Modelleringsonderzoek naar gezondheid en milieuimpact van voedingspatronen

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1 Introduction

A great deal of modelling research is conducted into the health and environmental impact of diets. Modelling research deals with theoretical shifts in diets, making it possible to examine more significant or other shifts than those based on the actual variation in consumption within the population.

There are two relevant types of modelling studies.

First, there are substitution studies, in which the aim often is to evaluate nutritional outcomes of predefined diets, such as the amounts of nutrients provided by these diets. The predefined diets may, for example, be recommended diets or diets that include less meat. Analyses can be performed using data from individuals, although this is not a required element.

Second, there are optimisation studies, in which the aim is to model an ‘optimal’ diet based on a predetermined set of conditions. The term ‘optimal’ may refer to the lowest possible environmental impact, optimal health impact, maximum affordability, or various combinations of the foregoing. In order to prevent outcomes from being too far away from the current diet, feasibility is often added as a precondition to the model. If there are too many conditions or conditions are overly stringent, the model may not find a ‘solution’. Environmental impact is often calculated using greenhouse gas emissions or other environmental indicators such as land and water use. Dietary reference values (DRV), and specifically the population reference intakes (PRI) or adequate Intakes (AI), are often included as requirements with regard to health, occasionally including dietary guidelines, such as the Dutch Dietary Guidelines 2015 (Richtlijnen goede voeding 2015). In the case of energy, however, the estimated average requirement (EAR) is used as DRV. If not, the recommendations would lead to weight gain. In the context of optimisation models, ‘critical nutrients’ are the nutrients that determine the outcomes of the models, that is, the nutrients that are the first to no longer reach the level of the DRV if the conditions of the model are met.

Dietary reference values in modelling studies

In order to assess the adequacy of a nutrient for a population, the average (modelled) intake must compared to the average requirement (Estimated Average Requirement, EAR). In practice, however, studies often carry out comparison with the Population Reference Intake (PRI) or Adequate Intake (AI). These are the intake levels that meet the requirement for almost the entire population. These levels are (by definition) significantly higher than the average requirement. The committee notes that the average nutrient intakes of a population at the level of the PRI or AI mean that intakes for most people would (by definition) be much higher than necessary, in which case the intake at population level is (more than) sufficient.

2 Methods

For the purposes of this advisory report, the committee made an overview of peer-reviewed Dutch modelling studies into the health aspects and environmental aspects of the the protein transition,[1-12] meaning studies that focus on source of protein in the diet and which report on relevant theoretical shifts and how this impacts the supply of nutrients. The committee restricted the overview to mainly Dutch studies, in order to be able to address the situation in the Netherlands as accurately as possible.

Studies specifically addressing the shift from a diet containing 40% vegetable protein to a diet of 60% vegetable protein were (virtually) not available. The committee has therefore had additional calculations carried out into the effects on the nutritional value and environmental impact of such a shift. This relates to a study into the shift from the 'current' diet for Dutch adults aged between 18 to 79 years with an average of 60% animal and 40% vegetable protein to a diet of 60% vegetable protein and 40% animal protein. This modelling study was carried out using the SHARP optimisation model based on intake data from the 2012-2016 Dutch National Food Consumption Survey (Voedselconsumptiepeiling, VCP).[13] For a detailed outline please see the report [in Dutch] 'Het effect van een verschuiving naar een inname van 40% plantaardig eiwit op de gezondheid van het voedingspatroon' (Impact of a shift from 40 to 60% vegetable protein intake on dietary health').

With regard to Dutch research, the committee has hence based its review on the following types of studies:

- Optimisation studies on the shift from 40:60 to 60:40 based on the SHARP model;
- Optimisation studies on healthy diets with the lowest possible environmental impact;
- Substitution studies on the health and environmental impact of predefined diets.

3 Results

Dutch modelling studies have primarily been based on data from the Dutch National Food Consumption Survey (VCP) and the studies are generally based on adults and occasionally on children[2,11] or the elderly[14] in the general population of the Netherlands. The VCP does not include pregnant or lactating women.

3.1 Optimisation study based on SHARP model

The SHARP optimisation models that were carried out for the purpose of the advisory report stipulated that the dietary patterns had to meet a percentage of vegetable protein of 60%. In the current diet, based on the VCP 2012-2016, this percentage was on average 40%. Three scenarios were used for the amount of protein in the diet. The first scenario is one in which no requirements for protein were included, whereas in the second and third scenarios protein intake was not allowed to exceed the average protein requirement (EAR) and the PRI for protein respectively. The calculation using the average requirement follows the population approach (the amount of protein that is sufficient on average) and the PRI follows the individual recommendation approach (the amount of protein that is sufficient for almost everyone within the population, based on the premise that an individual is not aware of his or her individual requirement). Given that individuals prefer the products they already eat, the model ideally chooses shifts that are as similar as possible to what is already in the diet. In order to ensure that the diet is or remains as healthy as possible, constraints were applied for the health of the diet based on the Dutch Healthy Diet (DHD) index, which in turn is based on the Dutch Dietary Guidelines 2015.[15] The intakes of nutrients other than protein were included as an outcome.

If protein and therefore dietary sources of protein are more strictly limited, it may be more difficult to meet certain guidelines (and/or dietary reference values). This turned out to be the case, given that the model was unable to achieve a 'solution' for part of the dataset when protein was restricted to the average requirement. In addition, the DHD-index appeared to be lower for this stricter protein requirement. The Committee therefore disregarded the calculations focused on the EAR of protein.

Results on environmental impact

All scenarios involving the shift to 40% animal and 60% vegetable protein resulted in lower greenhouse gas emissions, with the scenario with the lowest protein intake resulting in the greatest reduction in greenhouse gas emissions. The shift to a healthier diet (within a diet consisting of 40% animal and 60% vegetable protein) showed a relatively minor increase in greenhouse gas emissions.

Results on foods and dietary patterns
The shift to 40% animal and 60% vegetable protein leads to a healthier diet (a higher DHD-index), even in the scenario where the amount of protein is not restricted and no lower thresholds have been fixed for the DHD-index.

The increases and decreases in consumption of food groups reflect the components of the DHD-index and the extent to which the current diet relates to them. Compared to the current diet, the consumption of vegetables, fruit, cereals, coffee, tea and dairy (except cheese) increased and that of other (sugar sweetened) beverages, meat, cheese and eggs decreased. Fish consumption also initially decreased, but increased again with stricter DHD-requirements.

Results on protein
The results for nutrients are presented per 2000 kilocalories (kcal) based on group averages (without dispersion measures). It was not possible to conduct statistical testing on the figures or to present them as a percentage of people below the average requirement. In the current diet, protein intake is on average 78 grams/2000 kcal/day. Following optimisation without restrictions on protein, protein intake was 68 grams/day. When protein was restricted to the recommended amount, intake was 53 grams/day.

Protein supply was evaluated based on the method described in Heerschop et al., 2023[6] in which both the amount and quality of protein are taken into account. This was initially calculated within meals and subsequently calculated across the entire day. The results are based on a descriptive analysis based on the actual intakes in the VCP, hence not based on modelling and restrictions. In general, protein supply decreased as a higher percentage of vegetable protein was consumed, meaning an increase in the percentage of people at risk of a protein deficiency.

