Dutch diet optimisation in line with planetary boundaries

Methodology report

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1. Introduction

Current dietary patterns are a leading global cause of diet-related chronic diseases and environmental degradation. Poor quality diets, characterized by low amounts of vegetables, fruit, and whole grains and high amounts of refined carbohydrates, fats, sodium, added sugars, and red and processed meat, represent one of the greatest public health burdens of our day [1]. Besides negative health impacts, current diets contribute to adverse environmental impacts. The food system is a key driver of climate change, biodiversity loss, soil degradation, and water pollution and is a large drain of resources like land, water, energy, and nutrients [2,3]. While evidence for a healthy and sustainable diet is continuously growing, there is no universal approach, and healthy and sustainable diets need to be tailored to different cultures and contexts.

The role that food-based dietary guidelines can play in supporting consumers on not only how to make healthier food choices, but also more environmentally sustainable food choices, has been long acknowledged [4]. While attempts have been made to consider food system sustainability when designing recommendations by several national dietary guideline panels across the world, such as in Brazil, Australia, and The Netherlands [5], most guidelines are incompatible with the Paris Climate Agreement and other environmental targets [6]. In contrast, adoption of the EAT-Lancet planetary health diet recommendations was associated with general attainment of both global health and environmental targets [6]. Therefore, further work is needed in making national food-based dietary guidelines more sustainable.

This document describes the methodology behind the creation of the Dutch planet-based diet. A planet-based diet has environmental impacts within planetary boundaries for greenhouse gas emissions, land use, blue water use, and nitrogen and phosphorus application as defined by the EAT-Lancet report and minimizing the impact on biodiversity while balancing the cultural acceptability of the diet.[3,7] Besides adhering to the planetary boundaries, the planet-based diet is in line with relevant nutritional guidelines in the Netherlands such as the age- and sex-specific dietary reference values (DRVs) and food group recommendations, as advised by the Health Council of the Netherlands [8–10] and translated by the Netherlands Nutrition Centre (Voedingscentrum). The aim of this planet-based diet is to inspire further improvements in the environmental sustainability of the Dutch dietary guidelines and the translation of it into the Wheel of Five, of which an updated version is expected in 2026.

2. Methodology

A planet-based diet for the Netherlands was created using Optimeal®, a diet optimisation software that uses quadratic programming. The key elements of the project are explained in detail in the following paragraphs.

2.1 Reference diet

Food consumption data and nutritional properties

The reference diet is based on the most recent Dutch National Food Consumption Survey (DNFCS), conducted by the Dutch National Institute for Public Health and the Environment (RIVM) between 2019 and 2021 among the Dutch population.[11] The data is based on two 24-hour recalls of food intake and was conducted among 3570 respondents between 1 and 79 years old. Pregnant and lactating women were not included. For the purposes of this study, food consumption data of Dutch males and females aged 18-50 years were used (n=318 men and 284 women).

Foods were grouped into 18 main and 135 sub food groups according to the GloboDiet classification.[12] All food products were linked to the Dutch Food Composition Database (NEVO) 2021 version 7.1 by NEVO code.[13] Because the extended NEVO table was not available at the time of this study, food products with NEVO codes that were not in the NEVO table were matched to proxies.

An average diet was derived by first averaging food products reported during the two recalls (in grams per day) for each participant for men and women aged 18-50 years, respectively, then averaging food products across all participants. To obtain a balanced reflection of the daily food consumption, a weighted average is determined based on the 'representation factor' of each participant, as provided in the DNFCS data. This representation factor indicates to what extent the participant represents (or: counts for) persons with similar demographic characteristics to fairly represent the Dutch population. With this approach, the weighted average diet accurately reflects demographic diversity of the full population. Checks were performed to ensure the total quantity of each food group of the reduced diet equals that of the original DNFCS. The nutritional properties of the reference diets were similar but not identical.

