 1	Quartile 4	Quartile 1	Quartile 4
Participants	36209	9052	9052	9052	9052
Age (years)	48.6 (0.1)	45.6 (0.1)	51.6 (0.1)	46.3 (0.1)	50.6 (0.1)
% Males	26.3	39.6	19.3	32.9	20.3
Body Mass Index (kg/m^2)	25.6 (0.02)	26.3 (0.04)	24.9 (0.04)	25.6 (0.04)	25.6 (0.04)
% Current smokers	30.7	46.7	17.9	39.1	24.7
% Physically Active (CPAI)[a]	42.0	40.8	43.1	39.8	43.1
Energy intake (kcal/d)	2063 (2.7)	2172 (5.6)	1903 (5.5)	1910 (5.3)	2182 (5.3)
High education[b]	20.9%	16.5	24.5	18.8	25.1
Dietary intake (gram per day)					
Plant-based foods					
Potatoes	104 (0.3)	113 (0.7)	95 (0.7)	119 (0.6)	88 (0.6)
Vegetables	131 (0.3)	107 (0.5)	160 (0.5)	136 (0.5)	126 (0.5)
Legumes	9 (0.1)	7 (0.1)	13 (0.1)	9 (0.1)	10 (0.1)
Fruits	196 (0.7)	123 (1.3)	279 (1.3)	168 (1.4)	222 (1.4)
Nuts & seeds	9 (0.1)	5 (0.1)	13 (0.1)	7 (0.1)	12 (0.1)
Cereals	198 (0.4)	172 (0.7)	214 (0.7)	216 (0.7)	178 (0.7)
Sugar and confectionary	45 (0.2)	38 (0.3)	47 (0.3)	50 (0.3)	38 (0.3)
Cake and pies	30 (0.1)	20 (0.2)	38 (0.2)	30 (0.2)	28 (0.2)
Other non-alcoholic drinks	382 (1.8)	365 (3.8)	423 (3.8)	384 (3.7)	398 (3.6)
Sweetened beverages	203 (1.0)	254 (2.0)	174 (2.0)	257 (1.9)	164 (1.9)
Coffee and tea	847 (1.8)	811 (3.8)	876 (3.8)	914 (3.7)	787 (3.7)
Beer	84 (1.1)	168 (2.3)	58 (2.2)	87 (2.2)	75 (2.2)
Wine	52 (0.5)	68 (1.0)	33 (1.0)	51 (0.9)	54 (0.9)
Other alcoholic drinks	7 (0.1)	14 (0.3)	3 (0.2)	7 (0.2)	7 (0.2)
Condiments	20 (0.1)	20 (0.2)	20 (0.2)	22 (0.2)	17 (0.2)
Soups	72 (0.4)	77 (0.8)	67 (0.8)	85 (0.8)	57 (0.8)
Miscellaneous	9 (0.1)	9 (0.1)	11 (0.1)	11 (0.1)	7 (0.1)

Table 5.1. Characteristics (mean (SE)) of adherent of the Reduced Rank Regression derived "Prudent" and "Dairy-based" dietary patterns. (continued)

	Mean EPIC-NL	"Plant-based Pattern"		"Dairy-based Pattern"	
		Quartile 1	Quartile 4	Quartile 1	Quartile 4
Animal-based foods					
Dairy	387 (1.4)	336 (2.9)	408 (2.8)	256 (2.6)	523 (2.6)
Cheese	37 (0.1)	35 (0.3)	38 (0.3)	25 (0.3)	55 (0.3)
Red meat	61 (0.2)	79 (0.3)	41 (0.3)	56 (0.3)	63 (0.3)
Poultry	12 (0.1)	12 (0.1)	12 (0.2)	13 (0.1)	12(0.1)
Processed meat	31 (0.1)	51 (0.3)	18 (0.3)	32 (0.3)	30 (0.3)
Fish	11 (0.1)	8 (0.1)	14 (0.1)	9 (0.1)	12 (0.1)
Egg	16 (0.1)	18 (0.2)	15 (0.2)	19 (0.1)	14 (0.1)

Continuous variables are presented as mean and standard error corrected for age, gender and energy intake. Categorical variables are presented as percentage, also corrected for age, gender and energy intake.
a: Cambrigde Physical Activity Index (4 categories: inactive, moderate inactive, moderate active, active). b: Higher vocational training or university.

Lifestyle and anthropometric variables

At baseline, study participants completed a general standardized structured questionnaire. Blood pressure, weight, and height were measured by trained staff according to standardized protocols [25]. Physical activity was assessed using a validated questionnaire [33] and classified according to the Cambridge Physical Activity Index (CPAI) with single imputed data for missing values (n=4,930) [34]. The CPAI has four categories, i.e. inactive, moderately inactive, moderately active and active. Cigarette smoking was categorized as current, former, and never smoker. Educational level was classified as low (lower vocational training or primary school), medium (intermediate vocational training or secondary school) or high (higher vocational training or university).

Statistical analysis

Our first aim was to assess the association between the current Dutch guidelines and environmental impact of the diet. We assessed the association between the DHD15-index, which measures adherence to the Dutch guidelines, and GHG emissions. A linear regression model was created including total dietary GHG emissions as the dependent variable and the DHD15-index score as the independent variable, adjusted for age and sex.

Our second aim was to derive dietary patterns in our population based on health and the environment. We used RRR to extract in our population specific dietary patterns based on both the variations in the DHD15-index score and dietary GHG emissions. RRR was applied using the PROC PLS procedure in SAS. The predictor variables were the food groups in percentage of energy and response variables were the DHD15-index score and daily dietary GHG emissions. The hybrid RRR model derives dietary patterns, i.e. correlations of food groups that explain the variation in the response variables. By definition, RRR retains a number of patterns that are equal to the number of response variables. The dietary pattern labelling was based on the food groups contributing most to the pattern. Food groups were considered important to a pattern when their factor loading was >0.20. Each participant receives a pattern score for both of the derived patterns. The pattern scores were divided into quartiles. Participants in quartile 4 (Q4) of a pattern score were considered as highest adherents to that pattern. The participants in Q1 of a pattern score consume a diet inverse to that of the labelled pattern. We used general linear models to calculate differences in mean DHD15-index score and GHG emissions between the different quartiles of the two dietary patterns with adjustment for age, sex and energy intake. In order to calculate the p-value for the difference in GHG emissions and DHD15-index score between the Q4s of both patterns and between the Q4s and the cohort mean we rearranged the data to a long format in which participants can have more than one observation. This was done because participants can be adherents to both patterns. PROC GENMOD was used to compare the environmental impact and DHD15-index score between the patterns.

All statistical analyses were performed using SAS software (version 9.4, SAS Institute Inc., Cary, NC, USA). A two-sided p-value of <0.05 was considered statistically significant.

Results

In our sub-sample of the EPIC-NL cohort 73.7% of the participants are female, with average age for participants of 48 years at baseline (**Table 5.1**). The average BMI is 25.6 kg/m^2, about one third of the population are current smokers, and about one fifth has an education at higher vocational training or university level. Almost half of participants are classified as physically active. The DHD15-index score is on average 75.5 (SE: 0.1) points out of a maximum score of 140 points. Scores range from 18.2 to 130.3 points on the DHD15-index. The mean adjusted dietary GHG emissions is 4.1 (SE: 0.01) kg CO_2 eq/d in our population.

DHD15-index, single recommendations and GHG emissions

The populations' median consumption of the food groups from the DHD15-index recommendations and related GHG emissions are presented in **Figure 5.1**. The average GHG emissions per kilogram product of the food groups considered in the guidelines shows foods with the relative highest environmental impact are all animal-based (**Supplemental figure 5.1**). Food groups like fruits and vegetables, nuts, tea and legumes, that are also included in the DHD15-index, have relatively low GHG emissions per kg food. Since the intake of these foods is low in our population (**Table 5.1**), there is potential to increase the healthiness of the diet with a relatively small increase in GHG emissions.

When examining the association between DHD15-index scores and dietary GHG emissions, the crude scatterplot (**Supplemental figure 5.2**) illustrates that with similar total DHD15-index scores the GHG emissions of the diet vary greatly, but higher scores tend to be associated with lower GHG emissions. The linear regression model shows that after adjusting for age and sex, for every 10 points increase on the DHD15-index, dietary GHG emissions decrease by 0.2 (SE: 0.004, $p<0.0001$) kg CO_2-eq/d.

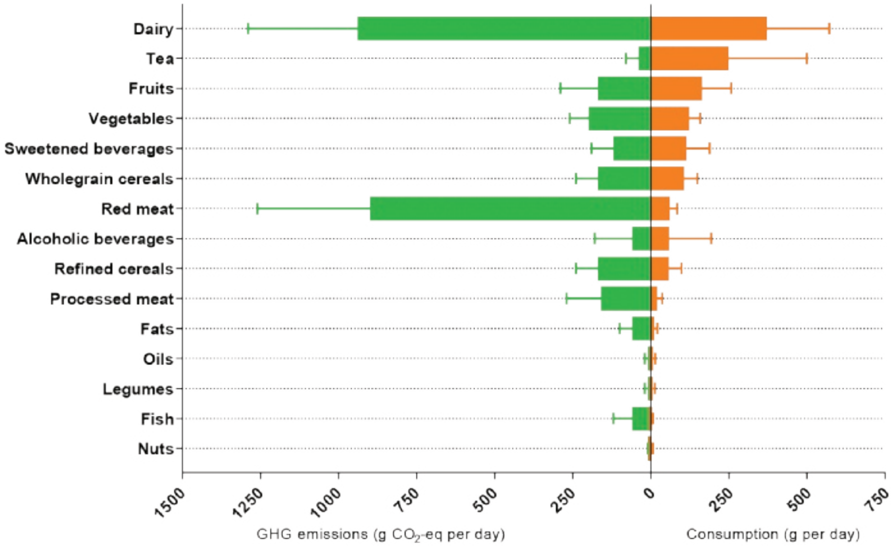

Figure 5.1. Median (interquartile range) consumption and associated greenhouse gas (GHG) emissions of the food groups in the Dutch Healthy Diet index 2015 sorted by consumption.

Dietary patterns including both health and environmental effects

With RRR two dietary patterns were identified. The first pattern ("*Plant-based Pattern*") explained 40.5% of the variance in GHG emissions and DHD15-index scores and 6.5% of the variance in food intake. For the second pattern ("*Dairy-based Pattern*") these were 6.4% and 2.9% respectively. In the "*Plant-based Pattern*", Q4 is characterized by a high consumption of fruits, boiled and raw vegetables, soy products, legumes, cake and pies, low fat fish, and a low consumption of fries, sugar containing sodas, other alcoholic beverages, red meat, and processed meat (**Figure 5.2**). The inverse dietary pattern (Q1 of the pattern score) of the "*Plant-based Pattern*" could be labelled as a "*Western Pattern*" due to the high amount of fries, sugar containing sodas, other alcoholic beverages, red meat, and processed meat. In the "*Dairy-based Pattern*", Q4 shows high consumption of cheese, low fat and high fat milk products, nuts and seeds and low consumption of coffee and tea, sugar-containing sodas, low-fiber bread, soy products, fats, and savoury sauces.

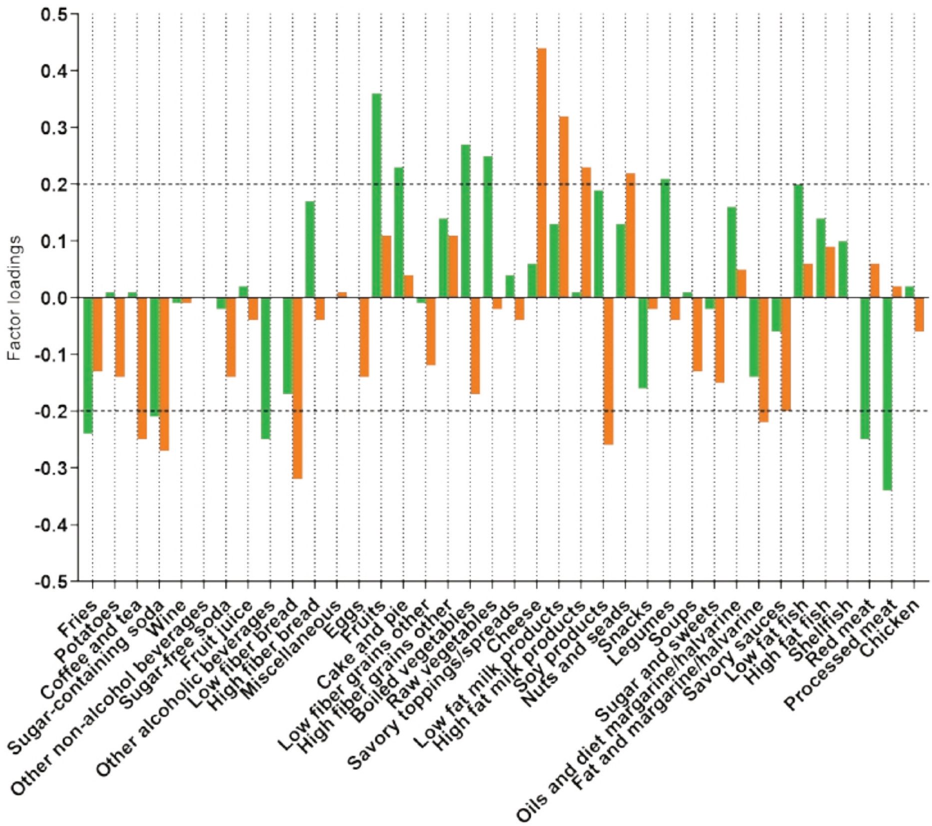

Figure 5.2. Factor loadings of the food groups on two dietary patterns derived with Reduced Rank Regression explaining the variance in greenhouse gas (GHG) emissions and Dutch Healthy Diet index 2015 (DHD15-index) scores. Food groups with factor loadings greater than |0.20| are considered important contributors to a dietary pattern. The red pattern is labelled '*Dairy-based Pattern*' and the blue pattern '*Plant-based Pattern*'.

Comparing Q4 to Q1 of adhering to the "*Plant-based Pattern*", thus comparing the "*Plant-based Pattern*" to the "*Western Pattern*", a statistically significant 49.9% higher DHD15-index score is observed (89.8 versus 59.9 points) after adjusting for age, sex and energy intake (**Figure 5.3**). In contrast, GHG emission is significantly 7.7% lower in Q4 than in Q1 (3.96 versus 4.29 kg CO_2-eq/d). With increasing adherence to the "*Dairy-based Pattern*" both a significantly higher DHD15-index score of 8.6% (77.9 versus 71.7 points) and GHG emission of 15.4% (4.43 versus 3.84 kg CO_2-eq/d) are observed.

When we compare the highest adherents of the two dietary patterns (participants in Q4 of the factor score) it shows that those adhering to the "*Plant-based Pattern*" are more likely to be women, less likely to be a current smoker and consume fewer calories (adjusted for age and gender) than those adhering to the "*Dairy-based Pattern*" (**Table 5.1**). DHD15-index scores are higher (89.8 versus 77.9 points, $p<0.0001$) and GHG emissions are lower (3.96 versus 4.43 kg CO_2-eq/d, $p<0.0001$) in Q4 of the "*Plant-based Pattern*" than in Q4 of the "*Dairy-based Pattern*". For both derived dietary patterns, adherents (Q4) have a higher DHD15-index score compared to the observed average EPIC-NL diet (**Figure 5.3**, both $p<0.0001$). However, GHG emissions are lower in adherents to the "*Plant-based Pattern*" and higher in adherents of the "*Dairy-based Pattern*" compared to the mean diet (both $p<0.0001$).

Discussion

In our population, increasing compliance to the Dutch dietary guidelines is associated with lower dietary greenhouse gas emissions. On average, for every 10 points higher scored on the DHD15-index (0 to 140 points), dietary GHG emissions were 0.2 kg CO_2 equivalents per day lower. This analysis included an a priori determined healthy dietary pattern and the finding confirms recent review study results [10, 11]. Based on the variation in dietary intake within the population, we derived two dietary patterns using the hybrid RRR approach. We derived a "*Plant-based*" (fruits and vegetables, fish, legumes and soy products) and its inverse dietary pattern that could be labelled a "*Western pattern*". The second dietary pattern was labelled as "*Dairy-based*" (cheese, low and high fat milk products, nuts and seeds). Consumers in the highest quartile of the "*Plant-based pattern*" had a 17.8% higher adjusted DHD15-index score and 2.5% lower GHG emissions compared to the average EPIC-NL diet. Shifting the population from an average diet towards a diet similar to the diet in the upper quartile of the "*Plant-based Pattern*" would therefore be a first step towards a more sustainable diet. The "*Dairy-based Pattern*" was the less dominant pattern and has an interesting trade-off between health and environmental impact; a similar score on the DHD15-index was observed in consumers in quartile 4 of this pattern compared to the average population, but at the expense of a higher environmental impact.

5

Currently only a limited number of dietary guidelines across the world include sustainability aspects, mainly in appendices of the main guidelines [7]. For example, the Swedish national food agency published additional guidelines on meat replacement, storage and prevention of food waste, and recommended eating less sweets, cakes, and cookies because of a their low nutritional contribution and impact on the environment [35]. By including environmental impact in our analysis, the results can be used to investigate how the Dutch dietary guidelines can be adapted to also include sustainability aspects. Although the overall recommendation of the Dutch health council to consume more plant-based rather than animal-based foods could be considered as more sustainable, this recommendation was based on evidence about diet-disease associations [14]. Rephrasing this statement, to 'Follow a dietary pattern that involves eating more plant-based and less animal-based foods *would be beneficial for health and would reduce the environmental impact of our diet*' would explicitly combine both aspects for consumers. For dairy and fish, the food specific guidelines could be expanded taking into account guidance on environmental aspects since consumers might perceive recommendations for these foods as 'more is better'. Although a high dairy intake (above the recommended 2-3 portions per day) may not be associated with increased health risks [36], the food group has a high environmental impact, as observed in our "*Dairy-based Pattern*". For fish, the largest health gain can be achieved when shifting from 'no fish' to 'fish once per week'. There seems to be no additional health effect with higher consumption [14]. However, a higher consumption would negatively affect current fish stocks which are already under pressure [37].

Besides dietary quality, dietary guidelines could also focus more on the total number of calories of a diet. Consuming adequate numbers of calories would be more beneficial for both health (weight) and the environment (less food needed) in our population since the mean BMI is just over 25 kg/m^2. We observed that high adherents of the "*Plant-based Pattern*" consumed fewer calories than the average EPIC-NL population (1,903 versus 2,063 calories per day). In our analyses, we adjusted the models for energy intake to be able to compare the environmental impact and quality of the diet more objectively. Without adjusting for energy intake the difference in GHG emission between the highest and lowest quartile of the "*Plant-based Pattern*" would be 10% (data not shown) compared to a moderate 2.5% after adjustment. In overconsuming Western populations, this clearly shows the importance of adopting a diet that is in line with the energy requirement as well as from an environmental point of view.

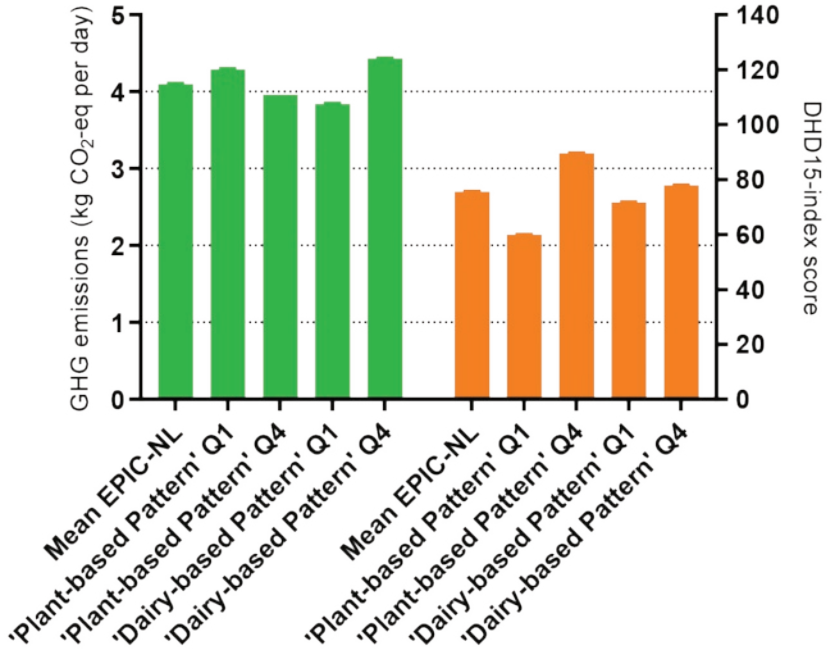

Figure 5.3. Mean (standard error)* greenhouse gas (GHG) emissions and Dutch Healthy Diet index 2015 (DHD15-index) score of the highest and lowest quartile of adherence of the two dietary patterns derived with Reduced Rank Regression compared to the cohort mean.
*Mean and standard error corrected for age, gender and energy intake

Part of the sustainable diets definition of the FAO is that these patterns should also be socially acceptable to make the necessary changes feasible [7]. Because the derived data-driven RRR dietary patterns are based on actual dietary intake present within our population, we might assume these patterns are culturally acceptable.