Results on other nutrients
The percentage of saturated fat in the diets modelled decreased slightly in each scenario compared to the current diet, however, on average the percentages remained slightly above ten energy percentage. Fish fatty acids decreased, as did fish, but increased again in scenarios with stricter DHD-requirements. The stricter the restriction on protein, the smaller the increase. Fibre intake increased as a result of the shift to more vegetable protein, but increased less and less as a protein restriction became more stringent. Calcium intakes decreased, with sharper decreases accompanying

more stringent protein restriction. When restrictions of protein were applied, average intakes were generally below the average calcium requirement; average intake was above the EAR if protein was not restricted. Total iron intake increased for the scenario without protein restriction (from 10 to 11 mg/2000kcal/day) and decreased slightly when protein was restricted to the recommended amount of protein compared to the current diet. It is relevant in this case that the increase primarily will relate to non-haem iron. Sodium incorporated into foods decreased compared to the current dietary pattern in all models and decreased even more as stricter requirements were applied for the DHD-index and total protein intake. Potassium intake, however, likewise decreased. Vitamin B12 intakes decreased, in particular with stricter restrictions on total protein intake, however, the average values remained at or above the level of the modelling conducted by Seves et al.,[3] which concluded that there were no problems in the supply of vitamin B12.

3.2 Other Dutch optimisation studies

In this section the committee outlines findings from peer-reviewed optimisation studies carried out in the Netherlands. Please see Table 1 for the overview of study characteristics.

Table 1 Characteristics of nutritional and environmental impact of Dutch diets based on optimisation models

Study	Aim, comparison	Design/method	Study population	Environmental impact	Dietary factors	Feasibility
Brink 2019[9]	Healthy and sustainable diet (week menus with recommended amounts of foods)	**Optimeal (quadratic programming)**	Adults and children from 1y onwards	Constraints: Upper limit for amounts of foods with a high environmental impact (meat, red meat, dairy, eggs, fish)	Constraints: Nutrients: PRI/AI/UL, 85% energy from foods in Wheel of Five Foods: DDG2015 Outcome: ratio animal to plant protein	As close as possible to the current diet (DNFCS)
Kramer 2017[11]	Healthy and sustainable diet - compared to the *current* diet (DNFCS 2007-2010); 207 of the 1599 food items	**Optimeal (linear programming)**	Adults and children, n=3819 m/f 9-69y Individual data	Optimised for composite measure of GHGE, FEU, LO (ReCiPe) on the basis of LCA	Constraints: Nutrients: PRI/AI/UL Including energy and amino acids (lysine) Outcome: Nutrient Adequacy: 'critical nutrients': nutrient at or outside set boundaries (PRI/AI/UL)	As close as possible to the current diet based on a 'penalty score'
Broekema 2020[16]	Healthy and sustainable diet DNFCS 2007-2010; 207 of the 1599 food items	**Optimeal (12 scenarios)**	N=699 m/f 31-50y Individual data	Optimised for GHGE (FEU, LO only descriptive) based on LCA. GHGE targets in relation to temperature increase of 1.5°C	Constraints: Nutrients: PRI/AI/UL Isocaloric model Outcomes: Food intake: food groups Nutrient adequacy: Comparison average intake to PRI/AI Ratio of animal to plant protein	As close as possible to the current diet
Grasso 2021[14]	Increase of protein with the lowest possible environmental impact - relative to *healthy* diet LASA FFQ; 354 items	**Optimisation (Optimeal), quadratic programming**	Older adults 56-101y, n=1354 Individual data	Optimised for GHGE (FEU, LO only descriptive) based on LCA	Constraints: Nutrients: PRI/AI, UL Foods: DDG2015 Isocaloric model Outcome: increases and decreases of food groups Amino acid intake Ratio animal to plant protein	Restriction to the 95th percentile of the intake of the population (stratified for sex)

Study	Aim, comparison	Design/method	Study population	Environmental impact	Dietary factors	Feasibility
Heerschop 2023[6]	Protein quality of feasible diet optimised for health (DHD-index) and GHGE.	**Optimisation (SHARP**)- benchmark modelling, i.e. optimisation based on variation present in the data set	Adults: 18-50y and 50-79y Individual data	Constraint GHGE (LCA)	Optimised for: DHD-index 2015 Outcomes: 'utilisable protein' based on protein quality (PDCAAS) per meal (summed over the day) intakes of iron, calcium, B12, and % protein, ratio plant to animal protein (per 2000 kcal, in quartiles of meat intake)	Constraint: dietary change within 33% of current consumption (on the level of each individual) or no constraint on feasibility

Abbreviations: AI: adequate intake, DDG: Dutch Dietary Guidelines, DHD index: Dutch Healthy Diet index, DNFCS: Dutch National Food Consumption Survey, FEU: fossil energy use, FFQ: food frequency questionnaire, GHGE: greenhouse gas emission, LASA: Longitudinal Aging Study Amsterdam, LCA: life cycle analysis, LO: land occupation, PDCAAS: protein digestibility-corrected amino acid score, PRI: population reference intake, UL: upper level

3.2.1 Outline of Dutch peer-reviewed studies based on optimisation models

Van Dooren et al. 2016[17]

Van Dooren et al. (2016)[17] defined a nutritionally healthy, environmentally friendly and culturally acceptable Low Lands Diet, based on the historical Dutch diet of 75 years ago. This 'Low Lands Diet' (based on data of adult males only) was compared to the present Dutch diet, Mediterranean diet and New Nordic Diet. Optimisations were performed with Optimeal® (Blonk Consultants). This study was an exercise to demonstrate the method of linear programming and hence this study is not further described.

Van Dooren et al. 2015[10]

In another paper by Van Dooren et al. (2015)[10] linear programming (Optimeal®) was used to define nutritionally adequate diets optimised for climate impact (greenhouse gas emission (GHGE), land use, energy use) and costs with consecutive additional constraints on nutrients, GHGE and costs. For men and women the model resulted in amounts of calcium, zinc, retinol activity equivalents, vitamin B1 and vitamin B12 of the optimised diet that were at or close to the amounts minimally required by the model. This was also the case for n-3 fish fatty acids, but the lower limit for intake was set at 450 mg/d whereas the adequate intake in the Netherlands currently is 200 mg/d.[18,19] For women, iron was at the lower end of the model requirement and for men this was the case for vitamin C and selenium. No information was provided on protein quality, amino acids or the ratio of animal to plant protein. Nutrient constraints (minimal intake as required by the model) were based on population reference intakes (PRI) or adequate intakes (AI).

Kramer et al. 2017[11]

Kramer et al. (2017)[11] used food consumption data of Dutch children and adults of 9-69 years of age from the National Food Consumption Survey 2007-2010 to optimise diets for nutrition and environmental impact, while minimising the distance from the current diet, in order to identify the most effective and acceptable options for mitigating environmental impact.[11] The publication focused on adults. Results on children were presented in the appendix, with similar results as for adults according to the authors. Optimisations were performed based on Optimeal®. The study was sponsored by Friesland Campina.

Energy and nutrient requirements were used as constraints in the model. The lower limits of the nutritional requirements were based on the PRI or, if that measure was not available, the AI. If tolerable upper intake levels were applicable, those were used as upper limits. The (average) requirements of the World Health Organization and the Food and Agricultural Organization (WHO/FAO) (2007) were used as requirements for essential amino acids, based on the average body weight of the population sample.