The average diet was reduced from 825 to 354 food products that represent the consumed weight and energy intake while balancing the product mapping with the available environmental data. A product was considered in the reduced diet when it met at least one of the following criteria:

- Represents at least 1% of the total calorie intake of products in its food group;
- Represents as least 1% of the total intake (in grams) of products in its food group;
- Is considered a relevant product in future diets (e.g., plant-based alternatives for meat and dairy).

Manual adaptations were done to combine foods with similar nutrient profiles for which no more specific environmental data was available, like Gouda cheese 48+ average, age 4-8 weeks, age 4-7 months, age 8 weeks-4 months.

2.2 Defining planetary boundaries for the Dutch diet

Background data

Food products in the reference diet were linked to environmental impact data of foods taken from an intermediate version of the Blonk database (June 2023). The database contains life cycle inventories (LCI) of approximately 400 commonly consumed food products in the Netherlands from cradle to grave. The LCIs were created in compliance with the ISO14040 and 14044 LCA guidelines and, where applicable, aligned with the Product Environmental Footprint Category Rules. [14–16] The basis of the methodology and assumptions can be found elsewhere (Agri-Footprint 6 methodology report[17]).

Planetary boundaries

This project considered the planetary boundaries (PB) defined by the EAT-Lancet Commission for global, sustainable food production, summarised in Table 1.[3] We recalculated the EAT-Lancet boundaries for food production as a per capita allowance, based on the forecasted population in 2030 and 2050,[18] and set them as constraints in the diet optimisation (per person) with the exception of biodiversity loss.

As the planetary boundary indicators differ from the mainstream environmental midpoint and endpoint impact categories calculated by the publicly available impact assessment methods (e.g. ReCiPe 2016, EF 3.1), there was a need to adapt the environmental impact assessment calculations to align with the planetary boundaries for this analysis, as explained below. We were unable to adjust familiar impact assessment methods into extinction rate as defined by the EAT-Lancet Commission, primarily due to ambiguities in methods in the EAT-Lancet report, and therefore decided to assess biodiversity loss as damage to ecosystems, explained in detail on page 6. Because we could not translate the EAT-Lancet PB for biodiversity loss into a metric we could measure, we decided to not set a PB for biodiversity loss but ensure that the impact was lower than the current impact of the diet.

Table 1. Planetary boundaries for 2030 and 2050 per capita per day based on UN population predictions[18]

	Greenhouse gas emissions	Nitrogen application	Phosphorus application	Consumptive water use	Cropland use	Biodiversity loss
***Food production* boundary** defined by EAT-Lancet	5 Gt CO_2eq/year	90 Tg N / year	8 Tg P / year	2500 km^3 /year	13 million km^2	Extinction rate: 10 extinctions / (million species year)
Per capita 2030 boundary used in this study	1.60 kg CO_2eq/day	0.029 kg N/day	0.003 kg P/day	0.801 m^3 /day	0.00042 hectares	Damage to ecosystems: Lower than current impact, determined by reference diet
Per capita 2050 boundary used in this study	1.41 kg CO_2eq/day	0.025 kg N/day	0.002 kg P/day	0.705 m^3 /day	0.00037 hectares	Damage to ecosystems: Lower than current impact, determined by reference diet

System boundaries

The EAT-Lancet report presents planetary boundaries based on the environmental impact of food production, a cradle-to-processing boundary. In our study, we apply the same system boundaries to the environmental impact data. In addition, we considered that knowing the total (i.e. cradle-to-grave) impact of consumed food was worth being analysed, since considering downstream phases including packaging, distribution, storage and preparation better reflect the actual impact of diets on the planet. Thus, the impacts up to processing and up to consumption are both reported.

Impact assessment method used to quantify the EAT-Lancet planetary boundary control variables

An overview of the EAT-Lancet planetary boundaries and the environmental indicators used and assumptions made in this study can be found in Table 2.