Other studies, using linear modelling of diets without applying possible consumer constraints (and thus including diets that differ considerably from the current one or diets with very limited variety in food items) show possible reductions in dietary GHG emissions as high as 70-80%. However, significant smaller changes are observed when these constraints are taken into account [11]. Green *et al*. used an optimisation tool to model the current UK diet so that it meets the WHO guidelines [38]. They observed that adherence would require several major changes to the current diet, of which a lower consumption of meat, dairy and eggs (particularly in men) and soft drinks were the most important. This WHO-UK diet would result in a 17% reduction in GHG emissions. Applying more drastic dietary changes such as leaving out meat or fish would result in much larger reductions in GHG emissions (20-30%, [11]) than from consuming our "*Plant-based Pattern*" (3%). This implies two things. First, to achieve small reductions in GHG emissions, advised diets could be built with the current diets as a starting point, like in our study, to make it feasible for people to slowly change their habits. Second, we need to acknowledge that if we aim for larger reductions in GHG emissions cultural change is needed in which the sustainable dietary pattern becomes a new standard. Such a cultural change would be much harder to achieve, but is required to adopt new sustainable and healthy dietary patterns. Maintaining existing dietary patterns may not be enough to reach the true potential of dietary change [38-40].

Reduced rank regression is a relatively new method to derive dietary patterns [15]. Compared to PCA for example, RRR derives patterns that are only slightly different but show stronger associations with diseases [20, 41, 42]. A previous study with EPIC-NL data reported that PCA derived two dietary patterns: a 'Prudent' and a 'Western' pattern [18]. The prudent pattern resembles a kind of "*Plant-based Patte*rn" and its opposite the "*Western' pattern*"; whereas the 'Dairy-based Pattern' was not derived. The added information of the response variables, thus seem to create more specific dietary patterns. The PCA patterns of Stricker *et al*. together explained 20.8% of the variance in food groups versus 9.4% of our RRR based diet patterns. Hoffman *et al*. produced similar differences in explained variance between PCA (19.7%) and RRR (10.5%) [41]. Similar comparison studies also showed that in general PCA-derived patterns explain more variance of the food groups but explain less of the variance in response variables [19, 41]. Our first RRR pattern explained 40.5% of the response variable variation, which is in line with results from other studies [19, 41, 43], but clearly leaves a proportion of the variance unexplained. Other factors, such as socio-economic status, age or gender might also impact GHG emissions of the diet and dietary quality.

Strengths of this study are that we used both dietary and environmental impact data from the same population. The EPIC-NL study is a large cohort in a representative sample of the Dutch population. The limitations of this study also deserve discussion. This cross-sectional analysis of baseline data in our cohort is based on a FFQ, which has been administered between 1993 and 1997. Dietary habits of our participants have most likely changed over time and thus the patterns derived in our study may not truly reflect current diets in the Netherlands. During the last five years in the Netherlands, the consumption of potatoes, fats and oils, alcoholic beverages, dairy products, cakes and biscuits and meat decreased [44]. Consumption of vegetables, and cereals and bread remained stable and use of non-alcoholic drinks and condiments and sauces increased. In addition, most Dutch adults do not meet the current dietary guidelines, just like in our cohort [45]. We believe that even though dietary habits may have changed, our current findings help to build more evidence on how a sustainable and healthy dietary pattern may or should look like. The indicators for environmental impact are based on Dutch life cycle analysis data and therefore apply to a Dutch setting only. Our results for environmental impact of the dietary patterns may therefore not be directly extrapolated to other countries where production methods, productivity, fossil energy use, in- and export and ways of transport may differ. However, the average GHG emissions of the diet seem comparable to previous studies [10, 11].

In conclusion, when deriving dietary patterns based on health and environmental aspects of the diet, a "*Plant-based*" and a "*Dairy-based*" pattern were present in our population. Of these, a plant-based diet with low amounts of meat, sugar containing sodas and alcoholic beverages benefits health as well as the environment in a socially acceptable way. Our study provides information on how to incorporate sustainability aspects in dietary guidelines.

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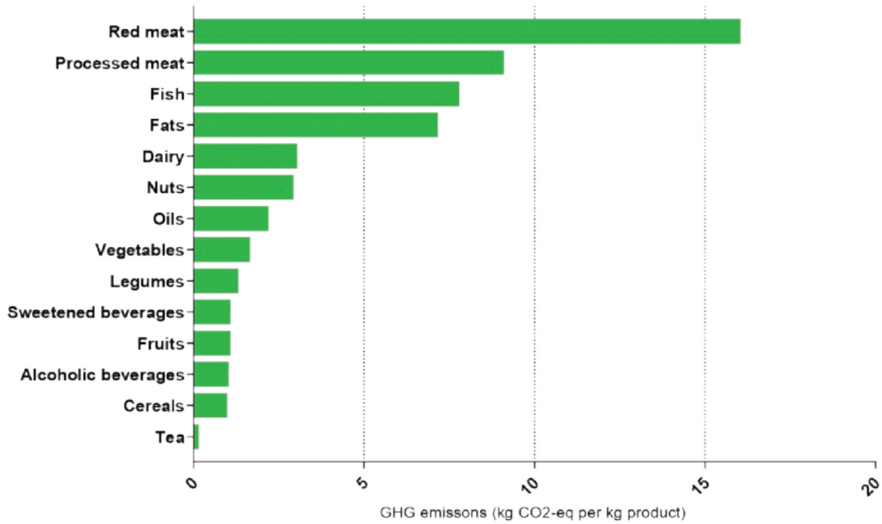
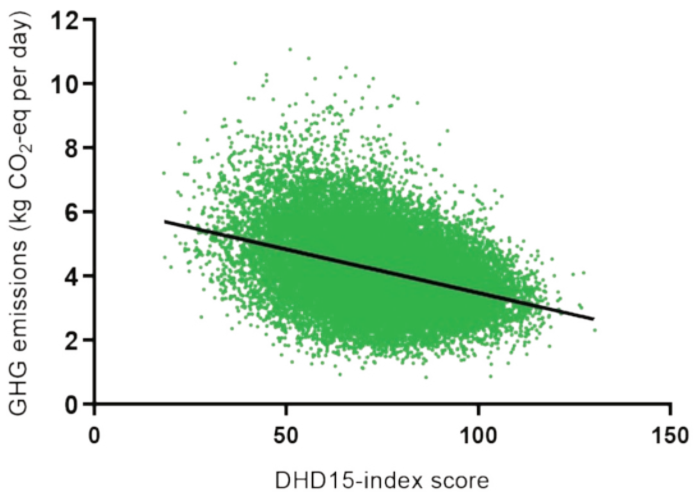
Appendix Chapter V



Supplemental figure 5.1. Greenhouse gas (GHG) emissions associated with one kilogram of the food groups considered in the Dutch Healthy Diet index 2015.



Supplemental figure 5.2. Scatterplot illustrating the unadjusted association between daily greenhouse gas (GHG) emissions and the Dutch Healthy Diet index 2015 (DHD15-index) score.

Supplemental table 5.1. Food group categories used in EPIC-NL.

Food group	Food items	Life Cycle Assessment food item
French fries	Fries	Fried potatoes
Potatoes	Potatoes	Boiled potatoes
Coffee and tea	Coffee	Coffee
	(Herbal) Tea	Tea
Sugar-containing sodas	Carbonated drinks	Cola
	Soft drinks	Cola
	Isotonic drinks	Cola
	Diluted syrups	Cola
Wine	Red wine	Red wine
	White wine	White wine
	Rose wine	Rose wine
Other non-alcohol beverages	Water	Water
Sugar-free sodas	Sugar-free sodas	Cola
Fruit juice	Fruit juices	Orange juice
	Vegetable juices	Tomato juice
Other alcoholic beverages	Spirits/brandy	Brandy
	Aniseed drinks	Brandy
	Liqueurs	Brandy
	Cocktails/punches	Brandy
	Beer	Beer
	Cider	Beer
	Drinks based on beer/ cider	Beer
Low fiber bread	Breakfast cereals	Breakfast cereals
	White bread	White bread
	Sea biscuit	Cracker
	Croissants	Croissants
	Crackers	Cracker
	Raisin bread	Raisin bread
	Sandwich	Sandwich
	Toast bread	Toast bread
High fiber bread	Whole grain bread	Whole grain bread
	Wheat bread	Wheat bread
	Rye bread	Rye bread
Eggs	Eggs	Boiled eggs

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Supplemental table 5.1. Food group categories used in EPIC-NL. (continued)

Food group	Food items	Life Cycle Assessment food item
Fruits	Olives	Olives
	Citrus fruits	Oranges
	Apples	Apple
	Pear	Pear
	Grapes	Grapes
	Stone fruits	Cherry
	Berries	Blueberries
	Banana	Banana
	Kiwi fruit	Kiwi fruit
	Strawberries	Strawberries
Cake and pie	Cakes	Cake
	Sweet pies	Apple pie
	Pastries	Apple pie
	Dry cakes	Cake
	Biscuits	Biscuits
Low fiber grains other	White rice	Boiled white rice
	Pasta	Boiled pasta
	Couscous	Boiled couscous
High fiber grains other	Brown rice	Boiled brown rice
	Whole grain muesli	Breakfast cereals
	Whole grain pasta	Boiled pasta
	Whole grain couscous	Boiled couscous
Boiled vegetables	Leafy vegetables	Boiled chicory
	Fruiting vegetables	Boiled tomato
	Root vegetables	Boiled carrots
	Cabbages	Boiled broccoli
	Mushrooms	Boiled mushrooms
	Grain and pod vegetables	Boiled green beans
	Onion	Boiled onion
	Stalk vegetables, sprouts	Boiled beansprouts

Supplemental table 5.1. Food group categories used in EPIC-NL. (continued)

Food group	Food items	Life Cycle Assessment food item
Raw vegetables	Pickles	Pickles
	Mushrooms (raw)	Mushroom
	Onion (raw)	Onion
	Peppers (raw)	Peppers
	Tomato (raw)	Tomato
	Carrots (raw)	Carrots
	Lettuce	Lettuce
	Mixed salad	Average vegetables
Savoury toppings/spreads	Peanut butter	Peanut butter
Cheese	Cheeses (all types)	Cheese (Goudse Cheese 48+)
Low fat milk products	(Semi)-skimmed milk	Milk
	Skimmed yoghurt(drinks)	Yoghurt
	Diet coffee milk	Coffee milk
High fat milk products	Milk	Milk
	Yoghurt(drinks)	Yoghurt
	Creams	Whipped cream
	Coffee milk	Coffee milk
	Milk-based ice cream	Yoghurt
	Custard	Yoghurt
Soy products	Soy based products	Soy-based hamburger
Nuts and seeds	Tree nuts	Peanuts
	Peanuts	Peanuts
	Seeds	Peanuts
	Coconut	Peanuts
	Chestnut	Peanuts
Snacks	Egg rolls	Egg rolls
	Pizza	Pizza
	Chips	Potato chips
	Pretzels	Potato chips
Legumes	Peas	Marrowfat pea
	Beans	Green bean
Soups	Soups	Clear vegetable soup

Supplemental table 5.1. Food group categories used in EPIC-NL. (continued)

Food group	Food items	Life Cycle Assessment food item
Sugar and sweets	Sugar	Granulated sugar
	Honey	Honey
	Jam	Jam
	Chocolate	Pure chocolate bar
	Candy bars	Pure chocolate bar
	Candy	Granulated sugar
	Ice cream (non-dairy)	Granulated sugar
Oils and diet margarine	All oils(soy, olive etc)	Olive oil
	Diet margarine	Diet margarine
	Vegetable-based margarines	Vegetable-based margarines
Fat and margarine	Butter	Butter
	Margarine	Margarine
	Solid frying fats	Solid frying fats
Savoury sauces	Mayonnaise	Mayonnaise
	Tomato sauce	Tomato sauce
	Salad dressing	Salad dressing
Low fat fish	Lean fish (<10 g fat/100 g)	Fried cod fish
	Lean fish products	Fried cod fish
High fat fish	Fatty fish (>10 g fat/100 g)	Fried salmon
	Fatty fish products	Fried salmon
Shellfish	Crustaceans	Boiled clams
	Clams	Boiled clams
	Shrimps	Boiled shrimps
Red meat	Beef	Steak
	Veal	Veal
	Pork	Pork tenderloin
	Mutton	Mutton
	Game	Deer
Processed meat	Bacon	Bacon
	Ham	Ham
	Liver containing items	Boiled beef liver (sliced)
Chicken	Poultry (all types)	Chicken

Supplemental table 5.2. Components and scoring criteria of the Dutch Healthy Diet index 2015 (DHD15-index).

DHD15-index	Maximum score (10 points)	Minimum score (0 points)
1. Vegetables (g)	≥200	0
2. Fruit (g)	≥200	0
3a. Wholegrain products (g)	≥90 (5 points)	0
3b. Replace refined with wholegrain products	No consumption of refined products or ratio wholegrain/ refined ≥11 (5 points)	No consumption of wholegrain products or ratio wholegrain/refined ≤0.7
4. Legumes (g)	≥10	0
5. Nuts (g)	≥15	0
6. Dairy products[b] (g)	300-450	0 or ≥750
7. Fish[c] (g)	≥15	0
8. Tea (g)	≥450	0
9. Replace butter and hard fats with margarines and oils	No consumption of fats or ratio oils/fats ≥13	No consumption of oils or ratio ≤0.6
10. Replace unfiltered coffee with filtered coffee	Consumption of only filtered coffee or no coffee consumption	Any consumption of unfiltered coffee
11. Red meat (g)	<45	≥100
12. Processed meat (g)	0	≥50
13. Sweetened beverages and fruit juices (g)	0	≥250
14. Alcohol (g)	≤10	Men: ≥30 Women: ≥20
15. Sodium (g)	<1.9	≥3.8

Abbreviations: g - grams

a: A score above the recommended intake is 10 points, whereas an intake below is given a proportional score between 0 and 10 points.

b: A maximum of 40 grams cheese per day could be included.

c: A maximum of 4 grams lean fish per day could be included.

5

PART III

Societal effects of food pricing policies in the Netherlands


MILK

CHAPTER VI

The modelled impact of price intervention policies to encourage healthy and sustainable food consumption in the Netherlands.

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Abstract

Background

Food consumption patterns might be changed in a more sustainable direction via the implementation of taxes or subsidies.

Objectives

This study estimates the effects of a tax (15% and 30%) on meat and a subsidy (10%) on fruit and vegetables (F&V) consumption in the Netherlands using a social cost-benefit analysis with a 30-year time horizon.

Methods

Calculations with the representative Dutch National Food Consumption Survey (2012-2014) served as the reference. Price elasticities were applied to calculate changes in consumption and consumer surplus. Future food consumption and health effects were estimated using the DYNAMO-HIA model and environmental impacts were estimated using Life Cycle Analysis. The time horizon of all calculations is 30 year. All effects were monetarized and discounted to 2018 euros.

Results

Over 30-years, a 15% or 30% meat tax or 10% F&V subsidy could result in reduced healthcare costs, increased quality of life, and higher productivity levels. Benefits to the environment of a meat tax are an estimated €3,400 million or €6,300 million in the 15% or 30% scenario respectively, whereas the increased F&V consumption could result in €100 million costs for the environment. While consumers benefit from a subsidy, a consumer surplus of €10,000 million, the tax scenarios demonstrate large experienced costs of respectively €21,000 and €41,000 million. Overall, a 15% or 30% price increase in meat leads to a net benefit for society between €3,100-7,400 million and €4,100-12,300 million over 30 years respectively. A 10% F&V subsidy leads to a net benefit to society of €1,800-3,300 million. Sensitivity analyses did not change the main findings.

Conclusion

The studied meat taxes and F&V subsidy showed net total welfare benefits for the Dutch society over a 30-year time horizon.

Introduction

There is a growing consensus that decreasing the environmental impact from food production and consumption are crucial to meet the Paris Climate Agreement and its goal to limit global warming [1, 2]. This is not surprising considering that agriculture and food production contribute an estimated 25% of total greenhouse gas (GHG) emissions [3]. Meat and dairy production is observed to be a disproportional contributor of emissions, attributing approximately half of food-derived GHG emissions, while only accounting for one-third of the dietary energy intake worldwide [1, 2, 4, 5]. Our dietary pattern not only affects our environment, it also has an effect on our health [6]. A Western-type diet has been strongly associated with non-communicable diseases (NCDs) such as cardiovascular diseases, diabetes, and cancer [1, 7, 8]. As a result, much attention has been paid to making diets more healthy [6].

Individual food choices can have a large environmental impact [9-11]. Recent modelling studies suggested that replacing meat with plant-based foods (8, 11), or selecting foods with low carbon footprints [9] reduce environmental impact and increase health. Nevertheless, the current Western diet is neither sustainable nor healthy [12-15]. Several factors could explain this. The link between individuals' environmental concerns as citizens and their behaviour as consumers was found to be quite weak and did not appear to influence meat-buying habits [16]. Healthy eating is not clear-cut for consumers, and is not understood and interpreted identically by everybody [17, 18]. This might even more apply to what it means to eat sustainable and environmentally friendly.

Governments may implement policy measures to stimulate healthy and sustainable choices. Systematic reviews demonstrate that subsidies to increase consumption of healthy foods and taxes to decrease consumption of unhealthy foods might be effective interventions in improving dietary behaviours and health [19, 20]. Similarly, modelling studies from various European countries predict taxes based on GHG emissions to be feasible to change dietary behaviours towards food groups with a lower environmental footprint [21-24]. Springmann *et al.* (2016) have estimated that the worldwide impact of taxing diet-related GHG emissions would result in a 9.6% decrease in GHG emissions originating from food production, while avoiding 500,000 deaths annually [25].

Price interventions may not only influence environment and health, but also have effects on other aspects of society, for example economic and distribution effects. A social cost benefit analysis (SCBA) can incorporate these effects into a single analysis [26]. The SCBA is an instrument that can provide an overview of the (dis)advantages of measures, if possible quantified in euros and presented as a balance [26]. In this study, a SCBA was used to estimate and monetize the 30-year societal effects of a tax on meat and subsidization of fruit and vegetables (F&V) in the Netherlands.

Methods

SCBA framework

The essence of the SCBA framework is to estimate all (positive and negative) effects of a policy scenario on the total welfare of a population. A policy scenario is compared to a reference scenario without the policy but considering other autonomous trends in society. Various stakeholders (e.g. government and consumers) are identified in the society potentially affected by the policy (**Supplemental file 6.1**). An overview of the included societal effects and their indicators is presented in **Table 6.1**.

Scenarios

Three scenarios are analysed within this study and compared to a reference (autonomous, no price change) scenario. Two taxation scenarios for total meat projected a 15% and 30% price increase at the consumer level whereas one scenario involved a subsidy on F&V resulting in a 10% price decrease. This manuscript does not discuss the way the price increase is implemented, e.g. via a CO_2-tax, via a VAT in- or decrease of specific foods, or excise.

Table 6.1. Overview of the included societal effects and their indicators.

Indicator	Model	Supporting Data
Consumption	Dynamo-HIA [27]	Dutch National Food Consumption Survey [28] Price elasticities [29] More detail: supplemental file 2
Health	Dynamo-HIA [27]	Disease associations Dutch Health Council [30] QALY value [26, 31] Dutch Cost of Illness study [32, 33] More detail: supplemental file 2
Productivity		Labour participation [34-38] Productivity (absenteeism and presentism [39]) More detail: supplemental file 1
Environmental impact	ReCiPe [40]	Dutch National Food Consumption Survey [28] Life Cycle Analysis (Blonk Consultants) Extrapolations to all foods consumed (S.F 3) Environmental indicator costs [41] More detail: supplemental file 3
Consumer surplus		Price elasticities [29] More detail: supplemental file 1
Policy revenue		Tax and subsidy Value Added Tax (VAT) More detail: supplemental file 1
Policy costs		Implementation costs [42] More detail: supplemental file 1
Stakeholders		Consumers Government More detail: supplemental file 1

Food consumption

Current food consumption in the Netherlands was obtained from the Dutch National Food Consumption Survey (DNFCS) 2012-2014 [28]. Food intake data from a representative sample of the population living in the Netherlands was collected between 2012 and 2014 on 2 non-consecutive days using 24hr dietary recalls. Only the consumption data for meat (red meat, processed meat, and poultry) and F&V were used for this study (**Supplemental file 6.2**). In the reference scenario, consumption changes over time were age and sex dependent but without an autonomous increasing or decreasing trend.

Price elasticities to calculate changes in consumption following a price change in the scenarios were obtained from a systematic literature review [29]. For total meat (red, white, and processed) the mean estimated price elasticity was -0.60 (95% confidence intervals (CI): -0.66; -0.54) and for F&V -0.53 (95% CI: -0.59; -0.48). Consumption changes over time were calculated using the Dynamic Modelling for Health Impact Analysis (DYNAMO-HIA) model [27]. See for more model details the next section.

Health impact assessment

The DYNAMO-HIA model was used to assess health impact of the scenarios [27]. DYNAMO-HIA is a Markov-type state-transition model and combines micro simulation of the risk factor and macro simulation of the disease and survival, using individual life tables with 1-year intervals to estimate developments in health over time. Boshuizen *et al.* describe the model in more detail [27]. Newborns and population size per given age and sex of the Netherlands derived from Statistics Netherlands were used as population input in the model.

Five diseases, diabetes type 2, stroke, lung cancer, coronary heart disease (CHD) and colorectal cancer, associated with meat and fruit and vegetables intake were assessed [30]. Disease incidence and prevalence of these five diseases in the Netherlands were included into the model based on Statistics Netherlands data of 2011. Disease disability and excess mortality weights of the model were used and were collected within the DYNAMO-HIA consortium in 2010.

Risk factor categories for the model were created using the relative risks (RR) of red and processed meat, and F&V consumption derived from a 2015 systematic literature review by the Dutch Health Council [30]. Since white meat (chicken and turkey) consumption is not associated with health it was not included in the health modelling.