GHGE, fossil energy use (FEU) and land occupation (LO) were used as environmental indicators (ReCipe method). In total, 207 out of the 1599 products consumed in the Dutch National Food Consumption Survey (DNFCS) were included. This selection represented 77% of the consumed weight and 56% of the energy intake.

The first solution of the optimisation only included the nutritional constraints. After that, environmental constraints were added, step by step, until no solution was possible within the constraints. The distance between diets was expressed by a penalty score. The ‘critical point’ was defined as the point where a diet becomes less acceptable (where the penalty curve moves from inelastic to elastic; beyond this point savings in environmental impact require proportionally more changes to the diet and/or the addition of less popular products).

Results on environmental impact:
The ‘critical point’ occurred between a 21 and 30% reduction of environmental impact, depending on gender and age.

Results on foods and dietary patterns:
In all scenarios, the amount of meat was reduced, the amount of vegetables, fruit, dairy remained the same, and the amounts of bread, fatty fish, legumes increased compared to the current diet. Less meat, especially beef, appeared most effective in reducing environmental impact. In addition, the reduction of alcoholic and non-alcoholic drinks was effective. Reducing dairy and fish was not. If at the same time saturated fatty acids (SFA) have to decrease and calcium has to increase, cheese will be preferred by the model compared to (red) meat. If iron has to increase, (red) meat will be preferred compared to cheese.

Results on nutrients
For the following nutrients, the mean intakes of the current diet were below the PRIs or AIs or above the upper limit for all adults: SFA, alpha-linolenic acid (ALA), dietary fibre, and fish fatty acids (EPA+DHA). Critical nutrients in the modelled diets were those outside of the boundaries set for nutrient requirements of the current diet, or those that were exactly at one of the boundaries after modelling. For women of 31-50 years of age, the mean iron intake was below the PRI for the current diet and iron became a critical nutrient for all women for the optimised diets. For women of 51-69 years of age the mean calcium intake was below the AI for the current diet and calcium became a critical nutrient for all women as well as men for the optimised diets. Protein and essential amino acids were not critical in any of the scenarios. No information was provided on protein quality.

Kramer et al. 2018[12]
Kramer et al. (2018)[12] modelled diets to quantify environmental impact and nutritional value of decreases and increases of bread and breakfast cereals, dairy, and meat (from 0% to 250% of the current diet (based on individual data of the DNFCS 2007-2010). The main focus of the study was on environmental impact of these three food groups. Nutritional value was captured in composite measures (the concept of nutrient balance). The study, based on the Optimeal® program, did not provide detailed information on individual nutrients, hence the results are not described further. The study was sponsored by members of the HealthGrain Forum, Nestlé, Cereal Partners Worldwide, Fazer, and GoodMills Innovation.

Brink et al. 2019[9]
The Netherlands Nutrition Centre (Brink et al. 2019) derived healthy and sustainable food-based dietary guidelines (FBDG) based on dietary reference values (DRV) and the Dutch Dietary Guidelines 2015 of the Health Council of the Netherlands for Dutch people of different ages, genders, activity levels, and food preferences. Recommendations were visualised in the Wheel of Five. This research was funded by the Dutch Ministry of Health.

Optimisation was performed with calculations based on Optimeal® and expert judgement. Constraints were set for food groups based on health effects as described by the Dutch Dietary Guidelines 2015. As constraints to the modelling, upper limits for intake were based on feasibility reasons (nuts and legumes), on increased disease risk (eggs and red meat), or on environmental aspects. Regarding environmental aspects, maximum levels were set at the 50th percentile of the current consumption of meat and red meat with a max of 500 g/week, the 75th percentile of current consumption of dairy, the current consumption of eggs and a maximum of one portion of fish per week. Food groups for which the Health Council of the Netherlands recommends that their consumption be substantially limited or as low as possible were excluded entirely (processed meat, sugary beverages). Foods that contain too much SFA, trans fatty acids, sugar or salt, or too little dietary fibre, based on food-group specific criteria, were also excluded from the Wheel of Five. Minimum and maximum constraints for nutrients and energy were based on the Dutch DRV. To derive food-based dietary guidelines, the Dutch dietary guidelines, the dietary reference values and the current Dutch consumption pattern were taken into account in an optimisation model and combined with expert judgement.

Results on environmental impact
The results on environmental impact have been described in the study of Van de Kamp et al. (2018).[7]

Results on foods and dietary patterns
The optimised diet was the closest to the current diet. As a constraint, the recommended amounts of foods in the Wheel of Five together had to deliver 100% of the essential nutrients. This could be realised when 85% of the total energy (EAR) of inactive persons was provided by foods in the Wheel of Five. Diets including week menus were derived for an omnivorous diet, a vegetarian diet including fish, and non-Western diets.

Results on protein and other macronutrients
Diets were composed in such a way that all PRIs were met. No information was provided on amino acids or protein quality. In a later analysis it was shown that the ratio of animal to plant protein was 50:50.[20]

Results on micronutrients
Diets were composed in such a way that all PRIs were supposed to be met. However, for children of some age groups, it was not possible for the model to meet all constraints for essential nutrients within the constraints for energy. This included vitamin A (boys: 14-18y), calcium (9-13y), iron (boys: 1-13y; girls 1-18y), potassium (1-3y), zinc (1-3y), alpha-linolenic acid (boys: 4-8y).

Broekema et al. 2020[16]
Broekema et al. (2020)[16] used individual data of Dutch adults from the DNFCS 2007-2010 to model diets that optimally satisfied nutritional requirements while remaining below GHGE targets (three different thresholds with regard to the years 2030 and 2050 and a less strict threshold) and with minimised deviations from the baseline (current) diet.[16]

In addition, isocaloric scenarios were modelled using five diets. The initial scenario was based on the nutrient ranges, the 2030 GHGE restrictions and the Dutch Dietary Guidelines 2015. Four specific diets were modelled by including additional restrictions: a flexitarian diet (35 g meat/day; 50% of the amount recommended by the Netherlands Nutrition Centre,[9] a pescatarian diet, without any meat, a (lacto-ovo) vegetarian diet, without any meat or fish and shellfish, and a vegan diet.

Authors reported financial support from Danone Nutricia Research, the Royal Tropical Institute and Blonk Consultants, outside the current publication.

The GHGE targets were derived from the Intergovernmental Panel on Climate Change (IPCC) 1.5-degree assessment study. The lower limits of the nutritional requirements were based on the PRIs or, if not available, the AIs. If tolerable upper intake levels were applicable, those were used as upper limits. The Netherlands, in agreement with the European Food Safety Authority (EFSA), did not derive dietary reference values for individual amino acids. Average requirements for amino acids from the WHO 2007[21] were used instead.

Results on nutrients
Diets were modelled in such a way that all PRIs or AIs were met. Regarding the observed diet (DNFCS), the average intake of several nutrients was (still) outside the boundaries set for the optimisations (energy, saturated fatty acids, sodium were higher and alpha-linolenic acid, fibre, EPA-DHA, thiamine (vitamin B1), riboflavin (vitamin B2), folate, iron, selenium were lower).

Lacto-ovo vegetarian and vegan scenarios did not meet the EPA and DHA requirements, due to low fish intake. The vegan scenario only met vitamin B12 and calcium requirements through high consumption of fortified soy milk (>500 g/day).

