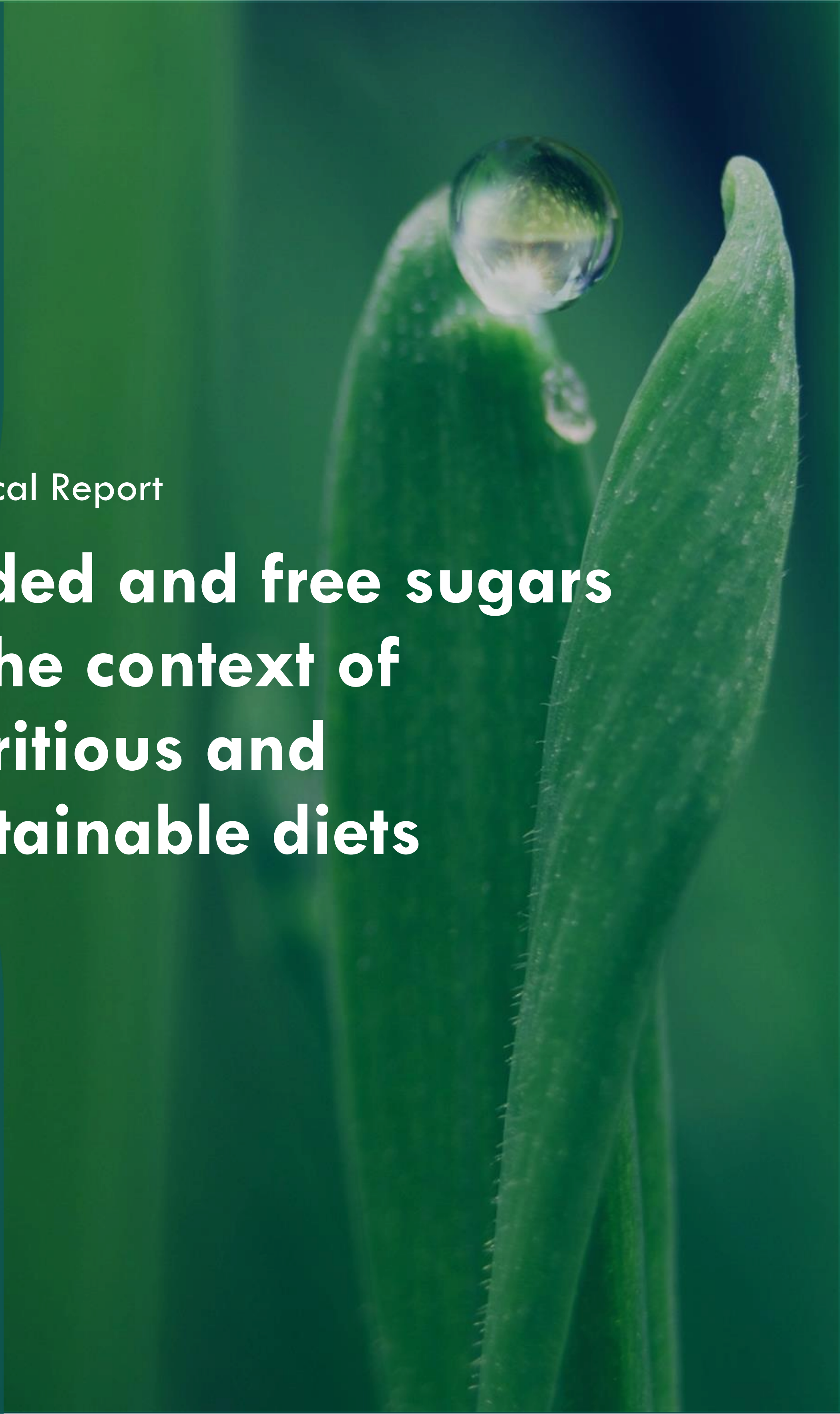
Technical Report

Added and free sugars in the context of nutritious and sustainable diets



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Blonk Consultants helps companies, governments and civil society organisations put sustainability into practice. Our team of dedicated consultants works closely with our clients to deliver clear and practical advice based on sound, independent research. To ensure optimal outcomes we take an integrated approach that encompasses the whole production chain.

Title	Added and free sugars in the context of nutritious and sustainable diets
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Abstract

The main research objective for this study is to explore how the amount of free sugars and added sugars in modeled Dutch diets that comply to national nutritional recommendations change when also aligning the diets with GHG emissions targets. The approach to this objective is a diet optimization study.

The average Dutch diet is determined based on the Dutch food consumption survey (VCP) 2012-2016 (van Rossum et al. 2018). Nutritional properties of the food products in the average diet are obtained from the VCP, based on the NEVO and NES tables (RIVM 2016, 2018). Environmental properties (farm-to-fork scope) for the food products are added based on Life Cycle Assessments (LCAs) performed by Blonk Consultants, representative for the Dutch market (van Paassen, Braconi, and Kuling 2019). Together, this information forms the basis for the reference ('baseline') diet, which is subjected to two optimization steps, using Optimeal® (Broekema et al. 2019).

The 'baseline' diet is first optimized to create three starting diets that meet nutritional guidelines but contain differing quantities of added sugars (5%, 11% and 15% of calories from added sugar). The nutritional guidelines for approximately 60 nutrients are based on Dietary Reference Values (DRVs), as advised by the Health Council of the Netherlands (Gezondheidsraad 2001, 2018; Spaaij and Pijls 2004). The Dutch food-based dietary guidelines were used to establish constraints for certain food groups (Brink et al. 2019; Kromhout et al. 2016).

Each of the diets are then optimized to meet nutritional constraints *and* an imposed greenhouse gas (GHG) target constraint. The GHG constraint is derived from the anticipated carbon budget for global agriculture considering the target to limit global warming to 1.5°C above pre-industrial temperatures (IPCC 2018).