Climate change

The authors of the EAT-Lancet report estimate the maximum allowable greenhouse gas emissions (GHG) from food production. The target of 5 Gt CO_2-eq/year is based on combined projections of methane and nitrous oxide emissions of 4.7 Gt of CO_2eq/year from food production and 0.7 Gt of carbon dioxide emissions from biomass burning on agricultural land in 2050. One assumption of the EAT Lancet report is that all carbon dioxide emissions from land use change will have been reduced to zero by 2050. Another assumption is that zero net emissions will come from energy use in the food supply chain. The authors ascribe emissions from burning of fossil fuels to the energy sector and assume emissions from energy use in all sectors to be reduced to zero due to the transition to clean energy by 2050. Nevertheless, transiting to clean energy wouldn't entirely avoid CO_2 emissions from fossil fuels; agricultural inputs derived from fossil fuels would still be needed, leading to CO_2 emitted in their sourcing and/or production.

We calculated GHG emissions of food production, expressed in kg CO_2 equivalents, excluding emissions from land use change (LUC) and peat oxidation but including emissions from fossil fuels. Although the EAT-Lancet scope excludes emissions from fossil fuels, we included them in the environmental impact assessment because of the high uncertainty of the path towards reducing the energy sector's reliance on fossil fuels. We applied the IPCC 2013 (AR5) characterisation factors.[19] To understand the impact of the assumptions made by EAT-Lancet, ReCipe Midpoint (H) was modified to also report on fossil-related emissions separately.

Land-system change

The EAT-Lancet report expresses this planetary boundary in surface area of cropland use, implying that only cropland is considered in the boundary for the control variable, therefore excluding grazing lands. Thus, we created an impact category that accounts for the area of cropland used for food production (m^2a). An additional indicator that accounts for both the area of croplands and of grazing lands is also reported, since grassland use is also a significant contributor to land use in the food system, mainly for the production of food by cattle.[20] To calculate the cropland and pasture (grass) land use, we took the country-crop cultivated area and yield data from FAO statistics.

Freshwater use

The EAT-Lancet report expresses this planetary boundary as consumptive blue water use. In LCA terms this would be defined as the blue water footprint. Blue water footprint refers to volume of surface and groundwater consumed as a result of the production of a good. The target does not account for green water (rainwater). For our impact assessment, a new impact category was created to include only water used for irrigation.

Nitrogen cycling

The EAT-Lancet report's target for nitrogen cycling focuses on nitrogen-related pollution, which they account for using surplus of reactive nitrogen as a control variable. Surplus of reactive nitrogen is a measure that accounts for all inputs and offtakes of nitrogen. Thus, we created an impact category assessing surplus reactive nitrogen as the emitted nitrogen in multiple reactive molecules: NH_3, NO_x, NO_3-, N_2O. Non-reactive forms of nitrogen are excluded (i.e. N_2)

Phosphorus cycling

The EAT-Lancet target for phosphorus cycling is defined as kg phosphorus (P) applied to agricultural soils. The scope is mined P applied to soils as a fertiliser. Specific emissions resulting from fertiliser application are not considered. The EAT-Lancet's phosphorus model excludes manure assuming that all animal manure is recycled. The approach is based on Steffen et al. with the adapted work of Carpenter and Bennett.[21,22] For our impact assessment, a new impact category is created that accounts for mined phosphorus to match the scope of the EAT-Lancet indicator. A contribution analysis was run to check if there are no other phosphorus sources included or that double counting occurs.

Biodiversity loss

The EAT-Lancet target is expressed in extinction per million species*year and is based on background rate of 1 E/MSY (extinction without humans, which is estimated from fossil records). A previous study aligning LCA metrics with the EAT-Lancet planetary boundaries followed the methodology in Chaudhary and Brooks (2018), which looks at biodiversity loss due to land use.23,24

The impact on biodiversity in this study (or: biodiversity loss) is calculated using the ReCipe 2016 endpoint indicator. The ReCipe 2016 biodiversity endpoint is measured as damage to ecosystems and is influenced by global warming, water use, freshwater ecotoxicity, freshwater eutrophication, tropospheric ozone formation, terrestrial ecotoxicity, terrestrial acidification, and land use. This impact assessment method calculates total number of species lost*year. For the final optimisation, we used a stepwise reduction approach meaning that we used the impact of the reference diet on biodiversity loss (species lost*year) as a starting point to further avoid species lost. From that point the lowest reduction possible within acceptability constraints is found. Although the ReCiPe method is the most usable and complete biodiversity method in LCA-context, drawbacks can be identified (e.g., poor consideration of impact on marine species).