Supplemental data show that for all scenarios the percentage of animal to total protein was lower than for the current diet. The animal to plant protein ratio was 55:45 for the scenario of only complying with the nutrient thresholds without GHGE restrictions, and 34:66 for the scenario of additionally complying to the 2030 GHGE restrictions and the Dutch Dietary Guidelines 2015. To compare, the ratios were 35:65 for the 2030 GHGE scenario (without Dutch Dietary Guidelines 2015) and 18:82 for the 2050 GHGE scenario (without Dutch Dietary Guidelines 2015). Information on protein quality was not available.

The Committee notes (although not clearly explained by the authors) that the lower limits of protein and the amino acids were at the level of average requirements, whereas the lower limits for the other nutrients were at the (higher) levels of PRI or AI. The Committee also notes a few unexpected findings. Firstly, the model resulted in an increased intake of EPA and DHA of 160 in the current observed diet to 1000 mg/day in the modelled diet (which is about 50 g of fish per day). Of note, the AI of EPA and DHA is 200 mg/d. Secondly, the modelled vegan diet contained a level of 12% of animal protein.

Results on environmental impact
The modelling was based on meeting 2030 and 2050 GHGE goals in relation to global warming. The authors conclude that to meet 2030 and 2050 GHGE targets large shifts in diets might be needed and the feasibility of those changes may be limited.

Results on foods and food patterns
The authors mention that none of the optimised diets contained beef, except for the scenario in which a maximum was set for dietary changes (33-150% to baseline amounts) (14 g/d) and the scenario in which the coproduction of dairy and beef was considered (8 g/d).

Grasso et al. 2021[14]
Grasso et al. (2021)[14] used individual data from 1,354 Dutch older adults (56-101 years of age) from the Longitudinal Aging Study Amsterdam (LASA) cohort. Optimisation modelling (Optimeal®) was used to isocalorically model high-protein diets (1.2 mg/kg body weight per day) with minimised departure from habitual intake. This study was financially supported by the European Commission (Horizon 2020).

In the first modelling step, nutritional adequacy had to be maintained or improved based on nutrient or food boundaries. If the average intake of the study population was higher than the PRI or AI, the PRI or AI was used as the lower boundary, otherwise the mean habitual intake was used. In the second step, additionally the compliance with the Dutch dietary recommendations was modelled regarding vegetables, fruit, whole grains, nuts, fish, meat and red meat (based on the Dutch Dietary Guidelines). Maximum amounts of meat and red meat were derived from the Food Based Dietary Guidelines of the Netherlands Nutrition Centre. In the next steps, the diets were further modelled for increasingly stringent reductions of GHGEs in steps of 10% reductions. To attain realistic dietary changes, food item quantities were constrained to an upper limit equal to the 95th percentile of the habitual intakes. The lower limit of fats/oils was set at the 5th percentile to prevent the removal of fats and oils from the diet.

Results on food groups
A high-protein diet in accordance with nutrient and food recommendations implied a higher consumption of vegetables, fruits (men only), cheese, eggs, nuts, and meat and dairy alternatives, and a decrease in meat (men only) and fish. Achieving this diet while meeting the Dutch and European GHGE reduction goal of 50% did not induce substantial changes in total meat from the limit of 500 g/d (it reduced to 482 g/d for women) but required the removal of beef and lamb from the diet as well as a reduction of processed meat and pork and an increase in poultry for both sexes. While the

quantity of cheese hardly changed for men (4% above habitual intake), it needed to be reduced by 36% below habitual intake for women. No upper limit was set for total dairy. For both sexes, moderate increases in whole grains (20–30%) and legumes (14%) and substantial increases in nuts (250–310%) and meat/dairy alternatives (190–250%) were needed, as well as substantial reductions in fats/oils (70–80%), dressings/sauces (30–40%), and sweets (60–70%) for both sexes.

Protein and other macronutrients
A high-protein diet in accordance with nutrient and food recommendations resulted in a decrease of total fat, saturated fatty acids, calcium, and an increase in polyunsaturated fatty acids, carbohydrates, fibre, folate, vitamin C, iron, and dry matter.

Compared to the high-protein diet in accordance with nutrient and food recommendations (including the limit of 500 gram meat per day), the animal to plant-based protein ratio (55:45) only slightly decreased according to increasing steps of GHGE reduction. When a >50% reduction of GHGE was modelled, the ratio was 49:51. Of note, these numbers need to be interpreted from the target of a high-protein diet (1.2 g/kg/d compared to the PRI of 0.83 g/kg/d) and an upper limit for meat.

The nine essential amino acids (based on the USDA food composition database) were used as a proxy for protein quality. As a consequence of the increase in total protein, the amounts of amino acids of the diets increased. From a GHGE reduction of 50% onwards, lysine content was lower than in the habitual diet, followed by methionine, leucine and histidine (60% reduction of GHGE), and leucine, isoleucine, threonine and valine (70% reduction of GHGE)

Heerschop et al. 2023[6]
Heerschop et al. (2023)[6] evaluated the protein adequacy of diets optimised for health and diet-related GHGE. Individual data were used from the DNFCS 2012-2016 of 4313 men and women between 18-50 and 50-79 years of age (in four strata). Optimised diets were derived as linear combinations of current diets that minimised GHGE and maximised the Dutch Healthy Diet 2015 score (based on the DDG2015,[22]) without acceptability constraints ('healthiest diets') or with acceptability constraints ('realistic diets') to keep dietary change within 33% of current consumption. This study was based on benchmark modelling; the SHARP model aims to calculate for each individual diet in the population a set of alternative diets of peers that are at least as healthy as the current diet.[23] This study was financially supported by the Dutch Dairy Association.

Protein adequacy was evaluated as the combination of quantity and quality of protein. The calculations of intake were based on consumption occasion (meals) from the perspective that amino acids that are limited in a certain product should be compensated by other protein sources consumed within a short time period. Protein adequacy was evaluated as 'metabolisable protein' in relation to the requirements. The PDCAAS was calculated for each meal and multiplied by the total amount of ingested protein in the meal. Data on amino acids were derived from the Danish (Frida), American (USDA), English (Mccance and Widdowson) and the Japanese food composition databases.

Results on environmental impact
In all four age and gender strata, the healthiest diets had higher GHGE; GHGE increased when diets scored higher on the DHD15 index. The most sustainable diets had lowest dietary quality (DHD15 index) but higher than current diets. When the health score was optimised without restrictions of GHGE, GHGE increased compared to the reference diet with 4.5% (realistic diets) and 4.8% (healthiest diets). When increasingly stricter criteria for GHGE were applied, the DHD15 remained high until 75% of one's maximal GHGE reduction was realised. The reduction of GHGE was -11.6% (realistic diets) and -32.6% (healthiest diets). The authors concluded that this diet, when limiting dietary change to 33% of one's current consumption, was the most promising trade-off leading to a reduction of GHGE by 12-16% compared to the current diet.