The changes in amount of added sugars in the diets are as follows:

- For a diet that complies to nutritional constraints and contains a high amount of added sugars (15% of caloric intake, =80g/day), the amount of added sugars needs to decrease by 28% when optimizing for the 1.5 degree GHG target.
- For a diet that complies to nutritional constraints and contains an average amount of added sugars (11% of caloric intake, =60g/day), the amount of added sugars needs to decrease by 18% when optimizing for the 1.5 degree GHG target.
- For a diet that complies to nutritional constraints and contains a low amount of added sugars (5% of caloric intake, =27g/day), the amount of added sugars needs to increase by 34% when optimizing for the 1.5 degree GHG target.

Starting with high, average and low amounts of added sugars in a diet, the optimizations show that a diet that complies to nutritional constraints and a greenhouse gas emission target in line with 1.5 degrees warming can still contain added sugar. The results show that a reduction in added sugars intake is not always necessary in order to meet the nutritional constrains and greenhouse gas target. When assessing these results, the limitations related to the scope and methodology of this study should be considered.

1. Introduction

A food system transformation is essential to limit global warming to 1.5 degrees Celsius. Food systems are significant drivers of global greenhouse gas (GHG) emissions, as well as to land occupation and degradation, biodiversity loss, natural resource depletion, and nutrient flow disruption. Further, current food consumption patterns are contributing to increases in diet-related chronic diseases. Numerous studies have shown that a shift toward healthier, more sustainable diets is essential to mitigate global warming, restore nature, and improve public health outcomes (Clark et al. 2020; Springmann et al. 2018; Tilman et al. 2017).

Cosun Beet Company is interested in the role of added sugars in this context of nutritionally adequate and sustainable diets. Cosun Beet Company is interested in understanding the environmental impact of diets with various amounts of free and added sugars, considering dietary reference values for nutrition. To obtain insight in this topic, this study applies (quadratic) optimization of diets.

2. Goal & scope

Research question: How does the amount of free sugars and added sugars in modeled Dutch diets that comply to national nutritional recommendations change when also aligning the diets with GHG emissions targets?

Scope: The results should be representative for the Netherlands and based on the most recent data.

For these reasons, the following **starting points** are used:

- Greenhouse gas emissions target based on carbon budget as defined by the IPCC, to limit global warming to 1.5 degrees Celsius, equitably distributed to a projected global population.
- Starting diet based on Dutch diet from Food Consumption Survey (VCP, acronym in Dutch) 2012-2016.
- Environmental footprints of food based on most recent RIVM LCI database, developed by Blonk Consultants and last updated in 2019.
- Using most recent environmental footprint for refined sugar in the relevant products, obtained from an LCA study performed by Blonk Consultants in 2019.
- Environmental footprint of food products are projected to 2030 using findings from a trend-analysis performed by Blonk Consultants in 2016.

3. Methodology

3.1 Approach

The overall approach to the research question consists of 2 optimization steps (and subsequent analyses):

1. Optimize the (current) average Dutch diet so that it complies with Dutch dietary guidelines *and* a specific percentage of calories from added sugars. Three diets will be the result of these optimizations, containing 5%, 11% (current average) and 15% calories from added sugars. All diets are set to be equal in total calories.

    - Analyze the carbon footprint (and other environmental properties) of the start diets. This will give an indication of how the amount of added sugars in the diet relates to the environmental impact of the diet.

2. Optimize the above nutritionally compliant diets on both a greenhouse gas target (in line with maximum 1.5 degrees global warming) and nutritional guidelines. Ensure all diets are equal in total calories.

    - Analyze the composition of the GHG constrained diets, specifically: how the amount of added sugars in the diets changes. This will help to identify the operating space for added sugars in the GHG constrained diets, that comply to both the nutritional and environmental constraints.

For both optimization steps, Optimeal® is used. Optimeal is a software solution developed by Blonk Sustainability, that applies optimization 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. During an optimization, 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 (Broekema et al. 2019). More information on the optimization algorithm is provided in the Optimeal® documentation (Broekema et al. 2019).

3.2 Definitions

Then discussing the terms added, free and total sugars, it is important to clarify the exact definition. The amount of added, free and total sugars in food products is obtained from the Dutch food consumption survey (VCP) 2012-2016 (van Rossum et al. 2018). Energy and nutrient content of the food items considered in the VCP are obtained from the Dutch Food Composition Database (NEVO) (RIVM 2016) and the Dutch Supplement Database (NES) dated 1 January 2018 (RIVM 2018). The content of added and free sugars are, however, not provided in the named sources and thus calculated based on several sources as described in (Sluik et al. 2016). The definitions of these added and free sugars are described in the same publication as follows:

"Total mono- and disaccharides or total sugars comprise intrinsic sugars, lactose in milk, and free sugars, but no exact uniform definition of added and free sugars exist. In general, added sugars comprise all sugars that are added during food manufacturing and preparation. Free sugars include added sugars as well as sugars that are naturally present in honey, syrup, fruit juices, and fruit concentrates." (Sluik et al. 2016)

4. Data

For the analysis, several types of information are required as inputs:

- A reference diet of actual food intake; based on the Dutch food consumption survey (VCP) 2012-2016 (van Rossum et al. 2018).
- Nutritional properties of the food products in the reference diet, taken from the VCP, based on the NEVO and NES tables (RIVM 2016, 2018).
- Environmental properties (farm-to-fork scope) for the food products in the reference diet; based on Life Cycle Assessments (LCAs) performed by Blonk Consultants, representative for the Dutch market (van Paassen, Braconi, and Kuling 2019).
- Constraints:
    - Nutritional constraints for approximately 60 nutrients; based on Dietary Reference Values (DRVs), in this case information from the Health Council of the Netherlands (Gezondheidsraad).
    - Environmental constraint: greenhouse gas target in line with limiting global warming to 1.5 degrees Celsius.

This chapter describes the data sources and adaptations that have been made.

4.1 Reference diet & nutritional properties

The analyzed Dutch daily diet is based on the most recent Food Consumption Survey (VCP, acronym in Dutch), conducted by the Dutch National Institute for Public health and the Environment (RIVM) between 2012 and 2016 among the Dutch population (van Rossum et al. 2018). The Food Consumption Survey is based on two 24-hour recalls of food intake and was conducted among 4,313 Dutch people between 1 and 79 years old.