Table 2. The scope of the EAT-Lancet planetary boundaries, applied environmental indicators, and assumptions made.

Process	EAT-Lancet Scope	Application in current study	Assumptions
Climate change	Only includes CH_4 and N_2O associated with biological processes in crop and livestock production, and CO_2 from burning of biomass on agricultural land. Excludes CO_2 from fossil fuel and land use change.	Included emissions from fossil fuels and excluded emissions from land use change and peat oxidation.	Conservative assumption is made regarding fossil fuel contributions in the future compared to EAT-Lancet predictions by including emissions of fossil fuels in the indicator.
Land system change	Cropland use	New impact category was created that includes only occupation of cropland (excluding occupation of grazing land, reported separately).	
Freshwater use	Consumptive blue water use	New impact category was created that includes regionalised data for blue water use.	Includes blue water; rain water is excluded
Nitrogen (N) cycling	Surplus reactive nitrogen, a measure that accounts for all inputs and offtakes of nitrogen. It includes addition of 'new' reactive N, i.e. N from application of mineral fertilizer and from biological fixation by plants.	New impact category was created that includes ammonia, nitrogen oxides, nitrogen monoxide, dinitrogen monoxides	Animal manure is excluded
Phosphorous (P) cycling	Mined P applied to soils as a fertiliser. Manure is not considered as it is recycled internally in the agricultural system.	New impact category was created with phosphorous use from nature as a substance flow. Included only mined P.	Animal manure is excluded
Biodiversity loss	Based on background extinction rate of 1 E/MSY (extinction without humans, which is estimated from fossil records).	ReCiPe endpoint indicator damage to ecosystems was used (species extinctions*year)	

LCA Forecasting scenarios

To incorporate expected improvements in 2030 and 2050, the environmental data was adjusted (forecasted) as described in the report "The Menu of Tomorrow" (in Dutch) and demonstrated in Broekema et al [a].[25,26] Such changes include, amongst other things: improved cultivation techniques, more efficient processing, and the use of cleaner energy sources. Next to sustainability, also cost reduction and environmental policies are driving factors for such changes. As a result of these trends, food production is more efficient, which reduces its impact per kilogram.

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[a] *The environmental boundaries used in the study by Broekema et al. (2020) are based on the 1.5°C threshold and derived from the total food system emissions in 2010 and therefore differ from the boundaries used in this study which are based on the EAT-Lancet planetary boundaries.*

2.3 Diet optimisation

To design a planet-based diet for Dutch adults, we used Optimeal 3.0®, a tool that applies mathematical optimisation techniques to simultaneously reduce the environmental impact of the diet and meet all nutritional and dietary requirements while staying as close to the current diet as possible.

Optimal diets are developed for both males and females aged 18-50 years old for the 2030 and 2050 scenario. The optimal diets meet age- and sex-specific nutrient requirements (see Supplementary Tables), national recommendations on specific food groups, such as fruit, vegetables and legumes, acceptability constraints, 33-150% of the current food group consumption, as well as environmental targets based on the planetary boundaries (Table 1).