Results on foods and food groups
The maximum DHD15 score of the realistic diets was 103 (out of 140), whereas the healthiest diets could reach 140, yet only for the situation without GHGE restrictions. For 'realistic' diets, the GHGE-minimised diet contained more plant foods (fruits, vegetables, nuts and legumes) compared to the current diets, which increased more when GHGE constraints were relaxed to meet optimally healthy diets. Regarding animal-based foods, the GHGE-minimised diet generally contained less fish and eggs compared to the current diet, but these intakes increased when GHGE constraints were relaxed. A similar pattern, but weaker, was observed for meat and dairy. In relation to this, the maximum DHD points for dairy are obtained for an amount of 300-450 g/d. For meat this is lower than 45 g of red meat per day and 0 g/d of processed meat. Compared to the current diet, the amount of sweets, snacks, fats and oils, and sweet beverages decreased. The amount of non-caloric drinks increased and the amount of cereals remained similar. Amounts of white meat were not presented.

Results on nutrients
The current diet (reference diet) provided 1.4 to 2.2 times the required amount of utilisable protein. The percentage of subjects with inadequate protein intake ranged from 28.9% to 4.2% depending on meat quartile and age/sex. Protein adequacy was also shown in meat quartiles, with almost similar adequacy in all quartiles. The protein quality was highest in the current diet and decreased when GHGE was further minimised, with the adequacy ratio being lowest (1.2) for women up to age 50. In the realistic diets for both men and women, there was considerable room for simultaneously increasing the DHD score and reducing the GHGE footprint with only small sacrifices of the protein adequacy.

Results for the energy percentage (En%) of protein, percentage of plant protein, calcium, iron and vitamin B12 were presented in quartiles of meat consumption for the most promising trade-off: the 'realistic diet' when GHGE was constrained to 75% individual reduction. Meat intakes were approximately 9, 55, 98 and 184 g/d across quartiles for all age and gender groups. Results on nutrients were standardised per 2000 kilocalories. It is not clear from the publication if the optimisations resulted in lower calorie intakes or lower protein intakes in general. For each age group, the En% of protein was almost similar between current and optimised diets within quartiles of meat consumption. The percentage of plant protein in the lowest meat quartiles ranged between 45.5 and 52.7% and within 30.0 to 31.2% in the highest meat quartile and increased somewhat within meat quartiles (with +0.6% to +4.5%, with highest increases in the upper meat quartile). For older women, vitamin B12 is higher in the optimised diets compared to the current diet, even though the percentage of animal protein was lower. Calcium and iron did not differ much between the current diets and the optimised diets and all means were above the EAR.

3.2.2 Reflections on optimisation models
Independently of the protein transition, the optimisation research provides insight into which food groups/foods should be eaten to a greater or lesser degree (at population level) in terms of health and environmental impact. This often means a decrease in meat and dairy consumption and consumption of sugary drinks and an increase of the consumption of vegetables/fruit/legumes. This does not yet provide information about the composition of an optimal diet at the level of the individual.

The results of optimisation studies are logically driven by the elements that make up the optimisation. Most optimisations rely on conditions for nutritional aspects by means of DRV, occasionally solely on DRV or in combination with recommendations for foods (the Dutch Dietary Guidelines or a derivative thereof). The optimisation for the Wheel of

Five is based on the Dutch Dietary Guidelines in conjunction with PRI/AIs of nutrients, given that the aim is to provide people with nutritional advice on an individual level that meets both the guidelines and the standards. Most other Dutch optimisation studies also used PRI/AIs to restrict the models.

Modelling a diet that complies (based on restrictions) with (all) PRIs or AIs will logically provide more than enough nutrients for most people. These optimisations, however, can provide guidance on how nutrients will increase or decrease compared to the reference diet. Nutrients that are or will be restricted in the modelling (if reported) are calcium and fish fatty acids and occasionally iron. Information on vitamin A varies between studies, with the amount occasionally increasing in the modelled diet and occasionally being identified as a nutrient that could become critical. Vitamin B2 intakes actually appear to be increasing, or rather not decreasing, compared to the current diet. In most optimisations, energy was either kept within certain limits or isocaloric modelling was carried out.

Information on the amount of vegetable protein compared to animal protein was provided in a number of studies. Heerschop et al. (2023) only provide these percentages based on a division into quartiles of meat consumption. Grasso et al. (2021) conclude that a diet with an increased amount of protein (1.2 g/kg day) that achieved 50% lower GHGE had a ratio of 50% animal and 50% vegetable protein, which corresponds to the ratio which is also achieved with a diet that follows the Wheel of Five. Broekema et al. (2020) do not specifically report on the ratio, but on animal and vegetable protein individually. By including the dietary reference values as requirements, the percentage of animal protein was shifted from 65% to 55%. In order to achieve the GHGE targets for 2030 and 2050, the percentage of animal protein would shift to 35% and 18% respectively. The scenario with less strict GHGE reduction requirements yielded a 44% percentage of animal protein. The (lacto-ovo) vegetarian scenario resulted in a percentage of 35% animal protein. It should be noted that in the vegan scenario the percentage of animal protein was still 13%.

Where the focus was not on total intake of protein, but rather on an increase of the percentage of vegetable protein, the total amount of protein decreased. In most cases, protein quality was not taken into account when assessing the total amount of protein. Indeed, this is a highly complex aspect. In the modelling conducted by Heerschop et al., however, an estimate of protein adequacy was made that is based on both the quantity and quality of protein. A higher percentage of vegetable protein logically leads to lower protein quality, however, the impact of this cannot yet be quantified. Some studies included essential amino acids alongside a requirement for minimum amounts or as an outcome. It was generally concluded that the intakes of amino acids were sufficient.

3.3 Substitution studies

In this section, the committee outlines peer-reviewed studies on environmental impact and nutritional aspects of substitution models conducted in the Netherlands. For an overview of these studies, see Table 2.

3.3.1 Outline of Dutch studies on substitution models

Temme et al. (2013)[1]

Temme et al. (2013)[1] investigated SFA and iron intakes in Dutch adult females (19-30 years; n=298) in two replacement scenarios: diets in which meat and dairy were partially (30%) or fully replaced (with similar weight) by plant-derived foods with similar use, in terms of the moment of consumption (breakfast, lunch, dinner, and between meals). Data of the Food Consumption Survey – Young Adults (2003) were used to estimate nutrient intakes for the reference scenario (baseline consumption). This study was financially supported by the Ministry of Agriculture, Nature and Food Quality in the Netherlands.

Results on environmental impact

The study focused on land use. Meat (39%) and dairy products (16%) were the most important food groups that contributed to land use. When all meat and dairy was replaced, land use reduced from 3.7 to 1.8 (SD 0.5) m^2/year/day. In this replacement scenario the major foods contributing to land use were brewed coffee and eggs. In the 30% scenario, the results were in the same direction, but less pronounced (to 3.1 m^2/year/day).

Results on nutrients

In this study, only SFA and iron were reported as nutrient outcomes. Iron intake statistically significantly increased from 9.5 (baseline) to 10.2 mg/day in the 30% replacement scenario and 12.0 mg/day in the 100% replacement scenario. At baseline, 10% of total iron was haem-iron and in the 100% scenario almost all iron was from non-haem sources. SFA intake decreased from 13.2 to 12.1 (30% scenario) and 9.2 energy percent (100% scenario). In a more extensive study by Seves et al. 2017 (see below) the replacement scenarios were studied in men and women between 19 and 69 years of age in relation to many more nutrients and a few more indicators of sustainability.