To obtain a balanced reflection of the daily food consumption, a weighted average is determined based on the 'representation factor' of each participant. This factor indicates to what extent the participant represents (or: counts for) persons with similar demographic characteristics to fairly represent the Dutch population.

The weighted average diet is then reduced from about 1800 different food products to about 200 products. A product is considered in the simplified diet when the product either:

- 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).

About 400 products comply to the abovementioned constraints. For very similar products (e.g., only a slight difference in preparation method exists), duplicates are removed. For the remaining 216 products, a match is made to the environmental data, as further explained in section 4.2.1.

It should be ensured that the simplified diet still represents the VCP correctly. For this, the total intake of all food-properties (quantity, calories, macro-nutrients, micro-nutrients, etc.) of the mapped food products in a food category are scaled up to include the intake of all non-mapped food products in that food category. Checks are performed to ensure the total quantity and calorie intake of the simplified diet equals the original VCP. The simplified diet is provided in Appendix 1. All nutritional properties of the food products are thus directly taken from the VCP, which in turn is based on the NEVO table.

Underreporting of food intake, in particular in overweight and obese subjects, is a widely recognized problem in diet surveys that rely on self-reporting (Barbara, Livingstone, and Black 2003), the current project chooses not to correct for this phenomenon.

4.2 Environmental properties

4.2.1 RIVM database

Food products in the average Dutch food consumption will be linked to environmental data that is as representative as possible. The RIVM LCI database will serve as a starting point for this. This database contains life cycle inventories (LCI) of the 250 most consumed products in the Netherlands and is the result of several collaborations between Blonk Consultants and RIVM (van Paassen et al. 2019). The scope of the products is 'from cradle to grave', including all life cycle stages (and thus relevant impacts) from extraction and cultivation to consumption and disposal. Food waste is considered in the database, at the retail and consumer stage. The LCI's are created in compliance with the ISO14040 and 14044 LCA-guidelines and where applicable, aligned with the Product Environmental Footprint Category Rules (ISO 14040 2006; ISO 14044 2006; Zampori and Pant 2019). The exact methodology can be found in (van Paassen et al. 2019) and a more general methodology description and results can be found in (RIVM 2019).

4.2.2 Mapping to LCI's

As discussed in the section on the VCP, the number of products in the diet is reduced to 216 relevant and sufficiently distinctive food items. Each of these food items have been linked to a representative product (or combination of products) from the latest version of the RIVM database. In case no suitable product is available in the RIVM database, slight adaptations have been made to the recipes of the products. An example is coconut-based ice-cream, which is a copy of the dairy-based ice-cream, only with the milk input replaced by coconut-milk. The methodology, assumptions and data sources are consistent with the methodology description of the RIVM database (van Paassen et al. 2019).

4.2.3 Forecasting of environmental impact

Since we optimise the diets to a GHG emission target for the year 2030, it is necessary to project the environmental impact of the diets to 2030. This is needed as there are some (ongoing) technological changes that will (likely) lead to a higher efficiency of food production in 2030.

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, more food can be produced within the aforementioned carbon budget. The climate impact trend analysis of the Menu for Tomorrow study (Kramer and Blonk 2015) formed the basis for projections of the environmental impact of food products in 2030.

This section will provide a summary of the implemented projections:

- As a result of improved efficiency at farm level, the impact of crop cultivation on all environmental indicators is reduced by 5% (Zhang et al. 2015).
- As a result of improved animal welfare (and thus longer lifespan, slower growth and more movement) the feed conversion ratio is expected to increase by 10% for pork and 20% for broilers (Hoste 2009).
- Conservative estimates project a 2% reduction in methane emissions from enteric fermentation in dairy systems and 5% reduction in GHG emissions related to manure management.

- Nitrogen efficiency is expected to increase in the coming years. It is expected that in 2030, a 30% lower input of N-fertilizers will provide the same (or improved) fertilization. All environmental impact associated with N-fertilizers are thus expected to reduce by 30%.
- More efficient technologies are expected to reduce the overall environmental impact of transport by 10% and of thermal energy by 5%. These projections are considered in all lifecycle stages.
- The prognoses of the carbon intensity reduction of average European electricity production projects a reduction of 70% between 2010 and 2050. Based on this outcome, but slightly more conservative, a 30% reduction on all environmental indicators from 2010- 2030 is applied to all electricity used in any life cycle stage (Capros et al. 2013).
- Continuous innovations in packaging are expected to reduce overall packaging emissions by 5% by 2030.
- Food waste at consumer and retail is reduced by 20% between 2010-2030 (assumption).

4.3 Constraints

4.3.1 Nutritional constraints

The nutritional constraints define the maximum 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 adults (averages for males and females), are the boundaries that are used for the optimisation process. Optimisations were conducted iso-calorically, meaning that the energy intake remained constant to 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 (Gezondheidsraad 2001, 2018; Spaaij and Pijls 2004). More specifically, population reference intakes are used where available. If values were not available, values for adequate intake were used. Upper limits of requirements were based on values for the tolerable upper intake level. DRVs for proteins, fats, and digestible carbohydrates were derived as a percent of total energy intake (en%) (Gezondheidsraad 2001). The Dutch food-based dietary guidelines were used to establish constraints for certain food groups (Brink et al. 2019; Kromhout et al. 2016).