Nutritional constraints

The nutritional constraints define the maximum and/or minimum intake of macro- and micronutrients and food groups necessary to obtain a healthy and nutritionally adequate diet. These minimum or maximum quantities, based on dietary reference values (DRVs) and food-based dietary guidelines for Dutch males and females aged 18-50y, are the boundaries that are used for the optimisation process. Optimisations are conducted isocalorically, meaning that the energy intake will remain equal to the current energy intake. This is done to focus on the changes in the composition of the diet. DRVs are based on recommendations from the Health Council of the Netherlands [8–10], and are translated and agreed with by the Netherlands Nutrition Centre (Voedingscentrum). More specifically, population reference intakes were used where available. If values were not available, values for adequate intake were used. Upper limits of requirements are based on values for the tolerable upper intake level. DRVs for proteins, fats, and digestible carbohydrates are derived as a percent of total energy intake (en%). The Dutch food-based dietary guidelines, as quantified in the Dutch Healthy Diet index[27], were used to establish constraints for certain food groups and/or products (grams per day): tea (min. 375), eggs (max. 21), alcoholic beverages (max. 0), legumes (min. 19), vegetables (min. 200), fruits and nuts (min. 215), fish (min. 15), and dairy and dairy substitutes (300-450). These are discussed and agreed upon with the Netherlands Nutrition Centre and WWF-NL.

Environmental constraints

The environmental constraints that are used to find the optimal Dutch diet are based on the cradle-to-processing gate per capita impacts for greenhouse gas emissions, cropland use, freshwater use, and nitrogen and phosphorus application as summarised in Section 2.2 – Considered indicators. The personal impact budget for food, shown in **Table 1** and explained under section 'Planetary boundaries', were applied as constraints. This was calculated by considering the projected population growth and sharing the budgets evenly among the global population in 2030 and 2050.[18] Furthermore, a progressively stringent constraint was placed on biodiversity loss, starting from the current impact. This is described further under 'Optimisation algorithm and strategy'.

Acceptability constraints

Besides the nutritional and environmental constraints, which apply to the whole diet, constraints are defined on a food group level. Minimum and maximum product constraints help to ensure that the optimised diet is acceptable for the general population. Maximum constraints ensure that the optimised diet does not contain large amounts of food groups which are generally not consumed in large quantities. Minimum constraints ensure that no food group is excluded from the optimised diet and thus contributes to a varied diet.

In past projects, several different approaches were taken, for example in the optimisation study for WWF Belgium, the 95th percentile of daily intake per food product was taken as a maximum and 10% of current consumption is the minimum constraint. For the recently performed optimisation study for WWF UK, the minimum constraint was set to 33% of the current food group consumption, and the maximum to 150% of current intake. This range takes into account the asymmetric distribution of food group intake, similar to what was done in Broekema et al.[25] The choice of these constraints can greatly influence the outcomes of the research and should thus be carefully determined. We have used the same constraints that were used for WWF-UK (i.e., 33-150%). Furthermore, this range is more conservative compared to taking the 95th percentile of daily intake per food product as a maximum constraint and 10% of current consumption as the minimum constraint.

Optimisation algorithm and strategy

For the optimisation steps, Optimeal® is used. Optimeal is a software solution developed by Blonk Sustainability, that applies optimisation to dietary questions involving sustainability and nutritional parameters. Optimeal will find the optimal adjustments to the starting diet, so it meets all the nutritional (and environmental) boundaries that have been set, while keeping closest to the starting diet as possible. During optimisation, consumed quantities of individual products are increased and reduced in the diet to make this happen. Quadratic programming is used to find the closest solution to the starting diet, resulting in a diet which complies to all nutritional and environmental constraints with the least changes to the starting diet. Reasoning behind this is that people find changing their dietary habits quite difficult and adoption of dietary changes is likelier to happen when the suggested diet is close to the reference diet. More information on the optimisation algorithm is provided in the Optimeal® documentation.[28]

To identify planet-based diets for Dutch men and women, a stepwise reduction in biodiversity was applied, starting from the current impact on biodiversity loss, while applying the nutritional, environmental and acceptability constraints as described above. The diet with the lowest possible impact on biodiversity loss, while remaining culturally acceptable, was identified and the resulting diet's effects on the remaining planetary boundaries is quantified. This can be illustrated in **Figure 1**. Changes in the diet served as a proxy for cultural acceptability. It is assumed that more changes made to the diet are less acceptable than fewer changes. The balance point, as shown in **Figure 1**, is identified by applying the concept of elasticity, borrowed from economics science. Before this balance point the changes in the diet are more effective in reducing biodiversity loss. A further reduction in biodiversity loss requires proportionally more changes to the diet, making it less acceptable for the average consumer.