Health effects were estimated by comparing the effects of the intervention compared to a reference scenario, in which no policy measures were implemented. Yearly differences in modelled chronic diseases and subsequent Quality Adjusted Life Years (QALYs) values between the reference and intervention scenarios were extracted from the model.

Uncertainty around the DYNAMO-HIA model estimates were evaluated using Monte Carlo simulations based on the 95% Confidence intervals (CI) of the relative risk estimates, assuming a normal probability distribution. The 95% CI of 100 simulations per scenario are reported. Transition rates of risk factor categories were estimated using the method described by Van de Kassteele et al. [43]. The model presented increased or decreased health by calculating gained or lost QALYs. More details of the DYNAMO-HIA modelling are presented in **Supplemental file 6.2**.

Environmental impact assessment

The environmental impacts of food were estimated with Life Cycle Analysis (LCA), a methodological tool to assess the environmental impact through the life cycle of a product (farm to plate principle). Supporting Life Cycle Inventories (LCI) data, individual unit processes in a supply chain, representative for Dutch market situations were provided by Blonk Consultants and were saved in SimaPro (version 8.52, PRe Consultancy B.V., Amersfoort, the Netherlands). Blonk consultants provided data on 225 foods in the Netherlands, covering approximately 80% of foods consumed in the DNFCS [28]. A panel of RIVM scientist performed extrapolations of the data to all foods consumed in the DNFCS 2012-2014. Environmental impact of the food products was then estimated using ReCiPe 2016 [44]. Environmental impact indicators that were estimated in the ReCiPe model were greenhouse gas emissions (kg CO_2-eq), acidification (kg SO_2-eq), eutrophication of salt (kg N-eq) and fresh (kg P-eq) water, and land use (m^2a).

Efficiency gains in production of foods over time were estimated with the observed average change in GHG emissions intensity of the Dutch agro- and fishery industry [45]. Between 2000 and 2016, the relative intensity decreased by 20% (1.25% per year). This decrease was further linearly projected up to 2048 in the main analysis for all environmental impact indicators. See **Supplemental table 6.3** for more detail on the environmental impact assessment.

Monetization of estimates

We applied both a value of €50.000 and €100.000 per Quality Adjusted Life Year (QALY) gained derived from the DYNAMO-HIA model and assumed the QALY value to remain stable over time, per Dutch guidelines [26, 31]. By using the QALY value in the main analyses, we assumed that consumers in their food choice decisions do not already value health aspects (informed consumers). Direct healthcare costs for diseases associated with consumption of meat and F&V were estimated using data from the Dutch Cost of Illness tool [46]. See for more details **Supplemental file 6.1**.

Environmental effects were monetized using the mean costs of GHG emissions (€0.057 per kg CO_2-eq), acidification (€5.40 per SO_2-eq), eutrophication of salt (€3.11 per kg P-eq) and fresh (€1.90 per kg N) water, and land use (€0.0261 per m^2) estimated specially for the Dutch situation (see **Supplemental file 6.3**, [41]).

Within the SCBA framework, additional societal effects such as productivity, consumer surplus and tax income and subsidy expenses are also considered. The three components of productivity include absenteeism, presentism, and labour participation. Labour participation and productivity effects were estimated using the human capital method, according to Dutch guidelines [31]. The number of prevented cases of disease between 15-75 years old, the definition of the working population by Statistics Netherlands (CBS), was extracted from DYNAMO-HIA. To prevent double counting of effects, only income tax and welfare payment effects following changes in labour participation were considered, as shown by Koopmans et al. [31]. Productivity gains were estimated using the costs of absenteeism and presentism, which was estimated using absenteeism and presentism estimates of the modelled chronic diseases derived from Loeppke et al [39].

For the meat scenarios, policy revenues were a combination of tax income minus the loss of VAT because of the reduced consumption. For the F&V scenario, these were the additional VAT benefits from an increased consumption minus the subsidy costs. The revenues were based on average cost per kg meat of F&V derived from CE Delft, adjusted yearly using the mean composite Consumer Price Index of the product category between 1996-2017 [47, 48].

Consumer surplus (CS), the welfare consumers derive from purchasing and consuming, was estimated by using the rule-of-half (RoH, see formula 1). The

RoH approximates the changes in consumer benefits and is proscribed to estimate the changes in CS by Dutch SCBA guidelines [26]. The last societal effect was the estimated policy implementation costs. To account for time effects, in the main analyses a discount rate of 3% per year was used for all indicators (**Supplemental file 6.1**).

(1) $\Delta CS = \frac{1}{2}(p0 - p1)(q0 - q1)$ *where P = price and Q = quantity.*

Sensitivity analyses

A one-way sensitivity analysis of the impact of different price elasticities on consumption and its related consequences was conducted. The price elasticity estimate was varied by adopting the upper and lower bound of the 95% confidence interval of the point estimate in assessing the change in consumption following a price intervention [29].

For the environmental impact calculations, a high and a low costs scenario were implemented. In the high costs scenario (High Environmental Costs-Low Efficiency Gains, HEC-LEG), the environmental impact indicators have high prices and in addition, the yearly efficiency gains in production were estimated to be low. In the low costs scenario, LEG-HEG, the opposite was estimated: low environmental impact costs at a high (1.75% per year) efficiency gain in production (**Supplemental file 6.3**).

Furthermore, the net welfare benefits were estimated when using a friction cost approach (instead of the human capital approach) to estimate productivity and participation. In addition, a perfect information scenario was calculated. In such a case, it is assumed that consumers consider and value all (known) costs, including (long-term) health before buying and consumption and therefore QALY gains or losses should not be considered. We also assessed the effect of changes in the discount rate used, by applying a rate of 1.5% and 4%, respectively [49].

Results

Food Consumption

In the reference scenario, in 2048, the total Dutch meat consumption is estimated to be 665,580,508 kilogram (kg). This translates to an average meat consumption of 39.2 kg per person per year or 107 gram per day. A price increase of 15% or 30% is estimated to reduce the average meat consumption to 98.2 gram per day in the 15% tax scenario and 90.3 gram per day in the 30% tax scenario in 2048 (**Figure 6.1**). In 2048, the estimated total F&V consumption is 1,551,852,898 kg or 250 gram per day. Following the price decrease of 10%, the average consumption is estimated to increase to 261 gram per day.

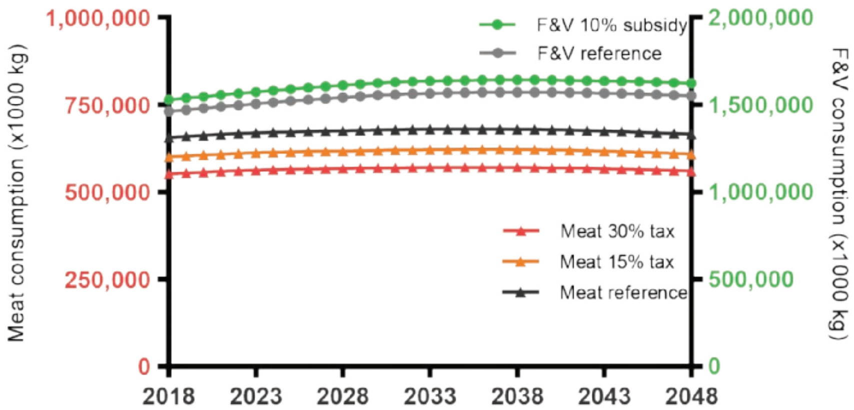

Figure 6.1. Modelled total Dutch consumption of meat and fruit and vegetables following food-pricing scenarios as compared to reference.

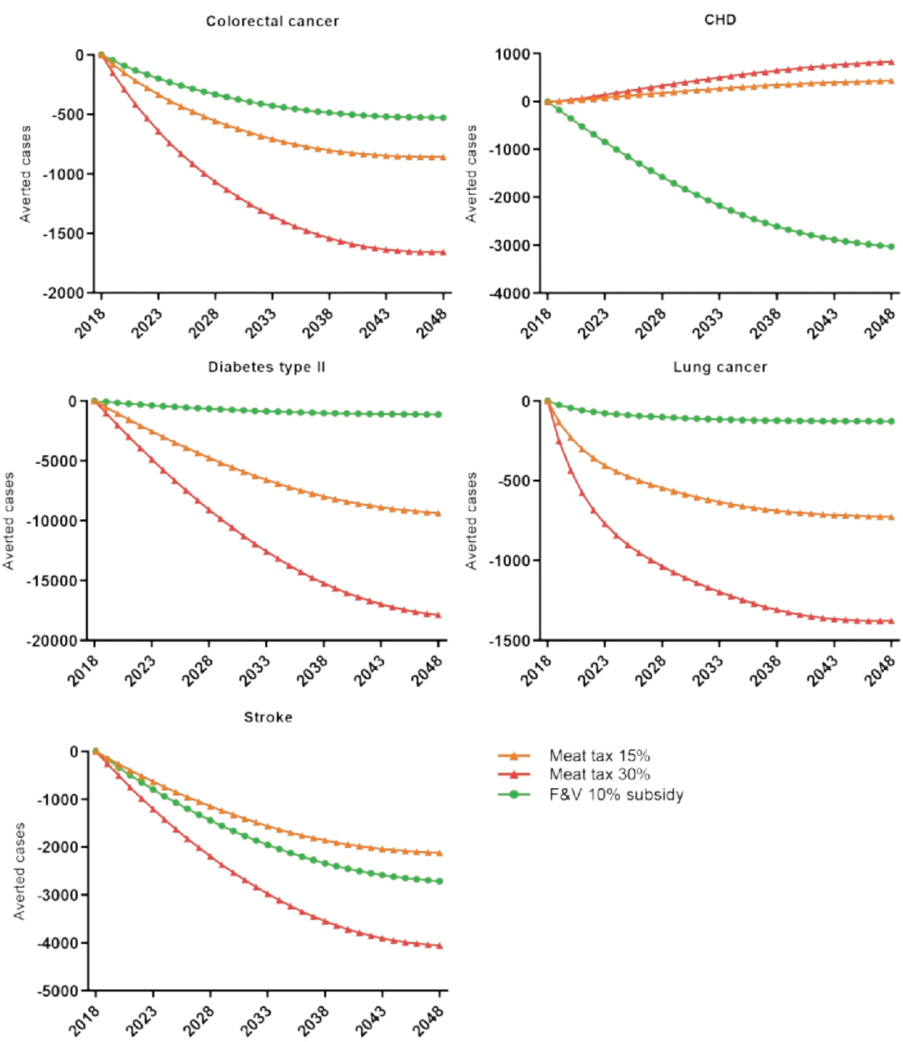

Figure 6.2. Modelled averted cases of associated chronic diseases following food-pricing scenarios compared to the reference scenario.

Health impact assessment

Figure 6.2 presents the average modelled number of cases prevented per disease in the respective scenarios. In absolute numbers, a meat tax has the most impact on diabetes type 2 prevalence, with between 2,093-15,449 (15% tax) and 5,550-29,398 (30% tax) averted cases in the year 2048 (**Supplemental file 6.2**). In the meat tax scenarios the incidence of CHD increases slightly, between 132-787 (15%) and 240-1,506 (30%) additional cases, because of the reduction in the prevalence of the other four diseases. The F&V subsidy has most impact on stroke prevalence, between 1,834 and 3,586 averted cases in 2048. The number of QALYs gained in the year 2048, compared to the reference scenario is between 1,119 and 3,525 for the 15% meat tax scenario, 2,122-6,691 in the 30% meat tax scenario, and 1,629-2,483 in the 10% F&V subsidy.

Table 6.2. Total societal costs and benefits for all scenarios compared to reference over a 30-year period.

	Scenario compared to reference (95% confidence interval)[a]		
Societal Effects	**15% meat tax**	**30% meat tax**	**10% fruits and vegetables subsidy**
Healthcare costs	€239 - 1,613	€462 - 3,081	€413 - 848
Health outcomes			
QALY €50,000	€834 - 2,246	€1,598 - 4,289	€1,043 - 1,564
QALY €100,000	€1,669 - 4,492	€3,196 - 8,577	€2,086 - 3,127
Productivity	€313 – 1,845	€604 - 3,521	€473 - 1,007
Environment	€3,390	€6,336	€-113
Policy revenue	€19,780	€36,334	€-9,888
Consumer surplus	€-21,468	€-41,264	€ 9,892
Policy costs	€-20	€-20	€-20
Total welfare benefits (QALY €50,000)	**€3,069 - 7,386**	**€4,050 - 12,276**	**€1,800 - 3,289**
Total welfare benefits (QALY €100,000)	**€3,904 - 9,632**	**€5,648 - 16,565**	**€2,842 - 4,853**

[a]Based on 100 iterations with the DYNAMO-HIA model using Monte Carlo simulations. Values are expressed in million 2018 euros.

Environmental impacts

In the reference scenario, total environmental impact of meat consumption in 2048 is estimated to be approximately 15,225,000 ton CO_2-eq (GHG emissions), 190,000 ton SO_2-eq (acidification), 3,000 ton P-eq (fresh water eutrophication), 33,000 ton N-eq (salt-water eutrophication), and 11,000 km^2 (land use). In 2048, in the 15% taxation scenario, reductions in impact of 900,000 ton CO_2-eq, 11,000 ton SO2-eq, 200 ton P-eq, 2,000 ton N-eq and

750 km^2 could be achieved. This is an 8.6% reduction for all impact categories over 30 years. In the 30% taxation scenario, the reduced consumption of meat could account for a 16% decrease in environmental impact compared to the reference scenario. In 2048, the estimated environmental impact of F&V consumption in the reference scenario is estimated to be 2,000,000 ton CO_2-eq (GHG emissions), 6,000 ton SO_2-eq (acidification), 200 ton P-eq (fresh water eutrophication), 1,400 ton N-eq (salt water eutrophication), and 250 km^2 (land use). The estimated higher consumption after a 10% subsidy of F&V could result in an increase of the environmental impact by 4.5% in 2048 (90,000 ton CO_2-eq, 250 ton SO_2-eq, 7 ton P-eq, 60 ton N-eq, and 11 km^2).

Social cost-benefit analysis

Total monetized effects over a 30-year period are presented in **Table 6.2**. In the 15% tax scenario, all benefits and losses lead to an overall net societal benefit between €3,100 and 7,400 million when a QALY value of €50,000 was applied. Introduction of a tax leading to a 30% price increase on meat-based products is estimated to result in overall benefits between €4,000 and 12,300 million over 30 years. Subsidization of F&V is estimated to amount to an overall net societal benefit between €1,800 and 3,300 million.

Stratifying the costs and benefits by consumers and government indicate that in the tax scenarios for consumers their positive health effects are outweighed by the loss in consumer surplus resulting in a net loss of welfare, especially in the 30% meat tax scenario (**Table 6.3**). However, in the F&V subsidy scenario, consumers benefit both from health gains as well as from an increased consumer surplus adding to their net social welfare. Because of the revenues of the tax and costs of the subsidy, the net benefits for the government are in the tax scenario and net costs in the subsidy scenario.

Table 6.3. Societal costs and benefits for all scenarios compared to reference over a 30-year period stratified by consumers and government.

	Scenario compared to reference (95% confidence interval)[a]					
Societal Effects	**15% meat tax**		**30% meat tax**		**10% fruits and vegetables subsidy**	
	Consumers	Government	Consumers	Government	Consumers	Government
Healthcare costs		€239 - 1,613		€462 - 3,081		€413 - 848
Health outcomes						
QALY €50,000	€834 - 2,246		€1,598 - 4,289		€1,043 - 1,564	
QALY €100,000	€1,669 - 4,492		€3,196 - 8,577		€2,086 - 3,127	
Productivity	€41 - 253	€272 - 1,592	€79 - 483	€525 - 3,038	€78 - 158	€396 - 849
Environment		€3,390		€6,336		€-113
Policy revenue		€19,780		€3,6334		€-9,888
Consumer surplus	€-21,468		€-41,264		€ 9,892	
Policy costs		€-20		€-20		€-20
Total welfare benefits (QALY €50,000)	**€-20,593 - 18,969**	**€23,661 - 26,355**	**€-39,587 -36,492**	**€43,637 - 48,769**	**€11,013 - 11,614**	**€-9,212 - 8,324**
Total welfare benefits (QALY €100,000)	**€-19,758 - 16,723**	**€23,661 - 26,355**	**€-37.989 -32.204**	**€43,637 - 48,769**	**€12,056 - 13,177**	**€-9,212 - 8,324**

Values are expressed in million 2018 euros.

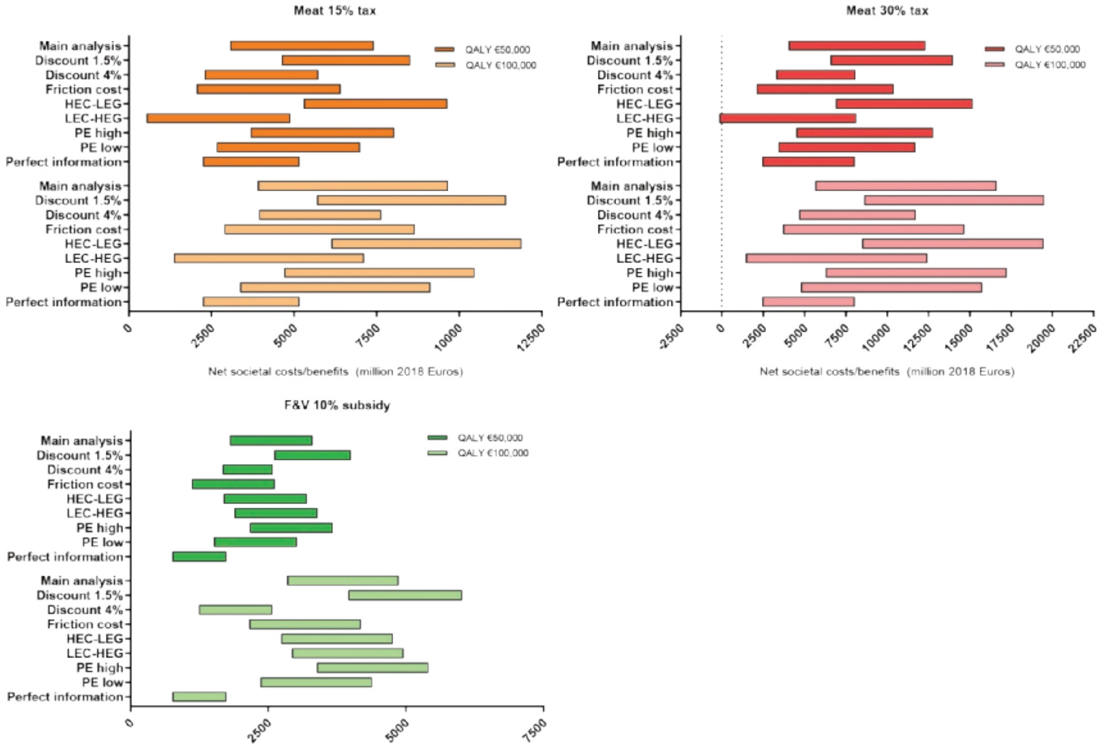

Figure 6.3. Net societal costs and benefits over a 30-year period of the sensitivity analyses of varying the discount rate, price elasticity and modelling methods as compared the no subsidy or tax scenario. HEC-LEG: High environmental costs at low efficiency gain in production over time. LEC-HEG: Low environmental costs at high efficiency gain in production over time. Price elasticity high: -0.66 for meat and -0.59 for fruit and vegetables. Price elasticity low: -0.54 for meat and -0.48 for fruit and vegetables. Perfect information: gained or lost health because of consumption already accounted for by consumers. QALYs not considered in total welfare.

Sensitivity analysis

Results of the sensitivity analyses are illustrated in **Figure 6.3**. Except for one analysis, the minimum estimated net benefits for society remained positive. In the 30% meat tax scenario (with a QALY value of €50,000), in which the costs incurred for environmental impact indicators is low and food production systems have a high efficiency gain (1.75% per year) over time results in a net welfare between €-141 - 8,085 million. In the sensitivity analyses involving a higher discount rate (4% instead of 3%), using the friction cost method instead of the human capital approach, lower price elasticities, or perfect information of consumers, the estimated benefits for society would be lower than observed in the main analyses. In contrast, choosing a lower discount rate (1.5% instead of 3%), environmental impact indicators at a high cost level with a limited gain in production efficiency over time, and assuming higher price elasticities would be scenarios in which the estimated benefits could be higher compared to the main analyses.

Discussion

A price increase for meat through a tax could lead to a net societal benefit of about €3,100-7,400 million and about €4,100-12,300 million for respectively a 15 and 30% tax. A price decrease of F&V by means of a subsidy could lead to a net societal benefit of about €1,800-3,300 million. Important contributors to net welfare gains or losses are consumer surplus and policy revenues/costs. Several assumptions, such as estimated costs of environmental impact indicators and production efficiency gains over time, as well as selected discount rate or using the informed consumers' assumption were shown to have a large impact on the estimated results. However, in almost all sensitivity analyses the total estimated effect was still a net welfare benefit for society.

A SCBA aims to take into account all types of costs and benefits of interventions, irrespective of which stakeholders win or lose from the policy scenarios. However, it is also important to show the distribution of these benefits and costs over the different parties, especially when the losses are financial while the gains are non-financial, such as a gain in QALYs. In the tax scenarios, consumers would be net payers because of the loss of consumer surplus, whereas the government would gain income from the tax revenues. For the subsidy scenario, this is the other way around.