Temme et al. (2015)[2]

Temme et al. (2015)[2] investigated nutrient intakes in children (2-6 years; n=1279) of two replacement scenarios: diets in which meat and dairy were partially (30%) or fully replaced (with similar weight) by plant-derived foods with similar use, in terms of the moment of consumption (breakfast, lunch, dinner, and between meals). Data of the Food Consumption Survey – Young Children (2005-2006) were used to estimate total nutrient intakes for the reference scenario (baseline consumption). This study was sponsored by the Netherlands Food and Consumer Product Safety Authority.

Nutrient intakes of the replacements scenarios were compared to the baseline scenario and adequacy of intake was evaluated based on the EAR cut-point method or comparison to the AI. With the EAR cut-point method the prevalence of inadequate intakes is estimated as the proportion of the population with usual intakes below the EAR. Similarly, proportions of usual intakes of nutrients above the upper level were measured to estimate safe intakes.

Foods replacing meat and dairy needed to be more ecologically sustainable (based on CO_2 emission and land use). Results were stratified by age (2-3y and 4-6y) and sex.

Results on environmental impact

Average land use and GHGE were evaluated for intake of meat and dairy and the plant-based replacers only and do not reflect the impact of the whole diet on these markers. The average land use and GHGE for a child's daily consumption of meat, dairy and plant-based substitutes in the reference situation was 0.82m2·year and 0.84 kg CO_2 equivalents, respectively. In the '30% less meat and dairy' scenario, the land use and GHGE was 0.68m2·year and 0.67 kg CO_2 equivalents respectively, per child per day. When all meat and dairy consumption was replaced, the land use was reduced to 0.46m2·year and GHGE to 0.36 kg CO_2 equivalents per child per day, both compared to the reference situation.

Results on protein (and other macronutrients)

Meat and dairy replacements of 30% or 100% decreased the total protein intake on average by 3% and 8% respectively. However, within all scenarios and all age-gender categories, the proportion of children with a habitual protein intake under the corresponding EAR equalled 0%. Although it was not specifically addressed, the authors expect that, given the variety of plant-based proteins in the replacement scenarios and high levels of daily protein intake compared to recommendations, the provision of essential amino acids would be sufficient and in balance. The ratios of animal versus plant proteins were not provided.

SFA intake decreased by 9% and 26% and fibre intake increased with 8% and 29% for the partial and full replacement scenarios respectively.

Results on micronutrients
Commercial meat and dairy replacers contained approximately a similar amount of calcium and iron compared to the foods they replaced. At baseline, regarding calcium the proportion of children below the EAR (2-3y: 500 mg/d; 4-6y: 800 mg/d) ranged was 10-11% for children of 2-3y and 55-59% for the children of 4-6y. After partial replacement of meat and dairy this was 11-17% for the youngest and 47-68% for the oldest children. After full replacement the proportions were 0-2% and 72-80%.

Replacement scenarios resulted in higher iron intakes, but the iron was of lower bioavailability (non-haem iron). Taking the bioavailability into account (under the assumption that the iron intake of those with a vegetarian diet would be twice as high as for those with a non-vegetarian diet), the intakes were still in line with the iron recommendations for both replacement scenarios.

Zinc intakes reduced especially in the full replacement scenario, leading to lower proportions exceeding the upper level of zinc intake.

For thiamine (vitamin B1), at baseline and for the partial replacement scenario, the proportion of children below the EAR was low. For the full replacement, the proportion under the EAR exceeded 10% only for girls between 4-6y (15%).

The levels of vitamin B12 intake were affected in a dose-response way, but at baseline and for the partial replacement scenario 0% of the population was below the EAR for all groups. For the full replacement scenario the proportions ranged between 0 and 10%.

The authors mention that the substitutes and their composition is crucial for the intake estimations. They advise that in the case of shift of children's diets towards lower intakes of meat and dairy, nutritional status analyses are needed to confirm adequacy of the diet. The authors conclude that replacement of 30% is beneficial for children's health by lowering SFA intake, increasing fibre intake and maintaining similar micronutrient intakes. When full replacements are made, attention is recommended to ensure adequate thiamine (B1), vitamin B12 and zinc intakes.

Seves et al. (2017)[3]

Seves et al. (2017)[3] investigated nutrient intakes in Dutch adults (19-69 years; n=2102) of two replacement scenarios: diets in which meat and dairy was partially (30%) or fully replaced (with similar weight) by plant-derived foods with similar use, in terms of the moment of consumption (breakfast, lunch, dinner, and between meals). Data of the Food Consumption Survey (2007-2010) were used to estimate total nutrient intakes for the reference scenario (baseline consumption). This study was financially supported by the Dutch Ministry of Economic Affairs.

Nutrient intakes of the replacement scenarios were compared to the baseline scenario and adequacy of intake was evaluated based on the EAR cut-point method or comparison to the AI. With the EAR cut-point method, the prevalence of inadequate intakes is estimated as the proportion of the population with usual intakes below the EAR. Proportions of usual intakes of nutrients above the upper level were measured to estimate safe intakes.

Foods replacing meat and dairy needed to be more ecologically sustainable (based on CO_2 emission and land use). Results were stratified by sex and for iron (women) and thiamine also by age groups (19-30, 31-50, and 51-69y).

Results on environmental impact

In the partial meat and dairy (30%) replacement scenario, GHGE and land use were both on average reduced by 14%. In the full replacement scenario (similar weight), reductions were 47% and 41% respectively.

Results on protein (and other macronutrients)

Energy content was more or less similar for meat and dairy compared to their alternatives. In the reference scenario the mean protein intake was 98 g/d for men and 76 g/d for women. The mean protein intake decreased to 77 g/d for men and 60 g/d for women in the full replacement scenario (92 and 71 g/d in the partial replacement scenario), but the percentage below the EAR remained low (3% for men and 1% for women). Although it was not specifically addressed, the authors expect that, given the variety of plant-based proteins in the replacement scenarios and high levels of daily protein intake compared to recommendations, the provision of essential amino acids would be sufficient and in balance. The ratios of animal versus plant proteins were not provided.

The replacement scenarios did not change energy intake significantly. SFA intake decreased from 13 (women) or14 (men) En% to 12 En% (partial replacement) and 9

En% (full replacement), decreasing the percentage above 10 En% from 91-97% to 79-89% (partial replacement) and 60-77% (full replacement). Mono- and disaccharide intakes increased by 6% and 16-18%. Replacement scenarios increased fibre intake although habitual intakes were still below the recommendations.

Results on micronutrients
Vegetarian meat substitutes contained less vitamin A and D and zinc than meat. Pulses do not contain vitamin B12 and have a lower protein content than meat. On the other hand, fibre content was higher in vegetarian meat and pulses than in meat products and cheese. The sodium content of commercially available meat replacers was relatively high compared to pulses and soy products. In general, the results on nutritional value are dependent on the exchanges as defined by the model and the extent to which plant-based alternatives are enriched with nutrients. According to the authors, most of the commercially available meat replacers were enriched with iron and vitamin B12 and dairy replacers may be enriched with calcium, riboflavin and vitamin B12 and D.

The mean calcium intakes in the reference scenario were 1128 mg/day for men and 989 g/day for women. Intakes decreased by 7.0-7.5% (1044 mg/d for men and 920 mg/d for women) for the partial replacement scenario and by 25-26% (839 mg/day for men and 737 mg/day for women) in the full replacement scenario. The mean calcium intakes in the replacement scenarios were below the adequate intake of 1000 mg/day, so therefore no statement could be made regarding calcium adequacy.