TABLE 1. NUTRIENT AND FOOD-BASED CONSTRAINTS

Nutrient requirements	*Lower constraint*	*Upper constraint*
Energy (kcal/d) [a]	2120	2120
Protein (g/d)	49.7 (9.3 en%)	132.5 (25 en%)
Carbohydrates	212 (40 en%)	-
Fat (g/d)	58.9 (25 en%)	94.2 (40 en%)
Saturated fatty acids (g/d)	-	23.5 (10 en%)
Trans fatty acids (g/d)	-	2.4 (1 en%)
Linoleic acid (g/d)	4.7 (2 en%)	
Polyunsaturated fatty acids (g/d)		28.3 (12 en%)
n-3 fish fatty acids (mg/d)	471.1 (0.2 en%)	
Fiber (g/d)	32	
Retinol activity equivalent (µg/d)	740	-
Thiamin (mg/d)	0.94	-
Riboflavin (mg/d)	1.6	-
Niacin (mg/d)	15	-
Vitamin B6 (mg/d)	1.5	-
Folate (µg/d)	300	1000
Vitamin B12 (µg/d)	2.8	-
Vitamin C (mg/d)	75	-
Vitamin D (µg/d)	3.3	-
Vitamin E (mg/d)	12	-
Vitamin K (µg/d)	105	-
Calcium (mg/d)	955	-
Phosphorous (mg/d)	550	-

Iron (mg/d)	13.5	24
Sodium (mg/d)	-	2400
Potassium (mg/d)	2500	-
Magnesium (mg/d)	325	565
Zinc (mg/d)	8	25
Selenium (µg/d)	70	300
Copper (mg/d)	0.9	-
Iodine (µg/d)	150	-
Food groups		
Vegetables (g/d)	250	-
Fruit (g/d)	200	-
Whole grains (g/d)	90	-
Nuts (g/d)	15	-
Milk and dairy products	300	450
Meat (g/d)	-	71.4
Red meat (g/d)	-	42.9
Fish (g/d)	14.3	-

[a] Based on mean habitual intake

4.3.2 Environmental target

Human-induced greenhouse gas emissions are accumulating in the atmosphere, increasing radiative forcing and in this way warming up our planet. The effects of global warming, summarized as 'climate change', are far-reaching and have a large impact on all life on earth. In the influential Paris Agreement, a target was set to limit global warming to 1.5 degrees Celsius above pre-industrial times. This target is ambitious, but required to limit the risk of disastrous effects of climate change for all life on earth. To reach the 1.5-degree target, net global greenhouse gas emissions should not exceed the annual carbon budget as determined by the Intergovernmental Panel on Climate Change (IPCC) (IPCC 2018). Staying within this carbon budget requires continuous emission reductions in all sectors.

For this study, the aim is to find a diet that might comply with the 1.5-degree target. This diet, in combination with the expected emission reductions that take place in food production (section 4.2.3), should stay within the fair share of the total carbon budget calculated for 2030. The carbon budget per person, per day is found by calculating the carbon budget for agriculture for the year 2030 and dividing this by the projected world population and the number of days in a year. This procedure is explained in more (technical) detail in the paragraph below.

The climate change constraint implemented in the second optimization step represents a globally equitable per person allocation of the anticipated carbon budget for global agriculture. This reduction target is based on the IPCC's 1.5 degree assessment study (IPCC 2018), which presents four pathways that can limit global warming to 1.5 degrees by 2050, and presents associated agricultural emission reductions for methane, carbon dioxide and nitrous oxide. These emission reductions are applied to the overall emissions of the agricultural sector in 2010, which is derived from the FAO analysis of agricultural emissions 1990-2011 (Tubiello et al. 2014) combined with the sum of emissions related to agrochemical production, food processing, distribution and consumption which was derived from Vermeulen (Vermeulen, Campbell, and Ingram 2012). This amounts to total emissions of 8.9 Gton CO_2eq for the global food system in 2010. Applying the derived reduction percentages for the greenhouse gases results in a target of 6.3 Gton CO_2eq for the global food system in 2030. When dividing this by the population forecast of 2030 (United Nations: Department of Social and Economic Affairs 2019) and the total number of days in a year, the maximum daily share of allowable emissions per person per day amounts to 2.04 kg CO2-eq. In this methodology, each person (regardless of their age and geospatial characteristics) is allocated a fair share of the global carbon budget. The calculated daily, personal carbon budget for food is thus equal throughout all analysed age groups. This methodology is explained in more detail in (Broekema et al. 2020).

4.3.3 Food product constraints

Besides the nutritional and environmental constraints, which apply to the diet as a whole, constraints are defined on an individual food product level. Minimum and maximum product constraints help to ensure that the optimised diet is acceptable to the general consumer. Maximum product constraints ensure that the optimised diet does not contain large amounts of individual products which are generally not consumed in large quantities. Minimum product constraints ensures that no individual product is excluded from the optimised diet and thus contributes to a varied diet. The maximum and minimum constraints are based on the Dutch food consumption survey (VCP 2012-2016).

The 95th percentile of food consumption was taken as the maximum constraint. This allows for reasonable (meaning not unrealistically large) dietary changes in the diets. The minimum consumption level of every product is set to 10% of the current diet. This minimum ensures that a diverse set of food products maintain in the diet, without compromising on the ability to find solutions in the optimizations.

5. Results

5.1 Overall finding

The overall results are depicted in Figure 1. The dots in the figure depict the different diets, the carbon footprint of the diets is shown on the horizontal axis and the amount of added sugars in the diets is shown on the vertical axis. The results show the following:

- For a diet that complies to nutritional constraints and contains a high amount of added sugars (15% of caloric intake, =80g/day), the amount of added sugars decreases by 28% when optimizing for the 1.5 degree GHG target.
- For a diet that complies to nutritional constraints and contains an average amount of added sugars (11% of caloric intake, =60g/day), the amount of added sugars decreases by 18% when optimizing for the 1.5 degree GHG target.
- For a diet that complies to nutritional constraints and contains an low amount of added sugars (5% of caloric intake, =27g/day), the amount of added sugars increases by 34% when optimizing for the 1.5 degree GHG target.

Figure 2 is similar to Figure 1, but instead of the amount of added sugars in the diets, the vertical axis depicts the amount of free sugars. The results are very similar to the results for added sugars, the main difference being that the amount of free sugars is always higher than the amount of added sugars.