Even though no study as of yet has estimated the total societal effects of a tax on meat or subsidies on F&V, various studies have assessed the effects on consumption, health or environment separately. Mhurchu *et al.* estimated a 2% decrease in all-cause mortality following a 20% subsidy on F&V in a modelling study in New Zealand [50]. In Sweden, Sall and Gren estimated a variable environmental tax (9-30%) on meat and dairy to decrease GHG emissions by 12%, at a specific point in time [21]. Briggs *et al.* applied a tax of £2.72/ ton carbon dioxide equivalents/ 100 g product applied to all food and drink groups with above average GHG emissions in the United Kingdom [51]. They estimated GHG emissions reductions up to 18,683,000 ton CO_{2-}eq per year compared to the current situation, while saving 7,700 lives per year. In our current study, introduction of a 15% tax on meat could reduce GHG emissions by 3,600,000 ton CO_2-eq in 2048 if our population size were similar to the UK, which population is around four times larger. This might be an indication that taxing of all foods with above average GHG emissions is more effective than singling out only meat.

In a recent paper, Springmann *et al.* estimated the global and national health care costs related to meat consumption and calculated from this the price of meat if all health effects were incorporated in the price [52]. In Western countries, such as the Netherlands, the increase in price should be 21.3% for red meat and 111.2% for processed meats. In addition to integrating health in the price of foods, also environmental and social factor could be added to calculate the 'true price' of a food [53]. Evidently, as Springmann *et al.* described that integrating health would already add 20% (red meat) and more than 100% (processed meat) to the price, integrating these other components would add to this even more. From a societal perspective, in the current analyses, it showed that the meat tax scenarios of 15% or 30% could result in net benefits for the society. Although it is clear, that not all health and environmental costs are then covered.

The analyses focus on the Dutch consumption, but the global perspective used in the article of Springmann *et al.* indeed is important to take into account.

When price policies are applied only nationally, there will be trading effects with economic consequences that are yet not included in the current analysis. In addition, foods and feed are imported from other regions. International or European agreements will be important to prevent the possibility of carbon leakage, in which the emission reduction by one country is followed by an increase in another country, as environmental effects are not confined to national borders [23, 54]. The used environmental impact is based on average Dutch market (including import) food consumption data [40] and their monetized values are not specific for the agro sector [41]. For monetized local environmental effects of Dutch foods this might be a good estimation, but some of our consumed foods and feed are imported and the associated environmental impact and associated costs are located in other countries [55].

Changing prices of food products will likely have diverse effects on groups within society, in particular regarding socio-economic status (SES). While the environmental impact of food consumption is similar between SES groups, low SES groups generally have an unhealthier diet and tend to eat less F&V and fish and more meat and fats compared to higher SES groups [28, 55]. A recent Dutch study indicates that the socioeconomic differences in healthiness of the diet are likely to further increase [55]. As low SES groups have been observed to be more responsive to the price of food, price intervention policies could be an effective approach to increase healthiness and environmental friendliness of diets [29]. A combined taxation on meat and a subsidy on F&V could compensate some of the losses felt especially in the low SES groups. The current model did not allow a combined calculation of the subsidies and taxes and for stratification by SES, which is predicted to be more effective and result in higher societal benefits than single interventions. In addition, more research is needed to estimate cross-price elasticities by SES as well: which foods items will be consumed more often to replace the more expensive meats.

This study has a number of strengths. The consumption data was from a representative sample of the Dutch population [28]. Estimated total Dutch consumption of meat at baseline is in line with other reports on Dutch consumption of 77 kg meat (excluding bones 38 kg [56]). Relative risks related to food consumption are supported by consistent and strong evidence derived from a systematic literature review [30]. The DYNAMO-HIA model allows dynamic simulations and used Dutch data as input with an integration of the 95% CI of the estimates. Additionally, the used environmental data is obtained from 2018 LCA analyses tailored for the Dutch food consumption context. The SCBA framework allows for comparison between different fields such as health, environmental and other societal effects by monetizing the effects allowing us to estimate the societal impact of taxes on meat or subsidies on F&V. The Dutch guidelines on SCBA analyses in the health and environmental domains were followed [26, 31, 49]. Finally, several multiple sensitivity analyses were used to demonstrate the effect of different input parameters and methods on the net societal benefit.

Like any modelling study, the current study also has limitations to consider. Firstly, in the model, cross-elasticities could not be used to consider replacements following a decrease in meat consumption. Replacement foods could be healthy and sustainable, such as F&V, but also have high environmental impacts or negative health effects, such as cheese. A replacement food may also partly compensate for the lost consumer surplus experienced in the meat tax scenario. In addition, the DYNAMO-HIA model is limited to one risk factor, and thus does not allow for analysis of a combination scenario of a meat tax and F&V subsidy. Secondly, when considering the consumption in the reference scenario, meat and F&V consumption were assumed similar over time per age and sex category. An autonomous trend in food consumption patterns was not included, as there was no conclusive evidence available about the changes in meat and F&V consumption in the Netherlands [28, 55, 56]. In addition, whether the number of vegetarians/vegans would increase following an increase in price of meat-based products or a decrease in price of F&V could not be predicted. Thirdly, the health modelling was performed using categorization of food consumption. As the observed effects in food consumption were relatively small, the categorization might lead to an underestimation of the true effect on health when the change is not large enough to be placed in another consumption category, while any change in food patterns, even small ones, may have positive effects for health and environment at population level. Fourthly, the used SCBA framework uses monetization of effects in order to estimate societal benefits or costs, comparing a scenario with a reference scenario. In the SCBA, consumer surplus was one of the largest contributors to the balance in both the tax (as costs) and subsidy (as benefits) scenarios. Although not financial euros, consumer surplus is to be considered in a SCBA per Dutch guidelines [26]. Another weakness is that this study has only estimated effects on the food consumption side, and not the food production side. For the tax on meat-based products, increases in export following a lower domestic demand for meat products could offset some environmental gains in terms of national GHG emissions and may worsen the financial situation for some livestock farmers. If not implemented in Europe, Dutch consumers might also increase spending across border to avoid the higher prices. With the Danish fat tax, however, this effect was observed to be relatively small [57].

The attention for healthiness and sustainability of food consumption grows [58]. Information like derived in this SCBA could prove crucial to accurately estimate long-term effects of new policies. To improve assessment of societal effects of price interventions, real-life assessment of price changes could prove highly informative in addition to price elasticities of demand. Virtual supermarkets such as those studied by Waterlander *et al.* [59, 60] can potentially increase knowledge about consumer behaviour following price changes, such as introduction of taxes and/or subsidies. Alternatively, discrete choice experiments (DCE) and/or willingness-to-pay (WTP) assessments could be used for studying healthier and more sustainable foods choices.

The presented results demonstrate that a reduction in chronic disease prevalence, from reductions in meat consumption or increase in F&V consumption, is leading to benefits to society following gains in quality of life, mortality, healthcare spending, and productivity. In terms of environmental impact, a reduction of 8.5% and 16% in the 15% and 30% tax scenario respectively but an increase of 4.6% in the subsidy scenario was estimated. Concluding, a 15% or 30% tax on meat or a 10% subsidy on F&V could lead to net welfare gains for the Dutch society.

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Appendix Chapter VI.I SCBA

Price interventions can have ambiguous effects on welfare by introducing unwanted consequences from an ethical, economic or social point of view [1]. By using a societal perspective, we aim to provide an integral estimate of the effects of implementing a tax on meat-based products or subsidization of fruits and vegetables. We followed the guidelines for a Social Cost-Benefit Analyses (SCBA) for the Dutch context [2-4]. We estimated effects of such interventions on health, environment, productivity, price intervention cost or revenue, changes in VAT revenue and implementation costs. We performed sensitivity analyses to assess robustness of the main analysis.

Healthcare cost

We applied both a value of €50.000,- and €100.000,- per Quality Adjusted Life Year (QALY) gained derived from the DYNAMO-HIA model and assumed the QALY value to remain stable over time, per Dutch guidelines [2, 3]. We assessed the value of the total QALYs gained in a scenario compared to the reference scenario per year and applied a discount rate of 3%. The net present value was given by the sum of monetized QALYs in 2018 euros. Additionally, we applied a rate of €100.000,- per QALY [3]. To estimate direct healthcare costs, we used the Dutch Cost of Illness study, using the average costs of treatment per patient from the NIVEL Netherlands Primary Care Database: General Practitioners. [5, 6] We present monetized estimations in **Supplemental table 6.1.1**. The QALY values of 100,000 are simply twice the benefits of the QALY €50,000 section.

Supplemental table 6.1.1. Total health cost-benefits of the three scenarios compared to reference scenario. All values are in million 2018 euros.

	Compared to reference scenario[1]		
Health costs	**Scenario 15% tax (95% CI)**	**Scenario 30% tax (95% CI)**	**Scenario 10% subsidy (95% CI)**
QALY value €50.000	€834 - €2246	€1,598 - €4,289	€1,043 - €1,564
Direct healthcare	€239 - 1,613	€462 - 3,081	€413 - 848
Net health	**€1,073 - 3,859**	**€2,059.84 - 7,369.34**	**€1,455 - 2,412**

[1]*95% confidence interval based on 100 iterations of the model using Monte Carlo simulations.*

Productivity

Labour participation and productivity results are presented in **Supplemental tables 6.1.2 and 6.1.3**. Per chronic disease, prevented cases between 15-75 years old, the definition of the working population in the Netherlands by Statistics Netherlands (CBS), were extracted from the DYNAMO-HIA model to estimate the change in labour participation. We applied the human capital method, according to the Dutch guidelines [3]. A friction cost approach was applied as a sensitivity analysis (see sensitivity analysis). Labour participation data for diabetes type 2 was derived from a Dutch study on diabetes in 2007 [7]. Labour participation for lung cancer and colorectal cancer were obtained from a 2012 Dutch study [8]. Labour participation data of coronary heart disease (CHD) was derived from a 2007 Dutch study into labour participation by TNO [9]. Finally, participation data of stroke patients was derived from an international systematic literature review due to lack of national data [10]. We estimated the effect of changes in labour participation on governmental income tax using an average tax rate of 34% and the cost of one full-time equivalent (FTE) of 2017, which is €57,646.21 [11]. To assess the difference in welfare payments from decreased unemployment due to chronic disease, we used the welfare subsidy for a single person in 2017, and assumed half of the welfare payments to be paid, per guidelines [11]. To account for rising wages, we increased the yearly cost of an FTE by 1.8%, the average growth of Dutch wages from 2001-2017 [11]. Welfare payments were increased yearly by 1.05%, the 20 year average growth factor in the Netherlands, as obtained from Eurostat [12].

Productivity gains were estimated using the averted costs of absenteeism and presentism. We present the results in **Supplemental table 6.1.3**. Absenteeism and presentism data for diabetes type 2, colorectal cancer, lung cancer and CHD were derived from a large multiemployer study by Loeppke et al [13]. As there was no data on presentism of stroke patients, we used fatigue as proxy derived from Loeppke et al, as studies show stroke patients to be heavily affected by fatigue when returning to and during work [13-15]. To monetize the change in productivity, we used the average cost of labour per day in the Netherlands derived from the CBS and used the human capital approach. We applied a 3% discount rate per year to account for time preferences, per

Dutch guidelines and increased the cost of labour per day by 1.8% per year, the average growth of Dutch cost of labour per day from 2001-2017 [3, 11].

Supplemental table 6.1.2. Labour participation compared to reference scenario per modelled disease. All values are in million 2018 euros.

	Scenario compared to reference scenario (95% confidence interval)[1]		
Participation	**Scenario 15% tax**	**Scenario 30% tax**	**Scenario 10% subsidy**
Diabetes type 2	€247.9 - €1,259.3	€475.7 - €2,402.2	€30.7 - €167.8
Colorectal cancer	€-2.3 - €40.7	€-4.1- €78.1	€6.7 - €15.8
Lung cancer	€9.3 - €26.5	€18.1 - €50.2	€2.1 - €4.4
Stroke	€78.1 - €277.9	€150.1 - €530.6	€152.4 - €300.1
Coronary heart disease	€-60.6 - €12.6	€-115.0 - €23.4	€203.8 - €360.7
Total labour participation	**€272.4 - €1,591.6**	**€524.7 - €3,037.7**	**€395.8 - €849.0**

[1]95% confidence interval based on 100 iterations of the model using Monte Carlo simulations.

Supplemental table 6.1.3. Productivity compared to reference scenario per modelled disease. All values are in million 2018 euros.

	Scenario compared to reference scenario (95% confidence interval)[1]		
Productivity	**Scenario 15% tax**	**Scenario 30% tax**	**Scenario 10% subsidy**
Diabetes type 2	€24.9 - €126.5	€47.9 - €241.4	€3.1 - €16.9
Colorectal cancer	€-2.2 - €39.6	€-4.0 - €76.1	€6.7 - €15.4
Lung cancer	€9.4 - €25.9	€18.0 - €49.1	€2.1 - €4.3
Stroke	€18.0 - €62.8	€34.5 - €120.0	€35.0 - €67.8
Coronary heart disease	€-9.1 - €-1.9	€-17.2 - €-3.5	€30.7 - €53.5
Total labour participation	**€41.0 - €235.0**	**€79.2 - €483.2**	**€77.7 - €158.0**

[1]95% confidence interval based on 100 iterations of the model using Monte Carlo simulations.

Price intervention revenue and consumer surplus

Governmental revenues generated by taxation of meat products and cost of subsidizing fruit and vegetable products were estimated using a weighted average price. Weights of meat-based product groups were based on Dutch meat consumption between 2005-2016, compiled by Wageningen Economic Research [16]. Price intervention revenues were calculated using yearly consumption derived from the DYNAMO-HIA model following the price intervention. To account for inflation, we adjusted the prices using the average Consumer Price Index from 1996-2017. We estimated the tax revenue by using formula (1), in which q_1 is the adjusted consumption following price intervention, and $p_1 - p_0$ is the change in price due to a tax or subsidy.

1) $Revenue = q1(p1 - p0)$

To assess the change in consumer utility, we estimated the change in consumer surplus (CS) using the rule-of-half (RoH), formula (2). The RoH approximates the changes in consumer benefits, which includes the change in surplus due to change in price for current consumers and change in welfare. An important assumption of the RoH is linearity of the demand function, which is assumed to be the case when price changes are not too large [17]. The RoH uses uncompensated demand curve, and the price effect is equal to the sum of the substitution effect and income effect.

2) $\Delta CS = ½(p0 - p1)\,(q1 + q0)$

We applied a 3% discount rate per year on both the difference in CS and policy revenues or cost.

VAT revenue and policy implementation costs

Changes in consumption will affect governmental revenue derived from value-added tax (VAT). We quantify this effect by assessing the change in consumption between the scenario and the reference scenario and applying a 6% tax rate to the value of the change, the VAT rate in 2018 for food products in the Netherlands. From 2019 onwards, the new VAT is 9%. Policy implementation costs, such as costs to the tax authorities, changing prices in cashier systems and other IT systems were estimated using the same method as the SCBA by De Wit et al [18]. Results are presented in **Supplemental table 6.1.4**.

Supplemental table 6.1.4. Price intervention cost, difference in VAT revenue compared to reference scenario and implementation costs over 30 years. All values are in million 2018 euros.

	Scenario compared to reference		
Effects	**Scenario 15% tax**	**Scenario 30% tax**	**Scenario 10% subsidy**
VAT revenue	€-725.8	€-1,335.3	€222,6
Policy implementation	€-20.0	€-20.0	€-20.0
Net policy revenue	**€-745.8**	**€-1,355.3**	**€202,6**

Sensitivity analysis

We performed one-way and scenario sensitivity analyses. We assessed the effect of a friction cost method for productivity and labour participation using a friction period of 85 days, the current friction period used in Dutch health economic guidelines (**Supplemental table 6.1.5**, [19]). We varied the price elasticity to the lower and upper bound of the 95% confidence interval (**Supplemental table 6.1.6a-f**). As scenario analysis, we assessed the effect of a 1.5% and a 4% discount rate (**Supplemental table 6.1.7a-c, 8a-c**). **Supplemental table 6.1.9** is a summary table of the effects of the sensitivity analyses on the net societal costs and benefits as presented in **Figure 6.3** in the main article.

Friction cost approach

Supplemental table 6.1.5. Friction cost method to estimate labour participation and productivity. All values are in million 2018 euros.

	Scenario compared to reference		
	Scenario 15% tax	**Scenario 30% tax**	**Scenario 10% subsidy**
Productivity	€3.2	€6.2	€3.5
Labour participation	€40.8	€75.3	€23.7
Total	**€44.0**	**€81.5**	**€27.2**
Difference with human capital	€-996.7	€-1,911.3	€-678.4

Price elasticity

Supplemental table 6.1.6a. Sensitivity analysis with main analysis (reference) and lower and upper bound of price elasticity in the 15% tax scenario. All values are in million 2018 euros.

Meat - Scenario 15% tax	Reference	Lower bound PE	Upper bound PE
Tax revenue	€20,506.2	€20,663.4	€20,288.9
Consumer surplus	€-21,467.9	€-21,549.1	€-21,359.3
VAT	€-725.8	€-668.4	€-807.8

Supplemental table 6.1.6b. Sensitivity analysis with main analysis (reference) and lower and upper bound of price elasticity in the 30% tax scenario. All values are in million 2018 euros.

Meat - Scenario 30% tax	Reference	Lower bound PE	Upper bound PE
Tax revenue	€37,669.3	€38,158.6	€37,065.6
Consumer surplus	€-41,264.3	€-41,514.1	€-40,962.5
VAT	€-1,335.3	€-1,266.3	€-1,470.5

Supplemental table 6.1.6c. Sensitivity analysis with main analysis (reference) and lower and upper bound of price elasticity in the 10% subsidy scenario. All values are in million 2018 euros.

Fruit vegetables 10% subsidy	Reference	Lower bound PE	Upper bound PE
Tax revenue	€-10,110.7	€-10,063.5	€-10,129.7
Consumer surplus	€9,892.2	€9,855.5	€9,888.7
VAT	€222.6	€211.9	€245.6

Supplemental table 6.1.6d. Sensitivity analysis with main analysis (reference) and lower and upper bound of price elasticity on health gains (Direct healthcare and QoL). All values are in million 2018 euros.

	Reference	Lower bound PE	Upper bound PE
Scenario 15% tax	€2,440.8	€2,247.3	€2,725.1
Scenario 30% tax	€4,681.3	€4,327.6	€4,945.2
Scenario 10% subsidy	€1,910.3	€1,671.4	€2,175.2

Supplemental table 6.1.6e. Sensitivity analysis with main analysis (reference) and lower and upper bound of price elasticity on productivity.

	Reference	Lower bound PE	Upper bound PE
Scenario 15% meat tax	€141.9	€130.7	€172.6
Scenario 30% meat tax	€271.8	€250.8	€285.9
Scenario 10% subsidy	€113.0	€104.2	€128.7

Supplemental table 6.1.6f. Sensitivity analysis with main analysis (reference) and lower and upper bound of price elasticity on participation.

	Reference	Lower bound PE	Upper bound PE
Scenario 15% meat tax	€898.7	€831.0	€1,017.8
Scenario 30% meat tax	€1,721.0	€1,594.4	€1,819.1
Scenario 10% subsidy	€592.5	€544.3	€680.3

Discount rate sensitivity

Discount rate 1.5%

Supplemental table 6.1.7a. Total welfare effect with discount rate of 1.5% – 15% meat tax. All values are in million 2018 euros.

Scenario 15% meat tax	Confidence interval low	Confidence interval high
Health - Low QALY	€1,064.1	€2,899.0
Healthcare	€1,145.8	€1,145.9
Environment	€4,122,3	€4,122,3
Labour productivity	€53.0	€323.2
Labour participation	€356.3	€2,100.7
Policy revenue	€25,351.5	€25,351.7
Consumer surplus	€-26,540.7	€-26,540.2
VAT revenue	€-897.4	€-897.5
Policy implementation	€-20.0	€-20.0
Total	€4,634.9	€8,484.3

Supplemental table 6.1.7b. Total welfare effect with discount rate of 1.5% – 30% meat tax. All values are in million 2018 euros.

Scenario 30% meat tax	Confidence interval low	Confidence interval high
Health - Low QALY	€2,037.0	€5,534.2
Healthcare	€2,189,9	€2,189,7
Environment	€7,705.4	€7,705.4
Labour productivity	€102.3	€617.2
Labour participation	€686.01	€4,008.7
Policy revenue	€46,570.4	€46,570.4
Consumer surplus	€-51,015.1	€-51,015.1
VAT revenue	€-1,677.6	€-1,677.6
Policy implementation	€-20.0	€-20.0
Total	€6,578.2	€13,912.9

Supplemental table 6.1.7c. Total welfare effect with discount rate of 1.5% – 10% fruit and vegetable subsidy. All values are in million 2018 euros.

Scenario 10% subsidy	Confidence interval low	Confidence interval high
Health - Low QALY	€1,345.6	€2,020.1
Healthcare	€791.2	€791.2
Environment	€-137.7	€-137.7
Labour productivity	€101.4	€205.4
Labour participation	€520.3	€1,119.0
Policy revenue	€-15,429.4	€-15,429.4
Consumer surplus	€12,319.1	€12,319.1
VAT revenue	€277.0	€277.0
Policy implementation	€-20.0	€-20.0
Total	€2,614	€4,001

Discount rate – 4%

Supplemental table 6.1.8a. Total welfare effect with discount rate of 4% – 15% meat tax. All values are in million 2018 euros.