In the ‘less meat and dairy’ and ‘no meat and dairy’ scenarios, habitual iron intakes increased by 7% and 21% for men and 6% and 19% for women, respectively, lowering the proportion of premenopausal women below the EAR from 40-57% to 30-49 (partial replacement) and 14-26% (full replacement). It should be noted that the EAR cut-point method is not valid for iron regarding premenopausal women because of the skewed distribution of the iron requirements. The prevalence of inadequate intake is therefore underestimated with the EAR cut-point method. For men and postmenopausal women the proportions below the EAR were 0-1%. Replacement scenarios resulted in higher iron intakes, mainly non-haem iron.

Zinc intakes decreased in the replacement scenarios. The risk of inadequate intakes remained low (1%) for the partial replacement scenario yet increased to 21-24% for the full replacement scenario.

Vitamin A intake (expressed as retinol activity equivalents; RAE) decreased significantly in the full replacement scenario, leading to 64% of men and 58% of women having an intake below the EAR. Vitamin A intake also decreased in the partial replacement scenario, although this was not statistically significantly different from habitual intakes. The percentages below the EAR increased from 17 to 25% for men and 19 to 27 for women, compared to the reference scenario.

Mean thiamine (vitamin B1) intakes decreased according to the different scenarios. However, these decreases were not statistically significantly different from the reference diet.

Mean riboflavin (vitamin B2) decreased according to the different scenarios. However, these decreases were not statistically significant with respect to the reference diet. The risk of inadequate intakes remained relatively low in both replacement scenarios.

Vitamin B12 in the replacement scenarios was lower than in the reference diet. The proportion of adults with an intake below the EAR was low in the reference diet (0-1%) as well as in the partial replacement scenario (1-4%), but increased to 23-29% in the full replacement scenario.

Vitamin D levels of the replacement scenarios were higher than in the reference diet. Mean intakes were below the AI of 10 microgram per day. Sunlight exposure, however, contributes more (2/3) to vitamin D status than diet (~1/3). The AI is based on both.

Van de Kamp et al. (2018a)[4]

Van de Kamp et al.[4] compared the environmental impact (GHGE) and nutrient content (energy, protein, mono- and disaccharides, saturated fat, sodium, and iron) of the current Dutch diet (DNFCS 2007-2010; reference diet) and several alternative diets. This study was financially supported by the Ministry of Economic Affairs.

Several scenarios were modelled and compared to the people with highest tertile of GHGE of the reference diet. In the ‘cheese scenario’, all cheese in between meals was replaced by plant-based alternatives. Foods replacing cheese had to have a lower GHGE (per kg) and had to contribute to a favourable shift in nutrient intakes. In the ‘meat scenarios’, red and processed meat during dinner was reduced (not replaced) by 50% or 75%. In the ‘water50’ and ‘water100’ scenarios, water replaced 50 respectively 100 percent of all soft drinks (all cold non-alcoholic drinks excluding tap water and dairy beverages) and alcoholic drinks. In addition, two combination scenarios (‘combi50’ and ‘combimax’) were modelled.

Results on environmental impact

All scenarios, except ‘water50’ and ‘cheese’, reduced GHGE, with the largest reductions for the scenarios including meat reductions. The scenarios, including a reduction of meat consumed during dinner, hold the largest reduction potential in terms of dietary GHG emission; ranging from approximately − 15% in the ‘meat50’ scenario to up to − 23% in the ‘meat75’ scenario.

Results on foods

Meat consumption contributed ~40% to the GHGE of the highest tertile of GHGE, compared to ~30% in the intermediate tertile of the reference diet. In the ‘combimax’ scenario, the remaining average daily meat consumption was 100 g for men and 60 g for women. Average cheese consumption was 37 g per day for men and 34 g per day for women when all cheese consumption in between meals was replaced by plant-based alternatives.

Results on nutrients

A 75% reduction of red and processed meat consumed during dinner resulted in significant decreases in energy, SFA, protein and iron intake for men as well as for women. Both combination scenarios led to a significant decrease in energy, protein, mono- and disaccharides, SFA and iron intakes compared to the reference. The ‘combimax’ scenario additionally resulted in a significant 8-11% reduction in sodium intake. Protein intake remained adequate in all scenarios; the proportion of adults with habitual intakes below the corresponding EAR remained 0% for both men and women. Replacing cheese by plant-based substitutes did not significantly alter the intakes of the selected nutrients. However, calcium intake was not evaluated. Mean iron intake in the scenarios was well above the EAR for men, and for women close to the EAR of premenopausal women. A low iron intake was an already existing problem in the subgroup of women of childbearing age. Iron adequacy could, however, not be assessed. The authors state that effort is needed to ensure adequate iron intakes of women of childbearing age, regardless of whether meat and alcoholic and soft drink consumption are maintained or reduced. Of note, in this study, meat was reduced without replacement, whereas in the study by Seves 2017[3] meat was replaced by plant-based alternatives, including enriched products.

No information was provided on protein quality, amino acids, or the ratio of animal based and plant based protein.

Van de Kamp et al. (2018b)[7]

Van de Kamp et al.[7] compared environmental impact (GHGE) and nutrient content of the habitual Dutch diet (DNFCS 2007-2010; reference diet) and four diets adhering to the Wheel of Five (2016)[9] in a scenario study. This study was financially supported by the Ministry of Economic Affairs.

The ‘regular healthy consumption’ and the ‘regular healthy consumption without meat’ scenarios both complied with the Wheel of Five (based on the DHD2015 and DRV of the Health Council of the Netherlands. Of note, the Wheel of Five has upper limits for meat, red meat, dairy, fish and eggs. See for more information on these scenarios the study of Brink et al.[9] The ‘sustainable healthy consumption’ and the ‘sustainable healthy consumption without meat’ scenarios also complied with the Wheel of Five, but in these scenarios only foods with relatively low GHGE were included.

Results on environmental impact

The effect on GHGE of changing the current Dutch diet to a diet according to the Wheel of Five (corresponding with the current diet as close as possible), ranged from −13% for men aged 31–50 years to +5% for women aged 19–30 years. Replacing meat in this diet and/or consuming only foods with relatively low GHG emissions resulted in average GHG emission reductions varying from 28–46%.

Results on nutrients

The main focus of the publication was environmental impact; the ‘regular healthy scenarios’ were modelled with the aim to meet the PRIs or AIs. Mean nutrient supplies of all modelled diets were compared to PRIs or AIs. Of note, the information on mean content of the nutrients in the scenarios do not, as such, provide information on nutrient adequacy (this evaluation should be based on comparing individual intakes with the EAR or with the AI). In all healthy diet scenarios, the number of DRIs being met was equal to or higher than in the current diet. In the scenarios in which only foods with relatively low GHGE were consumed, fewer dietary reference intakes (DRIs) were met than in the other healthy diet scenarios. Results on nutrients included energy, protein, saturated fat, fibre, calcium, iron, sodium, zinc, and vitamins B1, B2, B12, A and D. The evaluated diets supplied 85% of total energy based on products in the Wheel of Five. The other 15% of energy (outside the Wheel of Five) was not included in the scenarios. No information was provided on protein quality, amino acids or the ratio of animal based and plant based protein.