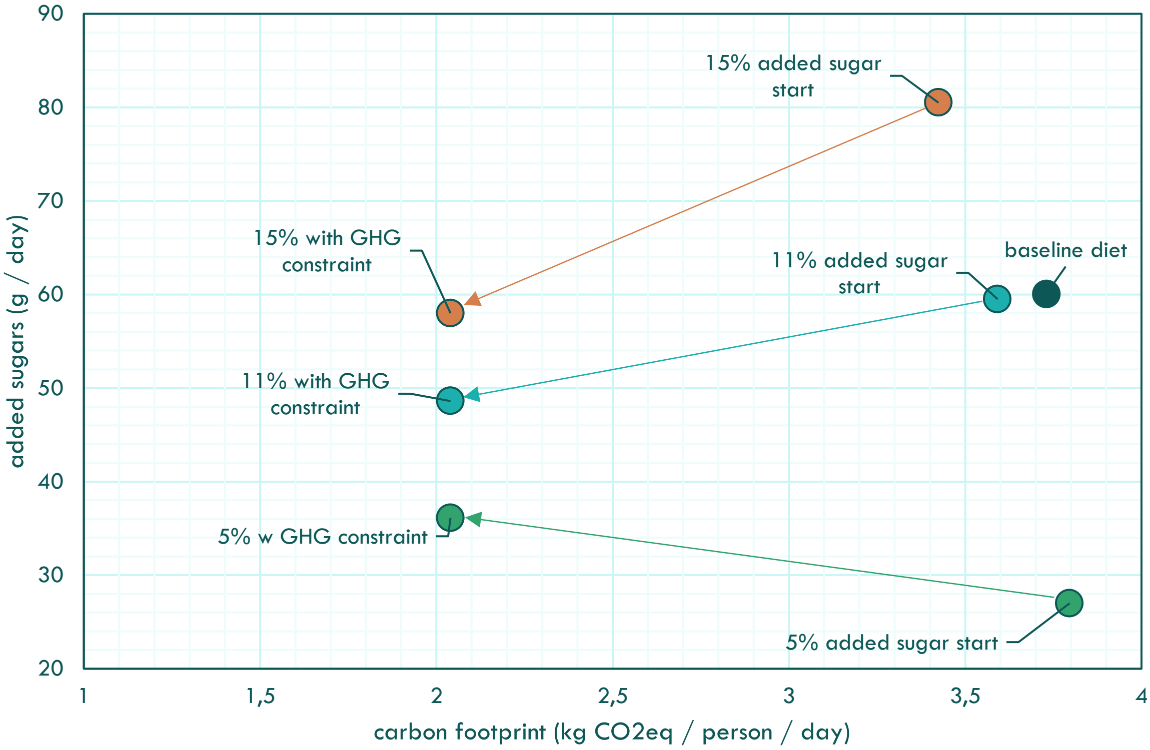

FIGURE 1. SUMMARY OF RESULTS, SHOWING CARBON FOOTPRINT AND ADDED SUGARS QUANTITY FOR THE BASELINE DIET, OPTIMIZATIONS WITH NUTRITIONAL CONSTRAINTS (START DIETS), AND OPTIMIZATIONS WITH NUTRITIONAL AND GHG EMISSION CONSTRAINTS.

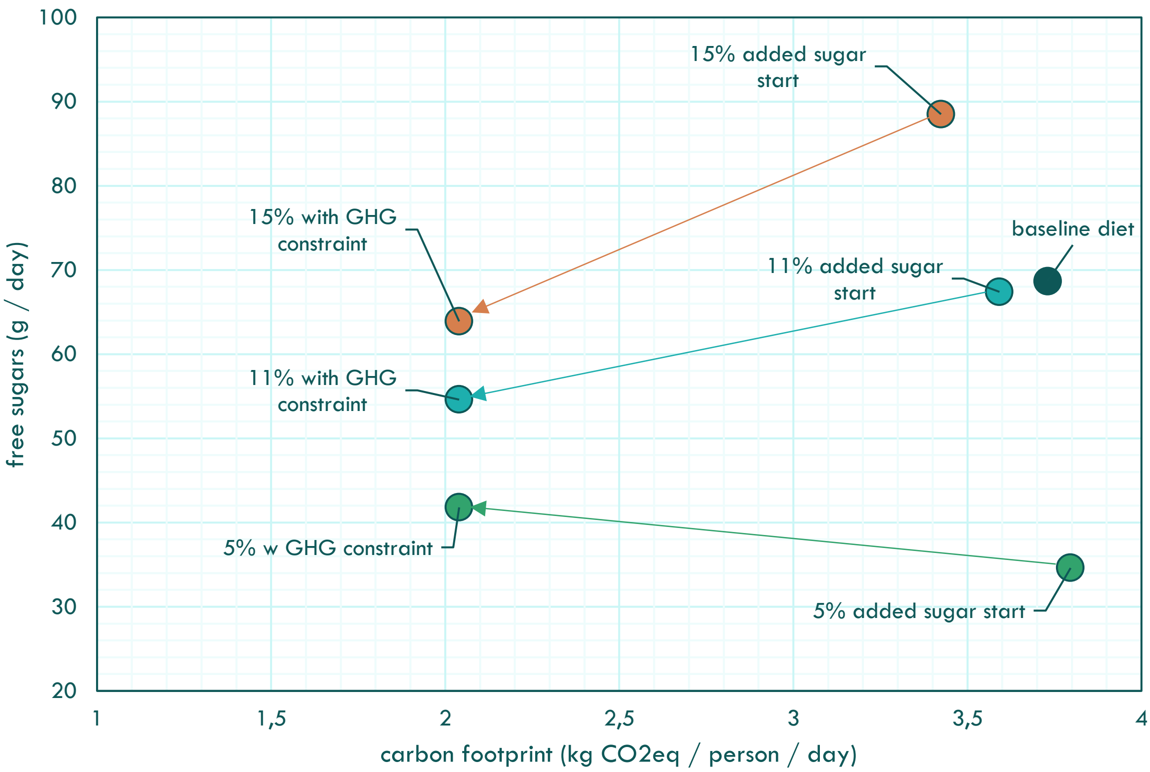

FIGURE 2. SUMMARY OF RESULTS, SHOWING CARBON FOOTPRINT AND FREE SUGARS QUANTITY FOR THE BASELINE DIET, OPTIMIZATIONS WITH NUTRITIONAL CONSTRAINTS (START DIETS), AND OPTIMIZATIONS WITH NUTRITIONAL AND GHG EMISSION CONSTRAINTS.