Scenario 15% meat tax	Confidence interval low	Confidence interval high
Health - Low QALY	€716.0	€1,911.6
Healthcare	€739,1	€739,1
Environment	€3,005.5	€3,005.5
Labour productivity	€34.9	€217.3
Labour participation	€229.9	€1,334.6
Policy revenue	€17,998.4	€17,998.4
Consumer surplus	€-18,842.5	€-18,842.4
VAT revenue	€-637.0	€-637.0
Policy implementation	€-20.0	€-20.0
Total	€3,224.3	€5,707.1

Supplemental table 6.1.8b. Total welfare effect with discount rate of 4% – 30% meat tax. All values are in million 2018 euros.

Scenario 30% meat tax	Confidence interval low	Confidence interval high
Health - Low QALY	€1,371.5	€3,651.0
Healthcare	€1,412,1	€1,412,1
Environment	€5,618.9	€5,618.9
Labour productivity	€67.3	€414.9
Labour participation	€442.8	€2,547.3
Policy revenue	€46,570.4	€46,570.4
Consumer surplus	€-51,015.1	€-51,015.1
VAT revenue	€-1,149.6	€-1,149.6
Policy implementation	€-20.0	€-20.0
Total	€3,298.4	€8,030.0

Supplemental table 6.1.8c. Total welfare effect with discount rate of 4% – 10% fruit and vegetable subsidy. All values are in million 2018 euros.

Scenario 10% subsidy	Confidence interval low	Confidence interval high
Health - Low QALY	€887.9	€1,330.0
Healthcare	€505,7	€505,7
Environment	€-100.8	€-100.8
Labour productivity	€65.6	€133.9
Labour participation	€332.7	€712.5
Policy revenue	€-8,832.0	€-8,832.0
Consumer surplus	€8,641.1	€8,641.1
VAT revenue	€194.6	€194.6
Policy implementation	€-20.0	€-20.0
Total	€1,674.7	€2,564.9

Supplemental table 6.1.9. Net societal welfare for all the sensitivity analyses compared to the reference no tax or subsidy scenario.

Total welfare	15% meat tax		30% meat tax		10% fruits and vegetables subsidy	
	QALY €50,000	**QALY €100,000**	**QALY €50,000**	**QALY €100,000**	**QALY €50,000**	**QALY €100,000**
Total welfare main model	*€3,069 - 7,386*	*€3,904 - 9,632*	*€4,050 - 12,276*	*€5,648 - 16,565*	*€1,800 - 3,289*	*€2,842 - 4,853*
Discount 1.5%	€4,635 - 8,484	€5,699 - 11,383	€6,578 - 13,913	€8,615 - 19,447	€2,606 - 3,983	€3,952 - 6,003
Discount 4%	€2,300 - 5,707	€3,940 - 7,619	€3,298 - 8,030	€4,670 - 11,681	€1,675 - 2,565	€2,563 - 1,235
Friction cost	€2,060 - 6,377	€2,895 - 8,623	€2,116 - 10,342	€3,720 - 14,672	€1,111 - 2,601	€2,154 - 4,165
HEC-LEG	€5,296 - 9,613	€6,131 - 11,859	€6,898 - 15,124	€8,496 - 19,413	€1,690 - 3,180	€2,733 - 4,743
LEC-HEG	€536 – 4,853	€1,371 - 7,099	€-141 - 8,085	€1,457 - 12,374	€1,887 - 3,377	€2,930 - 4,941
High price elasticity	€3,678 - 8,013	€4,699 - 10,445	€4,505 - 12,765	€6,261 - 17,213	€2,159 - 3,656	€3,377 - 5,394
Low price elasticity	€2,648 - 6,983	€3,360 - 9,107	€3,408 - 11,669	€4,774 - 15,725	€1,512 - 3,008	€2,357 - 4,375
Perfect Information	€2,235 - 5,140	€2,235 - 5,140	€2,452 - 7,988	€2,452 – 7,988	€757 – 1,726	€757 – 1,726

Values are expressed in million 2018 euros.
HEC-LEG: High environmental costs at low efficiency gain in production over time.
LEC-HEG: Low environmental costs at high efficiency gain in production over time.
Price elasticity low: -0.54 for meat and -0.48 for fruit and vegetables.
Price elasticity high: -0.66 for meat and -0.59 for fruit and vegetables.
Perfect information: gained or lost health because of consumption already accounted for by consumers; QALYs not considered in total welfare.

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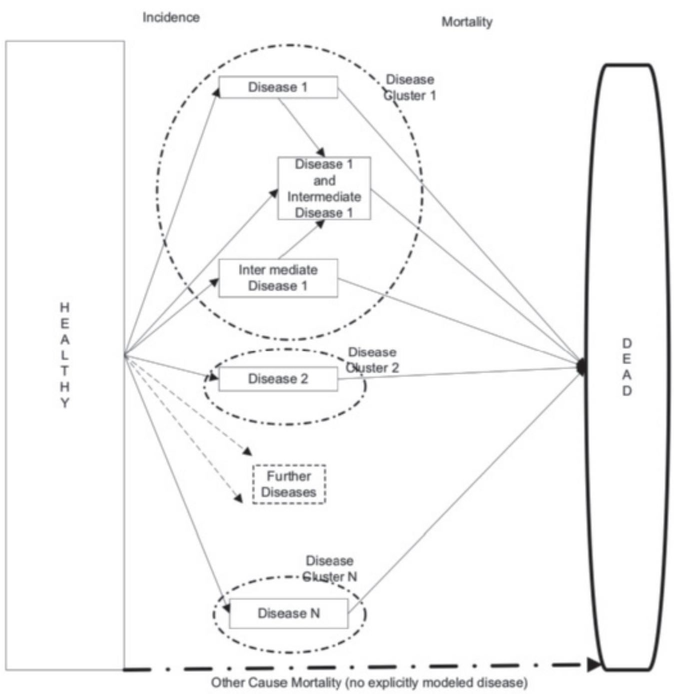
Appendix Chapter VI.II Health Modelling

DYNAMO-HIA model and data input

The DYNAMO-HIA (Dynamic Modelling for Health Impact Analysis, https://www.dynamo-hia.eu/en) model was used to assess the health impact of the selected scenarios. DYNAMO-HIA is a Markov-type model that combines microsimulation of the risk factor exposure and macro simulation of the disease and survival. The DYNAMO-HIA model simulates individuals and their risk factor biographies of every year, given age- and sex-specific transition risks within that risk factor. The risk factor status determines the relative risk of a person to contract a disease or to die. Transition probabilities of each individual is updated in annual increments, **Supplemental Figure 6.2.1** presents a stylized structure of the macro simulation as used in DYNAMO-HIA [1]. A more detailed description of the model was published by Boshuizen *et al*. [1], version 2.0.8 was used in the present study.



Supplemental Figure 6.2.1. Stylized structure of disease life table used in DYNAMO-HIA [1].

6

Population

Dutch population data was obtained from the DYNAMO-HIA website and included data on new-borns, size, overall Disability Adjusted Life Years (DALY) weights, overall disability, and overall mortality. Data collection was performed in 2011, and files were previously used in the DYNAMO-HIA modelling for the Public Health Foresight Study of the Netherlands in 2014 (VTV-2014). Within the simulations of this study, new-borns were included in our simulation.

Diseases

A detailed description of data collection of the excess mortality and disability weights of the modelled diseases can be found on the DYNAMO-HIA website: https://www.dynamo-hia.eu; Documents and publications. Prevalence and incidence of the modelled diseases in the Netherlands, based on 2011 data, were used in this study and can be found on the website.

Risk factors

Included risk factors were meat in one model, and fruit and vegetables (F&V) in another model. Disease relative risks associated with these food groups were derived from a 2015 systematic literature review of the Dutch Health Council. We used only the significant relative risks from the report of the Dutch Health Council [2, 3]. Although total meat is taxed in our scenarios, only the consumption of red and processed meat in associated with increased risk of several diseases (e.g. stroke, diabetes, lung cancer, and colorectal cancer). Therefore, in the DYNAMO-HIA model only these meat types were considered. Relative risks of F&V were pooled to estimate health effects.

Supplemental table 6.2.1. Included food groups and GloboDiet classifications.

Product	GloboDiet classification	Definition[2, 3]	Price elasticity [4]
Meat	0701 0702 0704 0705	Red meat that is only cut or is prepared in the form of minced meat (beef, pig, sheep/ lamb, horse and goat meat). Processed meat is meat that has been smoked or salted for preservation purposes or if preservatives have been added to it. Processed meat can be both white and red. White meat (poultry), includes chicken, turkey, and duck.	-0.60 (-0.66 to -0.54)
Fruit and vegetables	02 0401	Green leafy vegetables, fruit-bearing vegetables (including peppers and tomatoes), root crops, cabbage crops, onion and garlic, stem crops and other vegetables. Fruit is defined as citrus fruit and non-citrus fruit. Fresh as well as dried and canned fruit are included.	-0.53 (-0.59 to -0.48)

Consumption of red meat, processed meat, poultry, and F&V was based on data from the Dutch National Food Consumption Survey 2012-2014 and used as the baseline values in 2018. Food intake data was collected among a representative sample of the population living in the Netherlands on two non-consecutive days with 24hr dietary recalls conducted by dieticians [5]. Individual data of red meat and processed meat were aggregated to calculate meat intake values (**Supplemental table 6.2.1**). For meat consumption (without poultry), categories were created per 50 grams. For fruit and vegetable consumption, categories were created per 150 grams. Additionally, in both consumption groups a 0 category was added. Net transition probabilities between consumption categories were used to estimate the effects of future consumption. Net-transition retains the age-specific risk-factor prevalence constant, effectively assuming that consumption patterns per age category will remain similar over time. This approach was chosen due to uncertainty of presence and direction of an autonomous trend in consumption in the Netherlands, as shown by the recent Dutch national food consumption survey and a yearly report on meat consumption in the Netherlands by Wageningen Economic Research [6-8]. Price elasticity of demand estimates were obtained from a systematic literature review (**Supplemental table 6.2.1**, [4]). Consumption over time was modelled using DYNAMO-HIA. To also consider changes in the consumption of poultry, the ratio poultry to red & processed meat at baseline was used.

Estimated prevented cases compared to reference scenario

We performed probabilistic sensitivity analyses (PSA) on both the meat and fruit and vegetable models to estimate uncertainties of model estimates. We used the upper and lower estimates of the relative risks of consumption of the individual disease, derived from the systematic literature reviews and assumed the relative risks to be normally distributed. We applied 100 iterations of the model using Monte Carlo simulations. Only the upper and lower limit of prevented cases are used in the SCBA and presented in **Supplemental table 6.2.2, 6.6.3 and 6.2.4**. In **Supplemental table 6.2.5**, the gained Quality Adjusted Life Years (QALYs) of the scenarios are presented.

Supplemental table 6.2.2. Estimated difference in cases per year in a 15% meat tax scenario compared to the reference scenario based on the 95% Confidence Intervals of the risk factors. Only the upper (UL) and lower limit (LL) of prevented cases are used in the SCBA and presented.

	Estimated cases prevented compared to reference scenario									
	Colorectal cancer		Diabetes		CHD		Lung cancer		Stroke	
Year	LL	UL	LL	UL	LL	UL	LL	UL	LL	UL
2019	0	-160	-194	-862	5	13	-73	-195	-63	-210
2020	-2	-308	-378	-1,703	13	32	-127	-340	-122	-412
2021	-5	-443	-552	-2,525	23	56	-167	-449	-179	-605
2022	-8	-569	-720	-3,331	32	84	-198	-534	-233	-790
2023	-12	-685	-881	-4,119	42	114	-223	-602	-284	-969
2024	-17	-794	-1,035	-4,887	52	146	-243	-657	-333	-1,141
2025	-22	-895	-1,183	-5,637	61	180	-260	-705	-381	-1,306
2026	-28	-989	-1,324	-6,364	69	214	-275	-745	-426	-1,464
2027	-34	-1,077	-1,460	-7,068	76	248	-287	-781	-469	-1,616
2028	-40	-1,158	-1,589	-7,750	82	282	-299	-814	-510	-1,761
2029	-46	-1,235	-1,713	-8,407	87	316	-309	-844	-549	-1,900
2030	-52	-1,307	-1,830	-9,041	92	350	-319	-871	-586	-2,033
2031	-59	-1,374	-1,942	-9,650	95	383	-328	-898	-622	-2,160
2032	-66	-1,438	-2,047	-10,232	99	416	-336	-923	-656	-2,281
2033	-73	-1,497	-2,146	-10,787	101	449	-344	-946	-688	-2,395
2034	-80	-1,551	-2,238	-11,312	103	480	-351	-968	-718	-2,503
2035	-87	-1,601	-2,323	-11,803	105	511	-357	-987	-746	-2,604
2036	-94	-1,647	-2,401	-12,262	107	541	-363	-1,003	-771	-2,697
2037	-102	-1,688	-2,474	-12,691	108	569	-367	-1,019	-794	-2,783
2038	-109	-1,726	-2,539	-13,088	110	597	-372	-1,033	-815	-2,861
2039	-116	-1,760	-2,599	-13,455	111	623	-376	-1,046	-835	-2,933
2040	-123	-1,791	-2,653	-13,791	112	648	-379	-1,058	-852	-2,998
2041	-130	-1,817	-2,701	-14,095	114	671	-382	-1,067	-866	-3,055
2042	-137	-1,839	-2,743	-14,368	115	693	-384	-1,075	-879	-3,105
2043	-143	-1,859	-2,781	-14,613	116	712	-386	-1,082	-890	-3,149
2044	-150	-1,874	-2,813	-14,829	117	730	-387	-1,088	-899	-3,186
2045	-155	-1,888	-2,842	-15,021	118	747	-389	-1,093	-907	-3,219
2046	-161	-1,898	-2,866	-15,187	120	762	-389	-1,096	-913	-3,245
2047	-166	-1,907	-2,887	-15,330	121	775	-390	-1,099	-918	-3,267
2048	-170	-1,912	-2,903	-15,449	123	787	-390	-1,100	-921	-3,283

Supplemental table 6.2.3. Estimated difference in cases per year in a 30% meat tax scenario compared to the reference scenario based on the 95% Confidence Intervals of the risk factors. Only the upper (UL) and lower limit (LL) of prevented cases are used in the SCBA and presented.

	Estimated cases prevented compared to reference scenario									
	Colorectal cancer		Diabetes		CHD		Lung cancer		Stroke	
Year	**LL**	**UL**	**LL**	**UL**	**LL**	**UL**	**LL**	**UL**	**LL**	**UL**
2019	0	-306	-372	-1,643	9	23	-139	-370	-120	-398
2020	-3	-587	-727	-3,252	24	57	-242	-645	-234	-781
2021	-7	-848	-1,065	-4,826	40	102	-320	-854	-342	-1,150
2022	-13	-1,090	-1,388	-6,368	58	153	-381	-1,016	-447	-1,506
2023	-20	-1,314	-1,698	-7,874	75	210	-428	-1,145	-546	-1,849
2024	-28	-1,523	-1,995	-9,343	92	270	-467	-1,252	-642	-2,179
2025	-37	-1,718	-2,280	-10,776	108	333	-500	-1,342	-733	-2,497
2026	-47	-1,900	-2,552	-12,165	122	397	-528	-1,420	-821	-2,802
2027	-58	-2,069	-2,812	-13,511	135	463	-552	-1,488	-904	-3,094
2028	-69	-2,226	-3,059	-14,809	146	528	-574	-1,548	-984	-3,373
2029	-81	-2,373	-3,294	-16,060	156	594	-593	-1,603	-1,059	-3,639
2030	-93	-2,510	-3,517	-17,262	164	659	-611	-1,655	-1,131	-3,892
2031	-105	-2,639	-3,728	-18,417	171	724	-627	-1,704	-1,200	-4,134
2032	-118	-2,759	-3,928	-19,521	178	787	-643	-1,749	-1,264	-4,363
2033	-132	-2,871	-4,115	-20,568	183	850	-657	-1,791	-1,324	-4,579
2034	-145	-2,975	-4,290	-21,562	187	911	-670	-1,831	-1,381	-4,783
2035	-159	-3,071	-4,453	-22,498	191	971	-682	-1,868	-1,433	-4,973
2036	-173	-3,159	-4,604	-23,378	195	1,029	-693	-1,902	-1,482	-5,150
2037	-187	-3,240	-4,743	-24,200	199	1,084	-703	-1,933	-1,526	-5,313
2038	-201	-3,314	-4,870	-24,962	203	1,138	-712	-1,961	-1,566	-5,464
2039	-214	-3,380	-4,985	-25,664	207	1,189	-720	-1,986	-1,602	-5,600
2040	-228	-3,439	-5,089	-26,306	211	1,237	-726	-2,008	-1,635	-5,723
2041	-242	-3,491	-5,181	-26,887	215	1,282	-732	-2,026	-1,663	-5,832
2042	-255	-3,535	-5,263	-27,409	219	1,324	-736	-2,042	-1,687	-5,927
2043	-267	-3,572	-5,334	-27,873	222	1,363	-739	-2,054	-1,707	-6,010
2044	-279	-3,602	-5,395	-28,282	226	1,398	-741	-2,063	-1,724	-6,080
2045	-290	-3,625	-5,447	-28,635	229	1,430	-742	-2,069	-1,737	-6,138
2046	-300	-3,642	-5,490	-28,938	233	1,458	-742	-2,072	-1,747	-6,185
2047	-310	-3,655	-5,525	-29,192	236	1,484	-741	-2,074	-1,755	-6,222
2048	-319	-3,662	-5,551	-29,398	240	1,507	-740	-2,072	-1,759	-6,249

Supplemental table 6.2.4. Estimated difference in cases per year in a 10% fruit and vegetables subsidy scenario compared to the reference scenario based on the 95% Confidence Intervals of the risk factors. Only the upper (UL) and lower limit (LL) of prevented cases are used in the SCBA and presented.

	Estimated cases prevented compared to reference scenario									
	Colorectal cancer		Diabetes		CHD		Lung cancer		Stroke	
Year	LL	UL	LL	UL	LL	UL	LL	UL	LL	UL
2019	-30	-63	-37	-126	-132	-224	-18	-34	-120	-228
2020	-57	-121	-70	-248	-260	-443	-31	-60	-234	-447
2021	-82	-175	-100	-364	-384	-655	-41	-78	-344	-657
2022	-104	-224	-127	-476	-504	-862	-48	-93	-448	-857
2023	-125	-269	-151	-584	-621	-1,063	-54	-104	-548	-1,049
2024	-143	-311	-173	-688	-733	-1,258	-58	-113	-643	-1,233
2025	-160	-350	-193	-788	-843	-1,448	-62	-121	-735	-1,409
2026	-176	-386	-211	-885	-948	-1,632	-65	-128	-822	-1,578
2027	-190	-420	-227	-978	-1,051	-1,811	-67	-133	-906	-1,741
2028	-204	-452	-241	-1,066	-1,149	-1,983	-69	-139	-986	-1,896
2029	-216	-482	-253	-1,151	-1,244	-2,149	-71	-144	-1,062	-2,045
2030	-227	-510	-264	-1,232	-1,335	-2,309	-73	-148	-1,136	-2,188
2031	-238	-536	-273	-1,308	-1,421	-2,461	-75	-152	-1,205	-2,323
2032	-247	-560	-280	-1,380	-1,502	-2,605	-76	-156	-1,271	-2,452
2033	-256	-583	-286	-1,449	-1,580	-2,743	-77	-159	-1,334	-2,576
2034	-264	-604	-290	-1,513	-1,653	-2,872	-78	-163	-1,393	-2,692
2035	-271	-623	-293	-1,572	-1,720	-2,993	-79	-165	-1,447	-2,800
2036	-277	-641	-294	-1,627	-1,782	-3,105	-80	-168	-1,498	-2,900
2037	-282	-656	-295	-1,677	-1,840	-3,208	-80	-170	-1,545	-2,994
2038	-286	-670	-294	-1,723	-1,892	-3,302	-80	-171	-1,588	-3,080
2039	-290	-683	-292	-1,765	-1,939	-3,389	-81	-173	-1,628	-3,159
2040	-293	-695	-290	-1,805	-1,983	-3,469	-81	-175	-1,664	-3,233
2041	-295	-705	-287	-1,840	-2,022	-3,541	-81	-176	-1,697	-3,300
2042	-297	-714	-284	-1,871	-2,056	-3,605	-81	-177	-1,726	-3,359
2043	-298	-721	-280	-1,899	-2,085	-3,660	-81	-178	-1,751	-3,411
2044	-299	-726	-276	-1,923	-2,110	-3,707	-81	-178	-1,772	-3,455
2045	-299	-731	-272	-1,945	-2,132	-3,748	-81	-178	-1,791	-3,494
2046	-299	-735	-269	-1,965	-2,151	-3,785	-81	-179	-1,807	-3,529
2047	-299	-739	-267	-1,984	-2,167	-3,817	-81	-179	-1,822	-3,560
2048	-299	-741	-264	-2,000	-2,181	-3,844	-80	-180	-1,834	-3,586

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Supplemental table 6.2.5. Change in Quality Adjusted Life Years of the three scenarios compared to the reference scenario. The lower limit (LL) and upper limit (UL) of the QALYs are presented.