The protein intake of the ‘regular healthy scenario’ increased compared to the current diet for men and women (with 93.5 vs 91.6 for men between 19-30y and 83.8 vs 70.2

for women 31-50y), whereas total energy intake decreased. For men, but not for women, mean fibre was below the recommendation of 40g/day for all scenarios, but much higher than in the reference diet. For women, mean calcium content was slightly below the PRI for the sustainable scenarios as well as for the reference diet. For women, mean iron intakes were below the PRI for all scenarios but higher than for the reference diet. Mean vitamin A intake of all modelled diets was lower than the reference diet. Mean vitamin C levels were varying between models and between age and sex groups.

Table 2 Nutritional and environmental impact characteristics of diets based on replacement models in the Netherlands.

Study	Aim, comparison	Design/method (theoretical replacement models)	Study population	Environmental impact	Dietary factors	Feasibility
Temme 2013[1]	More sustainable diet - compared to the current diet DNFCS Young Adults 2003	*30% less meat and 30% less dairy; *100% less meat and 100% less dairy Replacement with plant-based product with similar weight	Young women N=389, 19-30y Individual data	Outcome: land use (LCA)	Outcome: Nutrients (saturated fatty acids, iron) Comparison of group mean to PRI/AI	Constraint: Products with similar use in terms of consumption occasion
Temme 2015[2]	More sustainable diet - compared to the current diet DNFCS Young Children 2005-2006	*30% less meat and 30% less dairy; *100% less meat and 100% less dairy Replacement with plant-based product with similar weight	Children N=1279, 2-6y Individual data	Outcome: GHGE and land use (LCA)	Outcome: Nutrients: EAR, adequacy EAR cut-point or comparison to AI	Constraint: Products with similar use in terms of consumption occasion
Seves 2017[3]	More sustainable diet - compared to the current diet DNFCS 2007-2010	*30% less meat and 30% less dairy; *100% less meat and 100% less dairy Replacement with plant-based product with similar weight	Adults N=2102, 19-69y Individual data	Outcome: GHGE and land use (LCA)	Outcome: Nutrients: EAR, adequacy EAR cut-point, or comparison to AI	Constraint: Products with similar use in terms of consumption occasion
Van de Kamp 2018a[4]	More sustainable diet - compared to the current diet DNFCS 2007-2010	*50% less meat (no replacement) *75% less meat (no replacement) *replacement of 50% of alcoholic and soft drinks with water *replacement of 100% of alcoholic and soft drinks with water *replacement of cheese by plant-based alternatives *combination scenarios	Adults N=2102, 19-69y Individual data	Outcome: GHGE (LCA)	Outcome: Nutrients: EAR, adequacy EAR cut-point, or comparison to AI	Constraint: Products with similar use in terms of consumption occasion
Van de Kamp 2018b[7]	Measure environmental impact of current Dutch diet and Wheel of Five diet (optimised for health, with restrictions of meat, dairy, fish, eggs)	*Wheel of Five diet *Wheel of Five diet without meat *Wheel of Five diet with reduced environmental impact *Wheel of Five diet without meat with reduced environmental impact	Adults 19-30y, 31-50y Group data	Outcome: GHGE (LCA)	Constraints: according to Wheel of Five [9] Outcome: Nutrients: comparison of nutrient content of scenarios with DRV (PRI/AI/UL)	Expert opinion Wheel of Five diet is designed to stay as close as possible to the current diet

AI: adequate intake, DNFCS: Dutch national food consumption survey, DRV dietary reference values, EAR: estimated average requirement, GHGE: greenhouse gas emission, LCA: life cycle analysis, PRI: population reference intake, UL: upper level

3.3.2 Reflections on replacement models

The available substitution studies included scenarios of 30% less dairy and meat and 100% less dairy and meat, with dairy and meat being substituted by plant based (partly enriched) alternatives. The findings are highly dependent on the products that replace each other.

The available substitution studies did not report on the percentages of animal and vegetable protein or on amino acid intakes. The substitution models show that replacing 30% dairy and meat with plant based alternatives compared to the 2005-2006 diet (children) and 2007-2010 diet (adults) generally leads to improvements in the intake of saturated fat and fibre, whereas this would have few negative consequences on the intake of other nutrients (see Table 3). Energy and protein intake did not change significantly, even though the substitution was not carried out isocalorically but conducted according to grams of products.

Table 3 Findings of meat and dairy 30% replacement scenarios of Temme and Seves[2,3]

	Boys 2-3y	Girls 2-3y	Boys 4-6y	Girls 4-6y	Men 19-69y	Women 19-69y
Energy	↔	↔	↔	↔	↔	↔
Protein	↔	↔	↔	↔	↔	↓ (0→0%<EAR)
SFA	↓	↓	↓	↓	↔	↓
Mono-disaccharides	n.r.	n.r.	n.r.	n.r.	↔	↔
Fibre	↑	↑	↑	↑	↑	↑
Vitamin A	n.r.	n.r.	n.r.	n.r.	↔	↔
Sodium	n.r.	n.r.	n.r.	n.r.	↔	↔
Calcium	↔	↓ (10→17%<EAR)	↔	↔	↓ (lower than AI; no statement adequacy)	↓ (lower than AI; no statement adequacy)
Iron	↔	↔	↔	↔	↑ (1→1%<EAR)	↔ 19-30y: (57→49%<EAR) 31-50y: (40→30%<EAR) 51-69y: (0→0%<EAR)
Zinc	↔	↔	↔	↔	↓ (0→1%<EAR)	↓ (0→1%<EAR)
Thiamine (B1)	↔	↔	↔	↓ (2→1%<EAR)	↔	↔
Riboflavin (B2)	n.r.	n.r.	n.r.	n.r.	↔	↔
Vitamin B12	↓ (0→0%<EAR)	↓ (0→0%<EAR)	↓ (0→0%<EAR)	↓ (0→0%<EAR)	↓ (0→1%<EAR)	↔
Vitamin D	n.r.	n.r.	n.r.	n.r.	↑	↔

Abbreviations: AI: adequate intake, DNFCS: Dutch National Food Consumption Survey, (E)AR: (estimated) average requirement, n.r.: not reported.
The table provides information on whether intakes increase or decrease significantly (or remain the same). In the case of decreases, the intakes in relation to the dietary reference values were examined in greater detail.

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De Gezondheidsraad, ingesteld in 1902, is een adviesorgaan met als taak de regering en het parlement ‘voor te lichten over de stand der wetenschap ten aanzien van vraagstukken op het gebied van de volksgezondheid en het gezondheids(zorg)onderzoek’ (art. 22 Gezondheidswet). De Gezondheidsraad ontvangt de meeste adviesvragen van de bewindslieden van Volksgezondheid, Welzijn en Sport; Infrastructuur en Waterstaat; Sociale Zaken en Werkgelegenheid en Landbouw, Natuur en Voedselkwaliteit. De raad kan ook op eigen initiatief adviezen uitbrengen, en ontwikkelingen of trends signaleren die van belang zijn voor het overheidsbeleid.De adviezen van de Gezondheidsraad zijn openbaar en worden als regel opgesteld door multidisciplinaire commissies van – op persoonlijke titel benoemde – Nederlandse en soms buitenlandse deskundigen.

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