5.2 Diet composition

The composition of the diets examined in this study are presented in Table 2 in terms of grams of food consumed in various food groups. All diets contain ~2120 kcal. The baseline diet, reflecting the current average Dutch diet, is the stepping off point for all optimizations. "Start diets" are those optimized to nutritional constraints with a set quantity of added sugars (5, 11 and 15% of caloric intake). These start diets are then further optimized with nutritional constraints *and* the GHG emission constraint.

One observation that emerges from this diet composition data is that in all GHG constrained diets, the quantities of both fruits and vegetables arrive at the minimum intake imposed by nutritional constraints, based on recommendations of 200 grams fruit and 250 grams vegetables per day (see Section 4.3.1). These minimums are reached because the optimization routine attempts to stay as close to the reference diet as possible (and the baseline Dutch diet contains less fruit and vegetables than are recommended). Also of note is the quantity of red meat (beef, lamb, pork) as well as chicken arrive at the minimum intake imposed by constraints on individual food products included in order to assure diversified diets (see Section 4.3.3). In other words, these meat-products would likely be further reduced in the optimization if these minimum constraints had not been imposed. Another interesting observation is that the quantity of vegetarian meat alternatives *decreases* when GHG emission constraints are imposed, likely because legumes and other protein sources have lower footprints.

TABLE 2. FOOD GROUP COMPOSITIONS IN DIETS INVESTIGATED. CELLS SHADED IN GREEN ARE AT THE MINIMUM VALUE ALLOWABLE UNDER NUTRITIONAL GUIDELINE CONSTRAINTS. CELLS SHADED IN ORANGE REPRESENT MINIMUMS IMPOSED BY FOOD PRODUCT CONSTRAINTS SET TO ASSURE DIVERSIFIED DIETS.

Food Groups	Quantity in diet (g/person/day)						
	Baseline diet	5% added sugar		11% added sugar		15% added sugar	
		start diet	w/ GHG constraint	start diet	w/ GHG constraint	start diet	w/ GHG constraint
Alcoholic beverages	140	133	96	128	93	124	92
Animal and vegetable fats and oils	22	30	77	25	77	23	76
Beef, lamb and pork	64	38	6	29	6	22	6
Chicken	29	20	3	17	3	15	3
Composite food	18	6	16	6	15	3	14
Dairy replacers	6	17	62	21	62	24	63
Drinking water	716	716	714	716	714	716	714
Eggs and egg products	13	14	12	13	11	13	11
Fish and other seafood	17	55	37	55	36	55	37
Fruit and fruit products	136	200	200	200	200	200	200
Grains and grain-based products	197	234	224	222	215	213	207
Herbs, spices and condiments	58	39	39	54	47	57	47
Legumes	19	95	73	86	73	87	77
Milk and dairy products	348	315	241	328	241	328	239
Non-alcoholic beverages	987	962	927	984	948	987	950
Nuts, seeds and peanuts	9	24	28	15	26	15	25
Snacks, desserts, and other foods	61	35	16	40	20	36	20
Starchy roots and tubers	61	65	62	63	60	62	59
Sugar and confectionary	29	2,94	21	33	25	60	36
Vegetables and vegetable products	114	250	250	250	250	250	250
Vegetarian meat alternatives	2	36	8	32	4	32	4

TABLE 3. QUANTITIES OF ADDED SUGARS, FREE SUGARS AND TOTAL SUGARS IN INVESTIGATED DIETS.

Diet	quantity in start diet (g)			quantity w/ GHG constraint (g)			Change (%)		
	Added sugar	Free sugar	Total sugar*	Added sugar	Free sugar	Total sugar*	Added sugar	Free sugar	Total sugar*
15% added sugar	81.1	88.5	140.8	58.0	63.9	117.5	-28.0	-27.8	-16.6
11% added sugar	60.0	67.4	121.2	48.6	54.6	110.2	-18.3	-19.1	-9.1
5% added sugar	27.0	34.6	91.0	36.1	41.8	101.6	33.8	20.7	11.7

*total mono- and disaccharides

5.3 Monte Carlo analysis

Monte Carlo analysis can assist in demonstrating the sensitivity of the optimization routine to potential uncertainty in underlying parameters. Optimeal includes a standard Monte Carlo functionality allowing up to 100 iterations (Broekema et al. 2019). For clarity, the analysis is briefly explained here. In the Monte Carlo analysis, the optimization is simulated not once but many times, each time with slightly different food properties drawn from the anticipated uncertainty (e.g., slightly more calories or lower carbon footprint per kg product). The result of this set of simulations is a distribution of results that represents the range of possible outcomes given the anticipated uncertainty of input parameters.

The Monte Carlo analysis assumes a coefficient of variation of 0.125 for all input parameters. Thus, each property will be assigned a random value between -25 and +25% (2 times the CV) of the start value in each Monte Carlo iteration. It is expected that this range covers the likely range of uncertainty of the food properties.

Table 4 shows the results of the Monte Carlo analysis in the last three columns. The first and third quartile (Q1, Q3) values in the last two columns represent the range between which 50% of all Monte Carlo simulations fall.

TABLE 4. QUANTITIES OF **ADDED SUGARS** IN DIETS, AND RESULTS OF MONTE CARLO ANALYSIS

Diet	quantity in start diet (g)	quantity w/ GHG constraint (g)	Change (%)	Monte Carlo distribution		
				Median (g)	Q1 (g)	Q3 (g)
15% added sugar	81.1	58.0	-28.0	59.0	54.8	62.4
11% added sugar	60.0	48.6	-18.3	50.7	48.1	53.2
5% added sugar	27.0	36.1	33.8	36.5	33.5	39.5

The Monte Carlo results show that the median of the distribution lies close (within 4%) to the second step optimization (column 'quantity W GHG target (g) in Table 4). Also, the ranges between the first and third quartile are rather narrow. What's more; all values within the range point towards the same conclusion as the main result: In the GHG optimization, the quantity of added sugars in the diet decreases for the diets with 11% and 15% calories from added sugars and increases for the diet with 5% calories from added sugars. This indicates that uncertainty in food properties would not alter this main results of the study: the optimization results are reasonably stable to input parameter uncertainties.