QALYs gained	15% meat tax		30% meat tax		10% fruit and vegetable subsidy	
Year	**LL**	**UL**	**LL**	**UL**	**LL**	**UL**
2019	145	296	276	564	135	195
2020	269	564	515	1,078	260	378
2021	377	811	723	1,552	376	549
2022	472	1,041	908	1,994	484	709
2023	557	1,256	1,072	2,407	585	860
2024	634	1,459	1,220	2,797	681	1,003
2025	703	1,650	1,353	3,165	771	1,138
2026	764	1,831	1,473	3,511	856	1,265
2027	821	2,001	1,581	3,838	936	1,387
2028	872	2,162	1,678	4,144	1,011	1,501
2029	918	2,313	1,765	4,432	1,081	1,608
2030	959	2,456	1,843	4,701	1,148	1,710
2031	997	2,590	1,913	4,954	1,209	1,804
2032	1,030	2,715	1,974	5,189	1,265	1,891
2033	1,060	2,831	2,028	5,405	1,318	1,973
2034	1,085	2,937	2,074	5,604	1,366	2,048
2035	1,105	3,033	2,113	5,784	1,409	2,116
2036	1,122	3,118	2,144	5,947	1,447	2,176
2037	1,135	3,194	2,169	6,093	1,481	2,230
2038	1,144	3,261	2,188	6,221	1,511	2,278
2039	1,151	3,320	2,201	6,331	1,536	2,320
2040	1,155	3,370	2,208	6,426	1,559	2,357
2041	1,156	3,411	2,209	6,503	1,578	2,388
2042	1,155	3,444	2,206	6,566	1,593	2,414
2043	1,152	3,471	2,199	6,615	1,604	2,434
2044	1,147	3,491	2,188	6,651	1,612	2,448
2045	1,141	3,507	2,175	6,676	1,618	2,460
2046	1,134	3,518	2,159	6,690	1,623	2,471
2047	1,127	3,524	2,142	6,695	1,627	2,478
2048	1,118	3,525	2,122	6,691	1,629	2,483

Sensitivity analysis

We varied the price elasticity (PE) using the upper and lower estimate of the 95% confidence interval. Meat: -0.60 (95% CI: -0.66; -0.54) and F&V: -0.53 (95% CI: -0.59; -0.48). This changed price elasticity will affected consumption changes and therefore related health outcomes. **Supplemental table 6.2.6, 6.2.7, and 6.2.8** present the estimated mean cases in the different PE scenarios as compared to the main analysis.

Supplemental table 6.2.8. One-way sensitivity analysis of price elasticity for the 15% meat tax scenario.

	Sum estimated cases compared to reference scenario		
Disease	**Lower bound PE**	**Main analysis**	**Upper bound PE**
Colorectal cancer	-16,950	-18,954	-20,252
Diabetes type 2	-168,645	-182,840	-205,197
CHD	6,938	7,647	7,924
Lung cancer	-16,009	-17,392	-19,509
Stroke	-39,250	-42,857	-47,341
QALYs	48,548	52,718	58,998

Supplemental table 6.2.7. One-way sensitivity analysis of price elasticity for the 30% meat tax scenario.

	Sum estimated cases compared to reference scenario		
Disease	**Lower bound PE**	**Main Analysis**	**Upper bound PE**
Colorectal cancer	-33,516	-36,461	-38,493
Diabetes type 2	-322,730	-349,136	-368,089
CHD	12,642	14,411	15,273
Lung cancer	-30,589	-33,075	-35,351
Stroke	-75,371	-81,808	-86,028
QALYs	93,587	101,465	106,721

Supplemental table 6.2.8. One-way sensitivity analysis of price elasticity for the 10% fruits and vegetables subsidy.

	Sum estimated cases compared to reference scenario		
Disease	**Lower bound PE**	**Reference**	**Upper bound PE**
Colorectal cancer	-10,735	-11,511	-13,357
Diabetes type 2	-20,860	-23,718	-25,092
CHD	-55,068	-59,842	-67,972
Lung cancer	-2,965	-3,176	-3,668
Stroke	-50,057	-54,079	-61,893
QALYs	37,698	44,375	50,282

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Appendix Chapter VI.III Environmental Impact

Life Cycle Analyses

The environmental impact of the Dutch food consumption was estimated with Life Cycle Analysis (LCA), a methodological tool to assess the environmental load throughout the life cycle of a product. The system boundaries of LCA were from cradle till plate, indicating all phases from primary production, processing, primary packaging, distribution, supermarket and transport through all phases (except from supermarket to consumer), storage, preparing, cooking and incineration of waste products. Life Cycle Inventories (LCI) data representative for Dutch situations were previously provided by Blonk Consultants in 2015-2018 and were saved in SimaPro. LCIs are all the in and out flows of a product system, including raw resources or materials, energy by type, water, and emissions to air, water and land. The LCI data was used by the RIVM to calculate the total environmental impact of the food consumption using the ReCiPe 2016 model [1]. The result is the average environmental impact per kg prepared food at the plate. The database included environmental impact data on the indicators land use (LU), greenhouse gas (GHG) emissions, acidification, and eutrophication of salt- and fresh water.

Extrapolations

Primary LCA data was available for 225 foods and drinks. Foods that were not covered were extrapolated as a proxy to primary LCA data. Extrapolations were done by an expert judgment of a panel of RIVM scientists including a cross check of each other's extrapolations. The extrapolations were based on ingredient composition, similarities in production system, and similarities in type of food and variety. Conversion factors were applied to calculate the impact of a processed item (shrinking, losses, drying etc.). For example, a factor for grapes was used to calculate the impact of dried raisins based on the water content of both. Standardized recipes from the Dutch Food Composition Table (2016) were used to calculate the environmental load of composite dishes. The RIVM panel constructed other recipes based on literature, ingredients list and expert knowledge when no standardized recipes were available.

Environmental impact of consumption

Data of the Dutch National Food Consumption Survey (DNFCS, [2]) 2012-2014 was used to estimate daily consumptions of meat products, as well as fruit and vegetables. Both the DNFCS as well as the environmental impact data were available at food product level. The mean environmental impact for all five environmental impact indicators (for example, mean CO_2-eq per consumed kg meat) in the DNFCS was calculated (**Supplemental table 6.3.1**).

Supplemental table 6.3.1. Mean environmental impact of a kilogram meat and fruit and vegetables.

Category	Unit	Meat	Fruit and vegetables
Climate change	kg CO_2-eq	22.88	1.29
Acidification	kg SO_2-eq	0.29	0.0036
Eutrophication, fresh water	kg P-eq	0.0047	0.0001
Eutrophication, salt-water	kg N	0.0493	0.0009
Land use	m^2a	15.90	0.15

Total estimated annual consumption of meat (white, red, and processed), and fruit and vegetables (F&V) for the Dutch population for the years 2018 until 2048 was derived from the Dynamo-HIA model (**Supplemental file 6.1**, [3]). The difference in annual total consumption was calculated comparing the scenarios (tax or subsidy) to a reference scenario. These estimated annual differences in consumption were then multiplied by the mean environmental impact (land use, greenhouse gas emissions, acidification, and eutrophication of salt- and fresh water).

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Production efficiency gains

It is expected that the environmental impact of food production per kg product will become lower (more efficient) over time. It was therefore important to take account of these expected production efficiency gains over time in the analysis. For the Netherlands, it was estimated that the agriculture and fishery sectors have reduced their standardized GHG emission by 20% in 16 years (1.25% per year, [4]), from 2000 to 2016. Therefore, in the main analysis we extrapolated this annual decrease up until 2048.

Cost of environmental impact

The environmental impact costs are described in a report of CE Delft [5]. The mean costs per enviromental indicator used in the Societal Cost Benefit Analysis (SCBA) are presented in **Supplemental table 6.3.2**. Cost levels in the SCBA are discounted by the recommend 3% each year to present all cost in 2018 Euro's.

Supplemental table 6.3.2. Environmental impact costs according to CE Delft.

		Environmental impact (external costs)		
Category	**Unit**	**Low**	**Mean**	**High**
Climate change	€/kg CO_2-eq	€0,014	€0,057	€0,057
Acidification	€/kg SO_2-eq	€1,19	€5,4	€10,7
Eutrophication, fresh water	€/kg P-eq	€0,41	€1,9	€3,71
Eutrophication, salt-water	€/kg N	€3,11	€3,11	€3,11
Land use	€/m^2a	€0,00647	€0,0261	€0,0507

Costs of consumption

In the main analysis of the SCBA, the mean estimated annual efficiency gain in production over time of 1.25% per year was used to calculate the environmental impact of the changes in meat and F&V consumption. These estimated annual differences in consumption were then multiplied by the mean environmental impact (land use, greenhouse gas emissions, acidification, and eutrophication of salt- and fresh water).

Sensitivity analyses

In the sensitivity analyses, a high cost (**Supplemental table 6.3.2**) of the environmental indicators and a low efficiency gain in production (-0.75% per year) (HEC-LEG) was calculated to represent the upper bound of expected environmental costs/benefits (**Supplemental table 6.3.3**). In addition, an analysis with low environmental costs (**Supplemental table 6.3.2**) and high efficiency gains (-1.75% per year) (LEC-HEG) was performed which represents the lower bound of expected enviromental costs/benefits.

Supplemental table 6.3.3. Discounted differences in costs of all environmental impacts in the fruit and vegetables subsidy scenario and the meat taxation scenarios compared to a reference scenario[ab].

Costs	Meat tax (15%)			Meat tax (30%)			Fruit and vegetables subsidy		
Year	LEC-HEG	Main	HEC-LEG	LEC-HEG	Main	HEC-LEG	LEC-HEG	Main	HEC-LEG
2019	-49.8	-185.9	-289.9	-125.2	-348.7	-477.5	1.54	6.43	8.29
2020	-47.9	-179.4	-281.3	-120.1	-336.0	-462.31	1.47	6.17	8.22
2021	-45.8	-172.4	-271.7	-114.9	-323.3	-446.9	1.41	5.93	8.17
2022	-43.9	-166.3	-263.34	-110.2	-311.6	-432.8	1.34	5.70	8.11
2023	-42.1	-160.4	-255.2	-105.8	-300.6	-419.4	1.28	5.46	8.03
2024	-40.4	-154.6	-247.4	-101.1	-288.8	-404.98	1.23	5.26	7.99
2025	-38.7	-148.7	-239.1	-96.7	-277.7	-391.2	1.17	5.04	7.92
2026	-37.0	-142.8	-230.7	-92.5	-266.9	-377.8	1.12	4.84	7.85
2027	-35.3	-137.2	-222.9	-88.5	-256.6	-364.9	1.07	4.64	7.78
2028	-33.8	-132.1	-215.5	-84.5	-246.4	-352.0	1.02	4.44	7.68
2029	-32.4	-127.0	-208.3	-80.8	-236.6	-339.7	0.97	4.25	7.60
2030	-31.0	-122.4	-201.8	-77.4	-227.9	-328.8	0.92	4.07	7.53
2031	-29.7	-117.6	-194.9	-73.9	-218.8	-317.2	0.88	3.90	7.45
2032	-28.3	-112.8	-187.9	-70.7	-210.4	-306.4	0.84	3.73	7.36
2033	-27.1	-108.7	-181.9	-67.6	-202.0	-295.6	0.80	3.58	7.31
2034	-25.9	-104.2	-175.3	-64.56	-194.0	-285.3	0.76	3.43	7.24
2035	-24.7	-99.7	-168.6	-61.7	-186.2	-275.1	0.73	3.28	7.15
2036	-23.5	-95.5	-162.2	-58.8	-178.4	-264.8	0.69	3.13	7.06
2037	-22.3	-91.0	-155.5	-56.0	-170.8	-254.8	0.66	3.00	6.99
2038	-21.1	-86.7	-148.8	-53.3	-163.5	-245.0	0.63	2.87	6.89
2039	-20.2	-83.3	-143.7	-50.8	-156.6	-235.9	0.59	2.74	6.81
2040	-19.2	-79.6	-138.0	-48.4	-150.0	-227.0	0.57	2.63	6.74
2041	-18.4	-76.5	-133.4	-46.1	-143.5	-218.2	0.54	2.51	6.65
2042	-17.5	-73.3	-128.4	-43.8	-137.2	-209.6	0.51	2.39	6.57
2043	-16.6	-70.1	-123.4	-41.7	-131.2	-201.4	0.49	2.28	6.46
2044	-15.8	-66.9	-118.5	-39.7	-125.4	-193.3	0.46	2.18	6.38
2045	-15.1	-64.2	-114.1	-37.7	-119.9	-185.8	0.44	2.09	6.32
2046	-14.4	-61.5	-109.9	-35.8	-114.3	-178.0	0.42	2.00	6.26
2047	-13.7	-58.9	-105.7	-34.1	-109.3	-171.0	0.40	1.92	6.20
2048	-13.0	-56.3	-101.6	-32.4	-104.4	-164.1	0.38	1.83	6.13
2019	-12.4	-53.8	-97.6	-30.8	-99.8	-157.7	0.36	1.75	6.03
Total costs[c]	-857	-3,3890	-5,617	-2,146	-6,337	-9,184	25.7	113.5	223.2

a: discount rate 3%

b: cost levels of million 2018 Euro's.

c: negative costs are benefits for society, positive costs are costs for society.

LEC-HEG: Low environmental impact indicators costs; high efficiency gains.

Main analysis: Medium environmental impact indicators costs; medium efficiency gains.

HEC-LEG: High environmental impact indicators costs; low efficiency gains.

6

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CHAPTER VII

General Discussion

Main findings of this thesis

The overall aim of this PhD thesis was to provide insight into how the healthiness of the Dutch diet may be increased while simultaneously lowering its environmental impact with the current observed diet as the starting point. In the first part of this thesis, we described the impact of the diet consumed in the Netherlands on health and the environment. The usual diet consumed by participants of the EPIC-NL cohort study (the Dutch contribution to the European Prospective Investigation into Cancer and Nutrition study) is associated with emissions of around 4 to 5 kg CO_2-equivalents per day (**Chapter 2 and 3**). Within this usual diet, animal-derived foods such as meat, dairy, eggs, and fish, constitute approximately 19% of the daily food consumption in gram per day but account for almost 60% of the daily dietary GHG emissions (**Chapter 2**). Meat consumption contributes half of this 60%. Although beverages have a relatively small environmental impact per kilogram, because of the high consumption levels they contribute around 12% to daily GHG emissions (**Chapter 2**). In order to study if sustainability of diets and health are linked we prospectively studied the association between dietary environmental impact and mortality in a longitudinal cohort study. After adjustments for age, sex, and energy intake, a diet with higher total GHG emissions was not associated with the risk of all-cause and cause-specific mortality (**Chapter 2**). This shows that a sustainable diet is not necessarily a healthy diet and vice versa. Although daily dietary GHG emissions were not associated with mortality, some food substitutions can create a healthier as well as a more sustainable diet. For example, we showed that replacement of 35 grams of meat per day by several plant-based foods or fish would significantly increase survival rates between 4 to 19%, while also reducing dietary-associated GHG emissions and land use between 4 to 12%.

We studied how dietary changes observed in our study population between 1993-1997 and 2015 affected dietary quality and environmental impact (**Chapter 3**). The observed dietary changes resulted in a healthier diet, as measured by the Dutch Healthy Diet Index 2015 (DHD15-index), with a 12% higher average dietary quality score at follow-up compared to baseline. With ageing, total energy intake decreased which also resulted in slightly lower absolute dietary GHG emissions (2% for men and 4% for women). However, after standardisation for energy intake, dietary GHG emissions increased by approximately 5% in men and did not change for women over the 20 years. During follow up, fish and chicken consumption increased but consumption of red and processed meat did not decrease, so dietary quality improved but environmental impact worsened.

In the second part of this thesis, we investigated whether adherence to several currently recommended diets was associated with mortality risk and environmental impact in the EPIC-NL cohort. We used the dietary guidelines from the World Health Organisation (WHO), the Dutch Health Council (DHD15-index), and the diet of the Dietary Approaches to Stop Hypertension (DASH) trial. In general, better adherence to these guidelines was associated with reduced mortality and reduced environmental impact (**Chapter 4**). In men, the largest difference in environmental impact was observed for higher scores on the WHOs Healthy Diet Indicator (3.7% lower GHG emissions per standard deviation (SD) increase in the indicator with a 95% Confidence Interval (CI) of 3.4 to 4.0). For women the largest differences in environmental impact were observed for the DHD15-index (2.0%, 95% CI: 1.9-2.2, lower GHG emissions per SD increase in the index). Of all indices, higher DHD15-index scores had the strongest association with all-cause mortality risk. The adjusted Hazard Ratio per SD was 0.88 (95% CI: 0.82-0.95) for men and 0.92 (95% CI: 0.88-0.96) for women.

In the EPIC-NL cohort, adherence to the 2015 Dutch dietary guidelines was low. The average score on the DHD15-index at baseline was roughly half of the possible maximum score leaving room for further improvements (**Chapter 3-5**). Therefore, increasing awareness of and adherence to these current guidelines has still a substantial potential for increasing health and reducing environmental impact of the diet. The observed variation in GHG emissions at a similar DHD15-index score in the EPIC-NL cohort is a clear indication that for a given diet specific food choices lead to large differences in total environmental impact (**Figure 7.1**). For example, consuming 40 grams of red meat per day results in 10 points on the DHD15-index meat component, whereas a consumption of 0 grams also results in 10 points but is associated with much lower GHG emissions. In addition, the within food group differences in environmental impact, such as the difference between apples (low environmental impact) versus strawberries (high environmental impact), create variations in daily environmental impact at a similar dietary index score. In **Chapter 5**, we therefore investigated which dietary patterns were present in our population that might be beneficial for both health and the environment. To derive these existing dietary patterns we used the DHD15-index score and GHG emissions to explain the variation in food group consumption. With this method, two dietary patterns were identified of which the first pattern was labelled "*Plant-based*" (high in consumption of fruits and vegetables, fish, legumes, and soy products) and the second as "*Dairy-based*" (high in consumption of cheese, low and high fat milk products, but also nuts and seeds). Consumers in the highest quartile of the "*Plant-based pattern*" had an 18% higher DHD15-index score and 3% lower GHG emissions compared to the average diet of the EPIC-NL participants. The "*Dairy-based pattern*" had similar DHD15-index scores as the average diet, but with a 12% higher environmental impact. Where the "*Plant-based pattern*" is thus an example of a dietary pattern with co-benefits for both health and the environment, the "*Dairy-based pattern*" is an example of a partial trade-off.

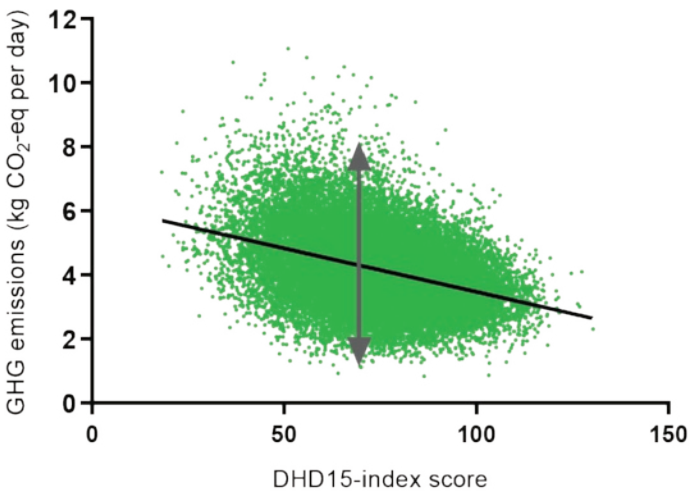

Figure 7.1. Scatterplot illustrating the direction and variation in the association between the Dutch Healthy Diet index 2015 (DHD15-index) score and daily greenhouse gas (GHG) emissions.

The first two parts of this thesis focused on the observed diet in a Dutch cohort setting. The last part is a modeling study on the potential effects of price policies in order to obtain a healthier and more sustainable diet (**Chapter 6**). Our results showed that introducing a 15% or 30% tax on meat or a 10% subsidy on fruit and vegetables in the Netherlands could lead to dietary changes that will reduce the incidence of several chronic diseases, such as type II diabetes, colorectal cancer, stroke, and lung cancer. These health gains are associated with benefits such as an increased quality of life, lower healthcare costs, and higher productivity levels as compared to a reference 'as is' scenario. In terms of environmental impact (GHG emissions, land use, eutrophication, and acidification), we estimated a reduction in the meat tax scenarios but a small increase in the fruit and vegetables subsidy scenario. Overall, an increase in the price of meat could lead to a net societal benefit over a 30-year period of about €3,100-7,400 million for a 15% tax and about €4,100-12,300 million for a 30% tax. A 10% decrease in the price of fruit and vegetables could lead to a net societal benefit of about €1,800-3,300 million.

Integrating health and sustainability of diets

Future diets

The 'healthy reference diet' presented by Willett *et al.* describes what the world's new diet could look like to promote health [1]. This reference diet is stricter than the current Dutch dietary guidelines in most aspects, especially concerning meat, legumes, and nut consumption (**Table 1.1**). For example, optimal red meat consumption was modelled to be between 0 and 28 grams per day, whereas the current Dutch recommendation is to consume less than 300 grams per week (43 grams per day), as interpreted by the Netherlands Nutrition Centre [2, 3]. Currently, the average Dutch diet is far from the recommendations of the Dutch dietary guidelines [4]. The more strict 'healthy reference diet' is therefore a future target to aim for.

As observed in this thesis, better adherence to the current Dutch dietary guidelines would decrease environmental impact (**Chapter 4 and 5**). Incorporating existing knowledge on sustainable diets in dietary guidelines may potentially accelerate the transition towards healthier as well as more sustainable diets [5]. At this moment, most countries have food-based dietary guidelines that are based only on health considerations and not on environmental aspects of the diet [5]. Both Sweden and Brazil consider sustainability aspects of the diet to a limited degree in their recommendations, often in appendices of the main guidelines. For example, the Swedish guidelines include the aspect of seasonality of food products and sustainability labels used for fish (MSC, ASC) [6].