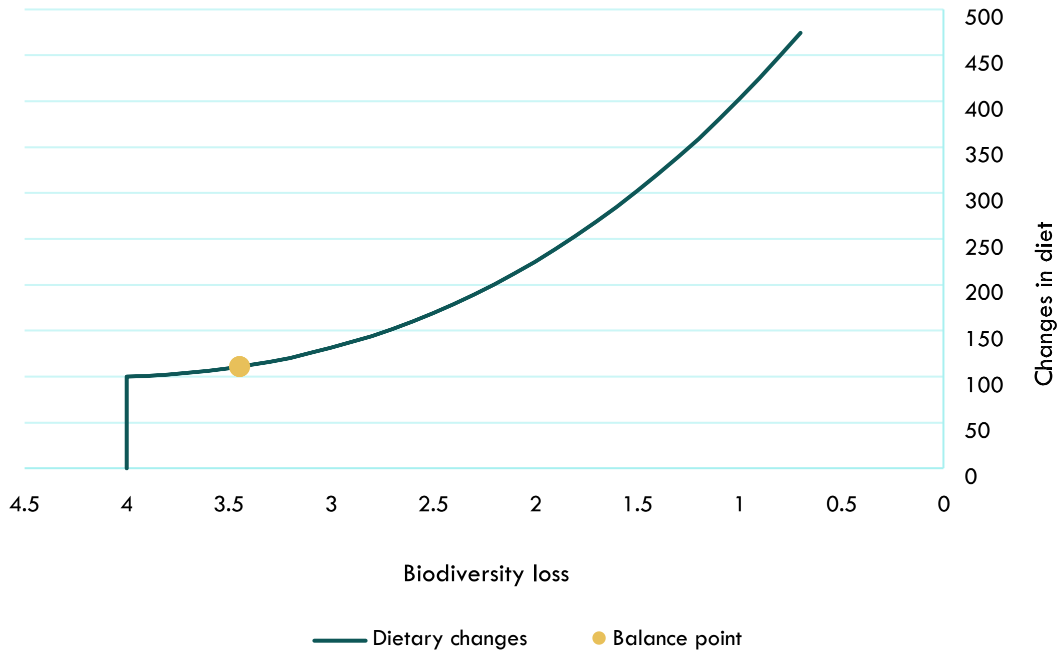

Figure 1 Identifying point that balances lowest environmental impact and cultural acceptability. This figure is indicative and does not show the curve and balance point of the study.

2.4 Analysis

To identify changes needed to be made to the diet to achieve a healthier and more sustainable diet, the differences between the optimised Dutch diets for 2030 and 2050 and the reference diets, the current dietary guidelines in the Netherlands (Wheel of Five) and EAT-Lancet plates were analysed.

Conclusions are drawn of what food group changes need to be made to the current average diet and the Wheel of Five in order to meet the planetary boundaries. In addition, conclusions are drawn on how the optimised Dutch diets align with the global healthy diet guidelines given by the EAT Lancet commission on a food group level, to understand the local feasibility of the commission proposal.

Additionally, suggested intake advice in grams per day are provided on the food group level to allow for added flexibility and ease of communication. However, reporting on the food group level adds a source of variability in nutritional characteristics of the diet and its environmental impact as different choices within food groups, for example, how to meet 200g vegetables per day, can lead to different nutritional and environmental impacts. This variability can be explained in best- and worst-case scenarios. For this, we highlight the extremes in the data (see Supplementary Tables).

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