5.4 Other environmental indicators

While environmental constraints imposed in the optimization were limited to greenhouse gas emissions, it is informative to consider other environmental impacts to assure that there aren't significant trade-offs when reducing carbon footprint. A full suite of environmental indicators, including, carbon footprint, acidification, freshwater eutrophication, marine eutrophication, land use, land use change and water depletion associated with the diets under study, presented relative to the baseline diet, are depicted in Figure 3. For more information on what the environmental impact categories entail, please consult Appendix II.

In this figure, the units of the environmental indicators are noted, but the vertical axis is the percent change from the baseline diet (baseline diet = 100%).

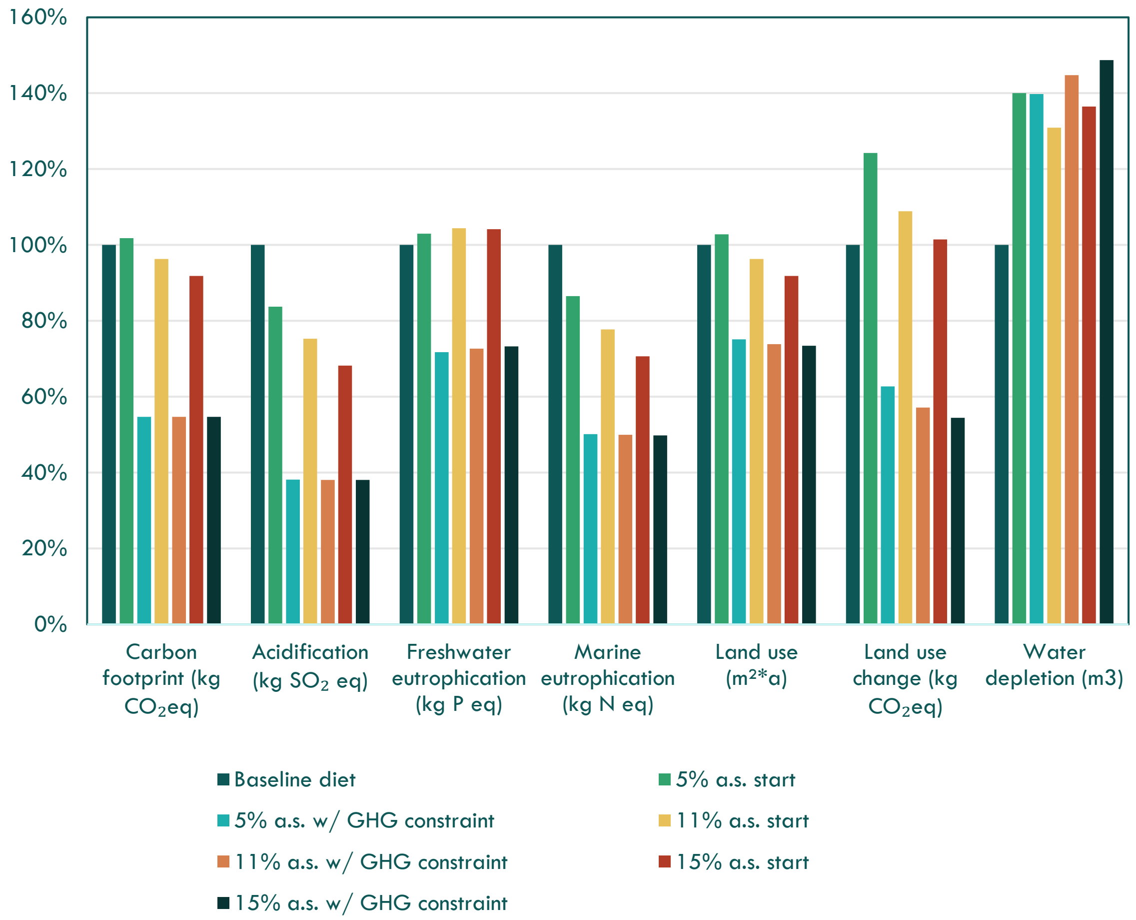

FIGURE 3. ENVIRONMENTAL IMPACT OF ALL DIETS UNDER STUDY RELATIVE TO THE BASELINE DIET (BASELINE DIET = 100%).

Comparing the environmental impacts of the start diets shows that the carbon footprint is lowest for the start-diet containing 15% calories of added sugars, followed by the 11% and the 5% start-diet. This is also visible in Figure 1. Similarly, the impact on acidification, marine eutrophication, land use and land use change emissions are lowest for the start diet containing 15% of calories from added sugars. For freshwater eutrophication and water use, the differences between the start-diets are less pronounced.

In the optimization with a greenhouse gas (or: carbon footprint) constraint, the impact on nearly all other environmental impacts also vastly reduces. In specific, the optimization reduces the impact on acidification (about 60% reduction for all diets); marine eutrophication (50% reduction for all diets); land use change emissions (between about 40 and 50% reduction); freshwater eutrophication and land use (about 25% reduction for both indicators for all diets). In contrary, an increase in water depletion impact is observed for all diets and the impact for GHG constrained diets is not lower compared to the start diets. An explanation for the first observation can be found in the high water impact of nuts and certain fruit products (e.g., oranges and orange juice) and their increased intake in the start diets and GHG constrained diets compared to the baseline diet.

In these GHG constrained diets, the difference between the 5%, 11% and 15% diets are less pronounced compared to the start-diets. Especially the impact on acidification, eutrophication and land use is nearly the same for all GHG constrained diets. The impact on land use change emissions is slightly lower for the diet containing 15% calories from added sugars, followed by the 11% and the 5% start-diet. The opposite holds for water depletion, where the impact is highest for the 15% diet.

6. Discussion

6.1 Context of diet optimization

All food products, and their properties, play a role in finding diets that comply to the set nutritional constraints and GHG target. A multitude of nutrients are provided by a multitude of food products; the ability to find a nutritious and GHG-compliant diet can thus not be attributed to a single food product or property.