Consumers often find it difficult to implement healthy dietary changes. Difficulty adopting new dietary habits might relate to the complexity of dietary recommendations. Adding a sustainability factor to new dietary guidelines might complicate public health messages even more. Therefore, it is important to identify where health and sustainability go together (co-benefits) and where there is friction (trade-offs). Two main recommendations for a healthier and more sustainable diet have been proposed before and are considered most important. The first is that animal-based foods should be replaced by plant-based foods and the second is that energy intake should match energy demand at a healthy body weight [1, 7].

Adapting dietary guidelines to include sustainability

The largest reduction in dietary environmental impact can be achieved by decreasing animal-based food consumption [1, 7]. In two systematic reviews, several sustainable dietary patterns were identified that showed possible reductions in GHG emissions ranging from 20% to 30% [8, 9]. These possible reductions were proportional to the extent of animal-based food restriction. The current Dutch dietary guidelines contain the overarching recommendation of shifting from an animal-based towards a plant-based diet, but this recommendation was only based on evidence about diet-disease associations [2]. In this thesis, we observed that substitution of meat by other foods is reducing mortality rates as well as increasing sustainability in terms of GHG emissions and land use of the diet (**Chapter 2**). Consuming a "*Plant-based*" dietary pattern was more compliant with current dietary guidelines (higher DHD15-index scores) and lower GHG emissions than the average EPIC-NL diet (**Chapter 5**). In order to explicitly combine health and environmental aspects of the diet in new sustainable dietary guidelines, a suggestion could be to rephrase the current overarching recommendation to '*Follow a dietary pattern that involves eating more plant-based and less animal-based foods to benefit* *health and the environment'* (**Table 7.1**). In the current Dutch diet, 40% of total protein intake is derived from plant sources and 60% from animal sources [4, 10]. Changing this 40/60 ratio to a 60/40 ratio is challenging but in line with the current overall recommendation to eat more plant-based and less animal-based foods [10]. This 60/40 ratio is challenging because this would often mean an almost vegetarian diet. Rephrasing the recommendation to limit red and especially processed meat to a stricter new recommendation could put more emphasis on the suggested upper limit of consumption of these animal-based foods.

The current Dutch dietary guidelines do not consider poultry since there is no positive or adverse association with health outcomes [2]. Although shifting from red meat to poultry is healthier and with regard to GHG emissions more sustainable as well, its relative impact on the environment compared to plant-based foods is still high (**Chapter 3**). The average Dutch poultry consumption (chicken and turkey) is 126 grams per week (18 grams per day) [4]. In the Wheel of Five, the translation of the Dutch dietary guidelines for consumers by the Netherlands Nutrition Centre, the recommended weekly total meat consumption is 500 gram or less with a maximum of 300 grams of red meat [10]. Compliance to the Wheel of Five results in around half of the proteins consumed being from animal-based foods, which is still above the preferred goal of 40% [10]. Therefore, we suggest including a maximum of 100 grams of poultry per week (14 grams a day) in the new Dutch dietary guidelines based on both health and sustainability.

Although the recommendations of consuming a few portions of dairy daily and eating one serving of fish a week do not imply more is better, it might be interpreted that way. A high dairy intake may not be associated with increased health risks [11], but this food group has a substantial environmental impact, as observed in **Chapters 2 and 5**. In addition, within the dairy category, cheese has a high salt and saturated fat content as well as the highest environmental impact. Therefore, rephrasing the recommendation on dairy to *'Eat two or three portions of dairy produce daily, preferably yoghurt or milk'* is suggested.

Table 7.1. Current and suggested Dutch guidelines when also considering sustainability.

	Current Dutch Healthy Diet guidelines [2]		Suggested additional or adapted components for the Dutch Healthy and Sustainable Diet guidelines
	Follow a dietary pattern that involves eating more plant-based and less animal-based foods.		Follow a dietary pattern that involves eating more plant-based and less animal-based foods to benefit health and the environment.
1.	Eat at least 200 grams of vegetables a day.		Consume at least 200 grams of vegetables and 200 grams of fruit a day, preferably selecting seasonal products.
2.	Eat at least 200 grams of fruit a day.		
3.	a. Eat at least 90 grams of wholegrain products a day. b. Replace refined cereal products by whole-grain products.		
4.	Eat legumes weekly.		
5.	Eat at least 15 grams of unsalted nuts a day.		
6.	Eat a few portions of dairy produce daily, including milk or yoghurt.		Eat two or three portions of dairy produce daily, preferably yoghurt or milk.
7.	Eat one serving of fish weekly, preferably oily fish.		Eat one serving of fish weekly, preferably oily fish with an MSC or ASC label.
8.	Drink three cups of black or green tea a day.		
9.	Replace butter, hard margarines, and cooking fats by soft margarines, liquid cooking fats, and vegetable oils.		
10.	Replace unfiltered coffee by filtered coffee.		
11.	Limit the consumption of red and especially processed meat.		Limit the consumption of red meat to a maximum of 300 grams per week and try to avoid the consumption of processed meat.
12.	Limit the consumption of sweetened beverages and fruit juices.		Replace sweetened beverages, fruit juice, and alcoholic drinks by black or green tea, coffee, and tap water.
13.	If alcohol is consumed at all, intake should be limited to one Dutch unit (10 gram ethanol) a day.		
14.	Limit consumption of table salt to 6 grams a day.		
		15.	Limit the consumption of poultry to a maximum of 100 grams per week.
		16.	Consume an amount of energy that is suited to achieve or maintain a healthy body weight.
		17.	Limit the consumption of processed foods such as cookies, cakes, and pizzas.

The largest increase in health gain can be achieved when shifting from 'no fish' to 'fish once per week', because there are little additional health benefits with higher consumption [2]. However, a higher than once per week consumption would negatively affect current fish stocks which are already under pressure [12]. The Dutch fish consumption is below the recommendation thus an increase to one portion a week would still increase the stress on fish stocks [13]. An increased use of farmed fish or fish that is currently discarded as by-catch can help maintain healthy fish stocks [13]. Similarly to the Swedish guidelines, sustainability labels used for fish consumption (MSC, ASC) could be included in the recommendations [6].

In addition to food choices, reducing energy intake can also have beneficial environmental impacts. Reducing energy intake in Western countries to get to an energy intake adequate to achieve or maintain a healthy body weight, will lead to less food consumed, lower environmental impact, and a lower incidence and prevalence of overweight and obesity [14]. In a French study, when caloric intake was reduced to meet the individual energy needs at normal body weight, the diet-associated GHG emissions would decrease between 2% and 11%, depending on the assumption made on the average physical activity level of the population [15]. In line with these results, in our cohort analyses, dietary GHG emissions were strongly associated with energy intake (**Chapters 2-5**). More than half of the men and 40% of the women in EPIC-NL had a body mass index above 25 kg/m^2 at baseline and could therefore be considered to be overweight or obese (**Chapter 3).** Consequently, mean energy intake should be reduced to obtain or maintain a healthy body weight. We suggest adding *'Consume an amount of energy that is suited to achieve or maintain a healthy body weight'* to the dietary recommendations.

Sugar-sweetened beverages and fruit juices contribute approximately 10% to daily energy consumption in the Netherlands [4]. While these drinks are addressed in the guidelines, rephrasing the recommendation to '*Replace sweetened beverages, fruit juice, and alcoholic drinks by black or green tea, coffee, and tap water*' would be healthier as well as more sustainable. Tea and coffee are included in the current guidelines because of their health effects and in addition, when compared to wine, beer, and sodas, they are associated with less GHG emissions as well. Within the beverages category tap water is both healthy and has the lowest environmental impact.

Little attention has been given to processed foods, such as cookies, cakes, and pizzas, in the healthy references diet or in the Dutch dietary guidelines [1, 2]. These foods are often high in salt, saturated fat, added sugar, and have limited nutritional value [16, 17]. Moreover, the processing steps of extracting ingredients, food preparation, packaging, and other factors create an additional environmental burden compared to unprocessed foods. In the Wheel of Five, the translation of the Dutch dietary guidelines for consumers, these foods are in the free space category of which a maximum of 3 portions per week may be consumed [3]. Although already implemented in the Wheel of Five, limiting the consumption of these types of foods is suggested to be added to an updated dietary guideline because of the combined health and environmental benefits of a reduced consumption of these foods. The Dutch government currently has an agreement with the food industry on reformulating processed foods so that they contain less salt, added sugar, and saturated fats [18]. In addition to reformulation based on nutrient content of foods, additional goals for reformulation towards lower environmental impact of these foods might be considered in the future as well.

Achieving dietary changes

Consumers often struggle to make healthy food choices [19-21]. Adding sustainability as another variable to consider will make it even more complex. In addition, the link between individuals' environmental concerns as citizens and their behaviour as consumers is found to be weak [22]. In order to help consumers make healthier and more sustainable food choices, governments could use different policy options to increase the knowledge or self-efficacy of consumers. Possible strategies for the government to mitigate our future consumption patterns are for example campaigns informing consumers about the health and environmental impacts of the diet, food labelling, or food pricing policies [23]. Aligning dietary guidelines, labels, or logos for health and sustainability will make the message clearer for consumers. Although often not very effective on their own, providing information and food labelling in combination with other policies, such as taxation or subsidy, could have added effects on dietary behaviours and public health [24-26]. Price policies are considered the most intrusive of all possible policy options but could be a powerful public health tool [27]. From interviews it appeared that Dutch consumers are in general positive about certain price interventions, especially when healthier foods would be made cheaper, but not when unhealthy foods are made more expensive [27].

Using the Social Cost-Benefit Analysis (SCBA) approach helped to identify which stakeholders benefit from a policy and which bear the costs (**Chapter 6**). Although both meat tax scenarios and the fruit and vegetables subsidy scenario show a net increase in total welfare for the Netherlands, the experienced costs and benefits differ for the stakeholders. In all scenarios, increased health and productivity (consumers) and decreased healthcare costs and labour participation (government) are benefits. However, in the tax scenarios, the consumers experience the increase in the price of meat as a loss in consumer surplus. Consumer surplus is the difference between the price that consumers want to pay for a product and the total amount that they actually pay. These losses in consumer surplus outweigh the consumers' benefits in health and productivity when expressed in Euros. In contrast, the fruit and vegetables subsidy is payed for by the government and these costs are higher than the expected benefits in healthcare costs and labour participation for the government.

Although not addressed in the current thesis, it has been reported that levying a CO_2-tax could result in substantial global environmental benefits (9% reduction in food related GHG emissions) as well as health gains (107,000 avoided deaths) by 2020 [28]. Similar results were found in two other modelling studies, one from the UK [29] and one from Denmark [30]. In order to compensate some of the potential side effects of such taxes, Springmann *et al.* recommended to exclude some healthy food groups such as fruits and vegetables from the taxation, selectively compensating lower socio-economic status (SES) groups for budget losses associated with tax-related price increases, or using a portion of tax revenues for health promotion [28].

Research limitations

Generalisability of cohort studies

The cohort-approach used in this PhD thesis to study long-term health effects of diets together with data on sustainability was new in the existing health and sustainable diets research. A disadvantage of using a cohort could be generalisability. The EPIC-NL cohort is not necessarily a representative sample of the current Dutch population. The cohort analyses (**Chapters 2-5**) are based on the observed food consumption in the EPIC-NL cohort sampled between 1993-1997 and in 2015. Although the observed diet-disease-environmental impact associations are likely translatable to the whole Dutch population, the reported absolute consumption of specific food items, such as fruit and vegetables, might not be generalizable because participants in cohort studies are often observed to be healthier than the average population (the healthy volunteer effect) [31, 32]. The estimated average dietary quality of the participants in the EPIC-NL cohort might therefore be higher than that of the general Dutch population. As a result, the average environmental impact of the Dutch diet will most likely be higher than observed in this thesis considering the decrease in dietary GHG emissions associated with higher dietary quality in our cohort. Therefore, the estimated reductions in GHG emissions and land use of the presented dietary changes in our thesis could be an underestimation of the changes in the total Dutch diet. Besides representability of the cohort population, the level of detail of the dietary assessment method can also limit the generalisability of the study. Nutritional surveys, like the Dutch National Food Consumption Survey, often provide more detailed information on food consumption at the population level when they are based on repeated 24-hour recalls in which information on all foods consumed during a specific day are collected [4]. This is in contrast to the estimated average long-term food (group) consumption assessed by the Food Frequency Questionnaires (FFQs) used in the EPIC-NL cohort. Although the total environmental impact was found to be slightly underestimated using FFQs compared to 24-hour recalls, findings from both methods show that dietary-related environmental impact was inversely associated with the DHD15-index score [33].

Environmental impact

The environmental impact analysis applied in this thesis is based on Life Cycle Analysis (LCA) data. These LCA data are based on the average Dutch food availability based on import/export and production data. Primary LCA data was available for 225 foods and beverages which combined cover 80% of the foods consumed in the Dutch National Food Consumption Survey [4]. Foods that were not covered were extrapolated from the primary LCA data. Extrapolations were done by an expert judgment panel of RIVM scientists, including a cross check of each other's extrapolations. Combined, this represented the average Dutch diets environmental impact.

The FFQs used in this thesis did not include information on production method or country of origin of foods. Therefore, we could only include the mean environmental impact of food items, for example an average tomato available in the Netherlands. However, tomatoes produced in UK glasshouses using fossil fuels can have GHG emissions five times higher than those field grown in Spain and transported by road to the UK [7]. The focus of this thesis was thus on food group level and less on specific food items. In addition, most of the work presented in this thesis used GHG emissions and land use of diet as primary indicators for environmental impact because of the lack of data for other indicators. This is consistent with most current research [15, 29, 34-36]. Following an update of the LCA data in 2018, we were able to include other impacts, including eutrophication and acidification in the Social Cost-Benefit Analysis (**Chapter 6**).

Future research

According to the definition of the Food and Agricultural Organization (FAO) a sustainable diet has a low environmental impact, which contributes to food and nutrition security and to healthy life for present and future generations [37]. In addition, sustainable diets are protective of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable, nutritionally adequate, safe and healthy, while at the same time optimizing natural and human resources. This thesis focused on GHG emissions and land use as indicators for a sustainable diet, but for most other indicators more research is needed to be able to include them in analyses like those presented here.

In addition, more insight is needed to combine and weigh up these different indicators especially when there are trade-offs between them.

Acceptable diets

Recommended diets should be socially acceptable in order to make the necessary changes feasible. In the 'healthy reference diet' by Willett *et al.* consumption of the recommended food groups are given with ranges to facilitate adaptations to make meals that are suitable for existing food cultures [1]. Nevertheless, as acknowledged by the authors, the required changes towards the 'healthy reference diet' are enormous: a greater than 50% reduction in the global consumption of red meat and sugar-rich foods, and a greater than 100% increase in the consumption of fruits, legumes, and nuts [1]. In this thesis, the data-driven dietary patterns derived in **Chapter 5** are examples of patterns that are currently present in the population, so these are assumed culturally acceptable patterns. However, the increase in healthiness as well as the decrease in environmental impact of these derived diets compared to the average observed diet was still rather limited. More research is needed to determine which additional dietary changes could further increase health and reduce environmental impacts and are still accepted by consumers.

In **Chapter 2**, several possible substitutions for meat replacements like fruits, vegetables, fish, and cheese were investigated to see which were healthier and more sustainable. Promising new foods that can add both health and sustainability to the diet, for example algae, insects, and cultured meat that have been suggested to replace meat as protein source, were not investigated. These foods were not included in the FFQ, because consumption of these foods was (and still is) very limited in the Netherlands. Data on the long-term health effects, acceptability, and nutrient bioavailability of algae and insect consumption are lacking in Western countries like the Netherlands [38]. Therefore, when considering new alternatives for meat, it is recommended for future research to focus on acceptability, bioavailability, but also digestibility (for example because of the exoskeleton of insects), and food safety [38, 39].

Affordable diets

Although not part of this thesis, a healthy and sustainable diet should also be affordable [37]. This is especially important for those with a low SES since they more often have unhealthy dietary habits as compared to higher SES groups [40-42]. One study found that small changes in the diet could have a large favourable impact on GHG emissions (-25%), without increasing costs [43]. In addition, several studies found that plant-based diets compared to animal-based diets are often more affordable [44, 45]. In contrast, higher adherence to the DASH diet was associated with lower GHG emissions but higher costs [46]. In a Dutch cohort, energy density of foods was found to be inversely associated with costs implying that healthier diets, which are often less energy dense, are more expensive [47]. A focus on healthy and more sustainable diets might therefore, in some cases, potentially further increase the health gap between low and high SES groups. Although not addressed in our SCBA (**Chapter 6**), most of the health benefits of lower meat consumption and higher fruits and vegetables consumption will likely be in the low SES group because of their on average higher consumption of meat and lower consumption of fruit and vegetables. However, because of their smaller budget an increase in the price of meat will be experienced as more restrictive for those with a low SES as compared to those in a higher SES group. Therefore, more research is needed to investigate potential win-win-wins for price-health-environmental impacts of food consumption. When designing guidelines and policies for a healthy and sustainable diet, governments should acknowledge affordability as an important factor. For example, a combination of a tax on unhealthy and unsustainable foods together with a subsidy on healthy and sustainable foods could help to keep diets affordable [28, 29]. Finding ways to identify future diets that are affordable is thus a remaining challenge for researchers and governments.

Nutritional quality

Another challenge of adapting diets towards sustainability is that these diets should still have a good nutritional quality. However, some low GHG emission diets (low in animal products) are found to be high in added sugar and low in essential micronutrients [48]. Similarly, in a French study by Vieux *et al.*, after adjustment for energy intake, diets of high nutritional quality had significantly higher GHG emissions (9% and 22% for men and women, respectively) than diets of low nutritional quality [49]. This is because nutrient-dense animal products, including meat and dairy, have high GHG emission values per 100 grams but much lower values per 100 kcal [50]. This is probably the reason why we did not observe any association between daily dietary GHG emissions and mortality in **Chapter 2**. Green *et al.* demonstrated that in the UK, a dietary shift away from snacks and animal products and towards more fruit, vegetables, and cereals would result in a 40% reduction of GHG emissions [51]. However, their model also showed that reductions beyond this point would potentially reduce the nutritional quality of the diet. Besides nutrient quality per se, plant-based foods have a lower bioavailability of some nutrients than animal-based foods. In a modelling study, decreasing the meat content was needed to achieve more sustainable diets that were still adequate in nutrients for French adults [52]. However, when they accounted for the lower nutrient bioavailability of plant-based foods with regards to iron, zinc, protein and pro-vitamin A, the estimated necessary meat reductions for a sustainable and nutritious diet were smaller. In a Dutch modelling study, when all meat and dairy consumption was replaced with plant-based foods the risk of inadequate micronutrient intakes for zinc, thiamine, vitamins A and B_{12}, and calcium increased compared to the reference scenario [53]. In another study, vitamin B_{12} and iron status were often too low in participants with a vegetarian diet and even more so for those with a vegan diet [54]. Therefore, when studying sustainable and healthy diets and when deriving recommendations, attention should be paid to nutritional adequacy as well.

Environmental impact indicators and data

This thesis, like many other studies, focused on GHG emissions and land use as indicators for a sustainable diet and the reason is data availability. However, the used Life Cycle Analysis (LCA) data often differs therefore making comparisons between studies difficult. The LCA method has several model choices and assumptions. In addition, availability of country-specific data is necessary to be able to estimate the enviromental impact of specific foods. When these types of data are missing, modelled data or data from similar countries is often used. Although LCA methodologies have been improved over time, further international standardisation could broaden the practical applications [55]. Besides the lack of uniformity of the LCA data, frequently the public availability of the data is limited. Frequently public disclosure of the data is not allowed, which is also the case for our LCA data. Open source methodology and databases would increase the transparency of the environmental impact data. In addition, it could help make data from different studies more comparable

Current dietary guidelines are only based on health aspects of the diet [5]. Besides the suggested recommendations in this thesis to add several sustainability-based guidelines, more research is needed on food specific differences in environmental impact. As mentioned before, the production method, way of transportation, and seasonality can affect the environmental impact of a specific food product [7]. Current dietary assessment methods, like the FFQ or 24-hr recall used in this thesis, do not include details on aspects like country of origin yet. Finding new methods to incorporate such differences into studies and communicate these food item specific differences in environmental impact in comprehensive ways to consumers remains a major challenge for the future [1]. Adding more environmental indicators, such as animal welfare and effects on biodiversity, can complicate the message of what sustainable foods are since weighing all these different indicators will be challenging, especially when the impact is low on one indicator but high on another. In addition, incorporating these different sustainability issues in one public health message will be difficult. For example, designing a logo that would aid consumers to make healthier food choices while taking into account all these different aspects of sustainability is still unexplored territory.

In addition to the necessity of adding a broader array of environmental impact indicators besides GHG emissions and land use, also country-specific impact should be considered. Many of the diet-derived environmental impact indicators, like GHG emissions are not confined to country borders, and importing food creates an environmental burden in other places as well [1, 56, 57]. Although some environmental impacts are not affecting the Netherlands, for example deforestation and loss of biodiversity in Brazil, they are partly caused by the Dutch food consumption demands. That is why, in addition to healthy diets, the concept of sustainable diets should also be considered from a global perspective [26].

True Cost

Taking pricing strategies one-step further than for example a 'simple' CO_2-tax or meat tax could be the True Cost approach. The production of food has several positive as well as negative impacts on society [58]. Examples of positive impacts are employment opportunities, knowledge development, and increased health whereas environmental impact, child labour, adverse health effects, animal welfare, and underpayment of producers or labourers are examples of negative impacts [58]. Including the negative health effects of red and processed meat consumption in the prices is estimated to increase the costs by 20% and 100% respectively in Western countries [59]. Based on data used in our SCBA (**Chapter 6**), the average price of meat should be €1.30 per kg higher to cover the associated GHG emissions and an additional €0.07 per kg for fruit and vegetables, based on the mean cost per kg CO_2-eq and mean GHG emissions. Including other impacts, such as animal welfare, would add even more costs. Getting insight in the true prices of foods and integrating them into the retail prices may be a potential future method to encourage healthier and more sustainable food production and consumption [60]. There are, however, still several challenges to tackle, one of which is to quantify and monetize all the different indicators in order to account for them in the final product price. More research is needed on how these true prices of foods will affect consumption levels and how these differences in consumption are changing the healthiness and sustainability of the total diet. As mentioned earlier, affordability of the diet will be of particular importance especially for those with a low SES to prevent further widening of the already existing health gap between low and high SES groups.

Overall thesis conclusions

The research described in this thesis investigated the link between environmental impacts of diets and health outcomes in order to gain more knowledge on ways to increase health and lower the environmental impact of the Dutch diet. The observed average diet in the EPIC-NL cannot be considered healthy or sustainable because of the low scores on the Dutch Healthy Diet index and high consumption of animal-based foods. We showed that a 35 gram per day shift in consumption from meat to plant-based foods or fish would significantly increase survival rates while also reducing dietary

GHG emissions and land use. In addition, over a 20-year period the observed increased consumption of some recommended foods, such as fish, nuts, and legumes, did not go together with a lower consumption of meat and therefore GHG emissions of the diet increased instead of decreased. This stresses the importance of substituting meat with healthy and sustainable foods rather than simply adding them to the current diet.

Even though the current Dutch dietary guidelines are designed from a health perspective, increased adherence to the current Dutch guidelines was found to be associated not only with decreased risk of all-cause mortality but also with lower GHG emissions. However, for similar scores on the DHD15-index we observed large variations in GHG emissions indicating that with similar healthy diets specific food choices can have a major impact on the environment. Furthermore, based on our research outcomes and existing evidence, we suggest several additions to and adaptations of the current Dutch dietary guidelines in order to define a healthy and more sustainable diet. Pricing strategies, such as the meat tax or fruit and vegetable subsidy presented in this thesis, could be used as a component of new policy measures aimed to increase the dietary quality and lower the environmental impact of the Dutch diet. Considering all these health and sustainability aspects in formulating guidelines, interventions, and policies will be challenging but the need for a future healthy and sustainable diet is urgently clear. Every small step will count and brings us towards a healthier and more sustainable diet.

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Summary

Unhealthy diets have been identified as one of the most important risk factors for non-communicable diseases in Western countries. In addition, food production systems also have a large impact on the environment. The Dutch Health Council has formulated guidelines for a healthy diet that benefit sustainability aspects via the recommended shift from an animal-based diet towards a plant-based diet. The recently proposed 'healthy reference diet' by Willett *et al.* is a healthy diet that can be consumed within the sustainability boundaries of our planet. However, such recommended diets are still far from what is currently consumed in the Netherlands. Therefore, this thesis takes currently consumed diets observed in a population-based Dutch cohort with 40,000 participants and 20 years of follow-up starting in 1993-1997 as starting point. This thesis provides insight into how healthiness of the diet may be increased while simultaneously lowering the environmental impact. The environmental impact of the diet was primarily assed using greenhouse gas (GHG) emissions and land use and health via mortality risk and dietary quality indicators.

Part I: Health and environmental impacts of observed Dutch diets

In order to study how sustainability of diets and health are linked, we prospectively studied the association between dietary environmental impact and mortality risk using the EPIC-NL cohort study (the Dutch contribution to the European Prospective Investigation into Cancer and Nutrition study). After adjustments for age, sex, and energy intake, diets with higher total GHG emissions or land use were not associated with the risk of all-cause and cause-specific mortality (**Chapter 2)**. However, in a modelling study we showed that replacing 35 grams per day of total meat consumption by several plant-based foods or fish would significantly increase survival rates by 4 to 19%, while also reducing dietary GHG emissions and land use by 4 to 12%. In **Chapter 3**, we studied how changes in dietary intake between 1993-1997 and 2015 in EPIC-NL affected health and environmental impact of the diet. During follow up, fish and chicken consumption increased but consumption of red and processed meat did not change. The observed changes resulted in a healthier diet, as measured by the Dutch Healthy Diet Index 2015 (DHD15-index). The average score was 12% higher at follow-up compared to baseline. However, after standardisation

for energy intake to account for a reduced energy intake with aging in the cohort, dietary GHG emissions increased by approximately 5% in men and did not change in women over these 20 years. The improved dietary quality was not yet accompanied by a lower environmental impact of the diet.

Part II: Health and environmental impacts of recommended dietary patterns

Better adherence to dietary guidelines from the World Health Organisation (WHO), and the Dutch Health Council (DHD15-index), and to the diet of the Dietary Approaches to Stop Hypertension (DASH) trial was associated with decreased mortality and reduced environmental impact (**Chapter 4**). In men, the largest difference in environmental impact was observed for higher scores on WHOs Healthy Diet Indicator. In men, the largest difference in environmental impact was observed for higher scores on the WHOs Healthy Diet Indicator (3.7% lower GHG emissions per standard deviation (SD) increase in the indicator with a 95% Confidence Interval (CI) of 3.4% to 4.0%). For women the largest differences in environmental impact were observed for the DHD15-index (2.0% lower GHG emissions per SD increase in the index, 95% CI: 1.9-2.2%). Of all indices, higher DHD15-index scores had the strongest association with all-cause mortality risk. The adjusted Hazard Ratio per SD was 0.88 (95% CI: 0.82-0.95) for men and 0.92 (95% CI: 0.88-0.96) for women. In **Chapter 5**, we investigated which dietary patterns were present in the EPIC-NL cohort that might be beneficial for both health and the environment. Two dietary patterns were identified, of which the first pattern was labelled "*Plant-based*" (high in consumption of fruits and vegetables, fish, legumes, and soy products) and the second as "*Dairy-based*" (high in consumption of cheese, low and high fat milk products, but also nuts and seeds). The diet of participants in the highest quartile of the "*Plant-based pattern*" had an 18% higher DHD15-index score and 3% lower GHG emissions compared to the average diet of the EPIC-NL participants. The diet of participants in the highest quartile of the "*Dairy-based pattern*" had a similar DHD15-index score as the average diet, but with a 12% higher environmental impact. The "*Plant-based pattern*" is thus an example of a dietary pattern with co-benefits for both health and the environment, while the "*Dairy-based pattern*" did not provide environmental and only marginal health benefits.

Part III: Societal effects of food pricing policies in the Netherlands

In **Chapter 6**, we studied the societal impact of introducing a meat tax (15 or 30%) or fruit and vegetables subsidy (10%) on health, environmental impact, tax incomes, consumer surplus, labor participation and productivity using the Social Cost-Benefit Analysis modelling technique. The timeframe of this analysis is 30 years (2018-2048). We showed that introducing a 15% or 30% tax on meat or a 10% subsidy on fruit and vegetables in the Netherlands could lead to dietary changes that reduce the incidence of several chronic diseases, such as type II diabetes, colorectal cancer, stroke, and lung cancer between 2018 and 2048. These health gains are associated with benefits such as an increased quality of life, lower healthcare costs, and higher productivity levels as compared to a reference 'as is' scenario. In terms of environmental impact (GHG emissions, land use, eutrophication, and acidification), we estimated a reduction in the meat tax scenarios and a small increase in the fruit and vegetables subsidy scenario. All modelled effects where then monetized to enable comparison of the overall costs and benefits of these policy scenarios. Overall, an increase in the price of meat could lead to a net societal benefit over a 30-year period of about €3,100-7,400 million for a 15% tax and about €4,100-12,300 million for a 30% tax. A 10% decrease in the price of fruit and vegetables could lead to a net societal benefit of about €1,800-3,300 million.

General Discussion

Finally, **Chapter 7** discusses the main findings of this thesis, the implications, and suggestions for future research. The current average diet in the EPIC-NL cohort can be considered neither healthy nor sustainable because of the low scores on the Dutch dietary quality index and the high consumption of animal-based foods. Based on our research outcomes and existing evidence, we suggest several potential additions to and adaptations of the current Dutch dietary guidelines in order to integrate sustainability aspects. Adding the importance of seasonality of fruit and vegetables, including a limit for poultry consumption in addition to the current advices on red and processed meats, and a recommendation to consume an amount of energy that is suited to achieve or maintain a healthy body weight are examples of such additions/adaptations. In addition to the observed diet-disease-environmental impact associations, the meat taxation or fruit and vegetables subsidy scenarios presented in this thesis, were shown to result in net benefits for the Dutch society when all costs and benefits were monetized.

According to the Food and Agriculture Organization (FAO), sustainable diets are diets that have low environmental impacts, contribute to food and nutrition security and to healthy life for present and future generations. In addition, sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable, nutritionally adequate, safe and healthy, while optimizing natural and human resources. This definition clearly goes beyond health and environmental aspects and includes economic and socio-cultural dimensions of the diet as well. This illustrates the complexity of the healthy and sustainable diet topic. This thesis covered some of these aspects of a healthy and sustainable diet, but considering all of them in future research, interventions, dietary guidelines, and policies will be challenging but necessary and urgent.

Samenvatting

In Westerse landen zijn ongezonde voedingspatronen een belangrijke risicofactor voor de ontwikkeling van chronische ziekten. Voedselproductiesystemen hebben daarnaast ook een aanzienlijke milieu-impact. De Gezondheidsraad heeft richtlijnen geformuleerd voor een gezond voedingspatroon. Dit voedingspatroon kan ook de milieu-impact beïnvloeden via de aanbevolen verandering van een voedingspatroon met veel dierlijke voedingsmiddelen naar een meer plantaardig voedingspatroon. Het recent voorgestelde 'healthy reference diet' van Willett en collega's is een gezond voedingspatroon dat past binnen de duurzaamheidsgrenzen van onze planeet. Dit soort geadviseerde voedingspatronen staan echter nog ver af van wat op dit moment wordt geconsumeerd in Nederland. In dit proefschrift wordt daarom de huidige voedselconsumptie als startpunt gebruikt door gegevens te gebruiken over het eetpatroon van 40.000 Nederlanders die vanaf 1993-1997 20 jaar gevolgd zijn. Ons onderzoek geeft meer inzicht in hoe het Nederlandse voedingspatroon gezonder kan worden en tegelijkertijd een lagere milieu-impact kan hebben. In dit onderzoek is de milieu-impact van het voedingspatroon voornamelijk bestudeerd via de indicatoren broeikasgasemissie en landgebruik en gezondheid via de indicatoren risico op sterfte en voedingsindexen.

Deel I: Gezondheid en milieueffecten van Nederlandse voedingspatronen

Om te bestuderen hoe de milieu-impact van voedingspatronen en gezondheid geassocieerd zijn, hebben we in **Hoofdstuk 2** prospectief gekeken naar het verband tussen de milieueffecten van voeding en het risico op sterfte in de EPIC-NL cohortstudie (de Nederlandse bijdrage aan de European Prospective Investigation into Cancer and Nutrition studie). Na correcties voor leeftijd, geslacht en energie-inname bleken voedingspatronen met een hogere totale broeikasgasemissie of landgebruik niet geassocieerd met het risico op sterfte en ook niet met oorzaak-specifieke sterfte. In een scenarioanalyse hebben we laten zien dat vervanging van de consumptie van 35 gram vlees per dag door een aantal plantaardige voedingsmiddelen of vis het sterfterisico zou verlagen met 4 tot 19%, terwijl ook broeikasgasemissies en landgebruik met 4 tot 12% zouden verminderen. In **Hoofdstuk 3** hebben we onderzocht hoe veranderingen in voedingspatronen tussen 1993-1997 en 2015 van invloed zijn geweest op de gezondheid en milieu-impact van de voeding. In 2015 bleek onder andere de consumptie van vis en kip te zijn toegenomen, maar de consumptie van rood vlees en bewerkt vlees was ongeveer gelijk. Dit resulteerde in een gezonder voedingspatroon, gemeten aan de hand van de Nederlandse index voor gezonde voeding 2015 (DHD15-index). Gemiddeld was de score 12% hoger in 2015 ten opzichte van de meting van 20 jaar eerder. Na correctie voor de lagere energie-inname die samenhangt met de veroudering van het cohort, steeg de broeikasgasemissie van het voedingspatroon met ongeveer 5% bij mannen en veranderde deze niet voor vrouwen gedurende de 20 jaar. De gezondheid van het voedingspatroon is dus wel verbeterd maar dit ging nog niet samen met een verminderde milieu-impact.

Deel II: Gezondheid en milieueffecten van aanbevolen voedingspatronen

Het volgen van de voedingsrichtlijnen van de Wereldgezondheidsorganisatie (WHO), de Nederlandse Gezondheidsraad (DHD15-index) of die van het Dietary Approaches to Stop Hypertension (DASH) onderzoek bleken geassocieerd te zijn met een lager sterfterisico en een verminderde milieu-impact (**Hoofdstuk 4**). Bij mannen werd het grootste verschil in milieueffecten waargenomen bij hoge scores op de WHO-indicator (3,7% lagere broeikasgasemissie per standaarddeviatie (SD) toename van de indicator, met een 95% betrouwbaarheidsinterval (BI) van 3,4% tot 4,0%). Voor vrouwen werden de grootste verschillen in milieu-impact waargenomen bij de DHD15-index (2,0%, lagere broeikasgasemissie per SD stijging van de score, 95% BI: 1,9-2,2%). Van alle scores had een hogere score op de DHD15-index de sterkste associatie met het sterfterisico (Hazard Ratio per 1 SD van 0,88, 95% BI: 0,82-0,95 voor mannen en 0,92, 95% BI: 0,88-0,96 voor vrouwen). In **Hoofdstuk 5** hebben we onderzocht welke voedingspatronen in het EPIC-NL-cohort aanwezig zijn die zowel gezond zijn als een lage milieu-impact hebben. Er werden twee voedingspatronen geïdentificeerd waarvan het eerste patroon het label "*Plantaardig*" kreeg (hoge consumptie van groente, fruit, vis, peulvruchten en sojaproducten). Het tweede patroon werd gelabeld als "*Zuivel*" (hoge consumptie van kaas, melkproducten met een laag en hoog vetgehalte, en ook noten en zaden). De voedingspatronen van deelnemers in het hoogste kwartiel van het "*Plantaardige*" patroon had een 18% hogere DHD15-indexscore en een 3% lagere broeikasgasemissie vergeleken met het gemiddelde voedingspatroon van de EPIC-NL deelnemers. Het voedingspatroon in het hoogste kwartiel van het "*Zuivel*" patroon had vergelijkbare DHD15-indexscores als het gemiddelde EPIC-NL voedingspatroon, maar met een hogere milieu-impact. Het "*Plantaardige*" patroon is dus een voorbeeld van een voedingspatroon met voordelen voor zowel gezondheid als het milieu, terwijl het "*Zuivel*" patroon op beide fronten geen (milieu) of nauwelijks (gezondheid) winst oplevert.

Deel III: Maatschappelijke effecten van voedselprijsbeleid in Nederland

In **Hoofdstuk 6** hebben we de maatschappelijke effecten bestudeerd van drie scenario's: een stijging van de vleesprijs door een belasting van 15% of 30% en een 10% lagere groente- en fruitprijs door middel van een subsidie. In de scenarioanalyses zijn onder ander de effecten op gezondheid, milieu-impact, belastinginkomsten, consumentensurplus, arbeidsparticipatie en productiviteit meegenomen door gebruik te maken van de Maatschappelijke Kosten en Baten Analysemethode. De tijdshorizon van deze analyse was 30 jaar, van 2018 tot 2048. Invoering van zowel de belastingen als de subsidie kan in Nederland leiden tot veranderingen in de voedselconsumptie die de incidentie van verschillende chronische ziekten, zoals diabetes type II, colorectale kanker, beroertes en longkanker verlaagt. Deze gezondheidswinst gaat gepaard met voordelen zoals een verhoogde kwaliteit van leven, lagere zorgkosten en hogere productiviteitsniveaus in vergelijking met een referentie 'alles gelijkblijvend'-scenario. In de vleesbelastingscenario's geeft minder vlees eten lagere milieueffecten dan het referentiescenario (minder broeikasgasemissie, landgebruik, eutrofiëring en verzuring). Meer groente en fruit eten (het subsidiescenario) levert een lichte stijging van de milieu-impact op. Alle gemodelleerde effecten werden vervolgens in geld uitgedrukt om de totale kosten en baten van deze beleidsscenario's te kunnen vergelijken. Zowel een stijging van de vleesprijs als een lagere groente- en fruitprijs leidt netto tot maatschappelijke baten over een periode van 30 jaar. Voor een 15% hogere vleesprijs is dit ongeveer €3.100-7.400 miljoen en voor een 30% hogere vleesprijs €4.100-12.300 miljoen. Een daling van de prijs van groente en fruit van 10% zou kunnen leiden tot netto maatschappelijk baten van ongeveer €1.800-3.300 miljoen.

Algemene discussie

Tot slot worden in **Hoofdstuk 7** de belangrijkste bevindingen van dit proefschrift, de implicaties hiervan en suggesties voor toekomstig onderzoek besproken. Gezien de lage scores op de Nederlandse voedingskwaliteitsindex en de hoge consumptie van dierlijke voedingsmiddelen kan het huidige gemiddelde voedingspatroon in het EPIC-NL cohort niet als erg gezond of met een lage milieu-impact worden bestempeld. Op basis van onze onderzoeksresultaten en aanvullende wetenschappelijke literatuur stellen we enkele mogelijke toevoegingen en aanpassingen voor van de huidige Nederlandse voedingsrichtlijnen om milieuaspecten beter hierin te integreren. Voorbeelden hiervan zijn het benadrukken van het belang van het eten van seizoensgroente en -fruit, een richtlijn die een limiet zet op de consumptie van gevogelte naast de al bestaande limiet voor rood en bewerkt vlees, en het advies om een hoeveelheid energie te consumeren die genoeg is om een gezond lichaamsgewicht te bereiken of te behouden. Naast de geobserveerde associaties tussen voeding, gezondheid en milieu-impact, bleken een vleesbelasting en groente en fruitsubsidie, zoals doorgerekend in dit proefschrift, te resulteren in netto baten voor de Nederlandse samenleving wanneer alle effecten in geld worden uitgedrukt.

Volgens de Voedsel- en Landbouworganisatie (FAO) heeft een duurzaam voedingspatroon geen nadelige gevolgen voor het milieu, draagt het bij aan voedselzekerheid en aan de gezondheid van huidige en toekomstige generaties. Daarnaast waarborgt een duurzaam voedingspatroon volgens de FAO ook biodiversiteit, is het cultureel aanvaardbaar, toegankelijk, economisch eerlijk en betaalbaar, qua voedingswaarde adequaat, veilig en gezond. Deze definitie van een duurzaam voedingspatroon gaat duidelijk verder dan gezondheids- en milieuaspecten en omvat ook economische en sociaal-culturele dimensies van het voedingspatroon. Dit toont de complexiteit van het onderwerp gezonde en duurzame voeding. Dit proefschrift heeft een aantal van deze dimensie bestudeerd. Het integreren van al deze aspecten rondom gezonde en duurzame voeding in toekomstig onderzoek, interventies, voedingsrichtlijnen en beleid zal niet eenvoudig zijn, maar is noodzakelijk en urgent.

Dankwoord

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Sander

About the author

Sander Biesbroek was born in Emmen, the Netherlands on December 20, 1988. He completed secondary school in 2007 at the Hondsrug College in Emmen. He then started the Bachelor education Nutrition and Health at Wageningen University. He completed his Bachelor's degree in 2010. From 2010 until 2011, he was chair of the board of the student association Navigators (NSW). In 2011, he started his Master education in Nutrition and Health with a major in Epidemiology and Public Health at Wageningen University, which he completed in 2013.

During his internship in 2013 at the Dutch National Institute for Public Health and the Environment (RIVM) Sander developed an interest in the combination of healthy and sustainable diets. After he graduated, Sander started as junior researcher at the RIVM and worked on several projects related to dietary patterns and cardiovascular health. During this time, Liesbeth Temme and Sander wrote a RIVM research proposal to get funding for a PhD project about healthy and sustainable foods. After this proposal was granted he could officially start his PhD at the RIVM, in collaboration with the Julius Center for Health and Primary Care of the University Medical Center Utrecht.

Sander completed his thesis under the supervision of prof.dr. W.M. Monique Verschuren (RIVM and Julius Center), dr.ir. Liesbeth H.M. Temme (RIVM) and dr.ir. Jolanda M.A. Boer (RIVM). During his PhD project Sander followed several courses to further expand his knowledge on nutrition, environmental impact, and epidemiology. Sander joined the PhD program Epidemiology of Utrecht University. He was also involved in the development of the Massive Open Online Course (MOOC) "Unravelling solutions for Future Food problems" from Utrecht University and was involved in the supervision of several MSc students.

After completion of this PhD thesis, Sander will continue his work in the field of healthy and sustainable diets as postdoctoral researcher at the Human Nutrition and Health division of Wageningen University.

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Marlin J Broeks[a], **Sander Biesbroek[a]**, Eelco AB Over, Paul F van Gils, Ido Toxopeus, Marja H Beukers, Elisabeth HM Temme. A Social Cost-Benefit Analysis of policies for a healthier and more sustainable food consumption in the Netherlands: meat taxation and a fruit & vegetables subsidy. a: Authors contributed equally to this manuscript. *Submitted*.