The changes in the diet composition, as stated in Section 5.2, show that the GHG constrained optimization causes a shift from animal-based products (such as meat and dairy) to nutritional plant-based alternatives (such as nuts and dairy replacers). Due to the high carbon footprint associated with animal-based products, this shift can be identified as the main activator of the carbon footprint reduction.

Identifying the exact role of added and free sugars in the optimization is challenging. The results at least show that added and free sugars fit into the diets that comply with nutritional constraints and the GHG target, thanks to the carbohydrates and calories they provide for a relatively low carbon footprint.

6.2 Specific findings

This paragraph discusses the results this study, and its reliability. The results are found through an optimization algorithm, which can, under some scenarios lead to erratic or unstable (i.e., highly sensitive to small changes) outcomes. For this reason, it is important to verify that different aspects of the findings point towards the same conclusion.

The results generally show that for a start diet which is relatively high in added sugars (15% of caloric intake), the amount of added sugars would reduce by 28% under nutritional and GHG-constrained optimization. For an average amount of added sugars in the start diet (11% of caloric intake), an 18% reduction in added sugars is observed. A start diet that is relatively low on added sugars (5% of caloric intake) shows an increase in added sugars of 34%.

Free sugars and total sugars (approximated by total mono- and disaccharides) show similar trends as added sugars in the optimizations. This is an indication that the change of added sugars in one direction is not offset by a change in other types of sugarsin the opposite direction.

To validate the reliability of the results, a Monte Carlo analysis has been performed. The Monte Carlo analysis shows that in 50% of the optimizations, the amount of added sugars in the GHG constrained diets does not vary more than 5% from the initially found value. This result shows that uncertainty in food properties does not have a strong influence on the overall optimization outcome. This strengthens the reliability of the results.

In the GHG constrained optimization, a reduction of impact on several other environmental indicators is also observed. The impact on water depletion, however, increases. This finding shows that the GHG constrained diets may comply to the set GHG target, but does not directly mean that the diet is 'sustainable' regarding all environmental pressures.

6.3 Assumptions and limitations

The assumptions and limitations are presented in bullet points and mainly apply to the methodological choices made in the study.

- The acceptable amount (or range) for added sugars in the GHG constrained diets can vary with different starting diets. The starting diets now comprised 15, 11 and 5% of caloric intake from added sugar. With diets that contain more than 15% or less than 5% of caloric intake from added sugars, it is likely that the amount of added sugars in the GHG constrained diets may be outside of the found range.
- It is assumed that diets with the smallest deviation from the start diet are easiest to adopt by consumers. The diets that are noted in the results section are thus solutions with the smallest deviation from the start diet, however, more diet compositions can be found that comply with the set constraints (which require a larger deviation from the start diet).
- The minimum intake of each food product in the Dutch diet is set to at least 10% of the current average intake of that food product, this assumption steers the results. The constraint forces the optimization to maintain all the products, guaranteeing diversity in the GHG constrained diet, but also limiting the

possible solutions. Certain high-footprint food products (e.g. beef products) might have been completely eliminated in the GHG constrained diets if this constraint were not in place.

- It is important to keep in mind that in this study, nutritionally adequate diets are defined as diets that comply to the dietary reference values (DRVs) and food-based dietary guidelines for Dutch adults (Brink et al. 2019; Gezondheidsraad 2001, 2018; Kromhout et al. 2016; Spaaij and Pijls 2004). Possible other health advices, among those related to added sugars intake, are out of scope of this study.
- The reference diet is based on full population from 0-79 year-olds, not specifically on the population group which is in scope: adults.
- In the diets, no distinction is made between men and woman, although dietary compositions vary among these groups. The overall conclusions are assumed to hold for both females and males.
- The Dutch food-based dietary guideline to minimize the intake of sugar-containing beverages is not considered in the optimization, as it would require a value-choice to quantify this qualitative recommendation into a numerical constraint.

7. Conclusions

The main research objective for this study was to explore how the amount of free sugars and added sugars in modeled Dutch diets that comply to national nutritional recommendations change when also aligning the diets with GHG emissions targets. The approach to this objective was a diet optimization study. The average Dutch diet is first optimized to create three starting diets that meet nutritional guidelines but contain differing quantities of added sugars(5%, 11% and 15% of calories from added sugar). Each of the diets are then optimized to meet nutritional constraints *and* an imposed GHG target constraint.

The changes in amount of added sugars in the diets are as follows:

- For a diet that complies to nutritional constraints and contains a high amount of added sugars (15% of caloric intake, =80g/day), the amount of added sugars needs to decrease by 28% when optimizing for the 1.5 degree GHG target.
- For a diet that complies to nutritional constraints and contains an average amount of added sugars (11% of caloric intake, =60g/day), the amount of added sugars needs to decrease by 18% when optimizing for the 1.5 degree GHG target.
- For a diet that complies to nutritional constraints and contains an low amount of added sugars (5% of caloric intake, =27g/day), the amount of added sugars needs to increase by 34% when optimizing for the 1.5 degree GHG target.

Starting with high, average and low amounts of added sugars in a diet, the optimizations show that a diet that complies to nutritional constraints and a greenhouse gas emission target in line with 1.5 degrees warming can still contain added sugar. The results show that a reduction in added sugars intake is not always necessary in order to meet the nutritional constrains and greenhouse gas target.

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Appendix I Life cycle assessment

This description of a life cycle assessment is taken from a previous report written by Blonk Consultants for WWF-Belgium (te Pas, de Weert, and Broekema 2021).

Life Cycle Assessment (LCA) is a method to evaluate and quantify the environmental impact of a product or service. Life Cycle Assessment captures the whole supply chain (from cradle to grave) with its individual stages. From raw-material production, production, distribution, transportation, use and disposal of a specific product (or service). Different environmental impacts are assessed, for instance greenhouse gas emissions, water consumption and fossil depletion.

The goal of an LCA is to get insights in the environmental impacts of a product or service, by quantifying all inputs and outputs of material flows. The results of an LCA can be applied for product development, strategic planning, marketing, and communication towards customers.

Figure AII1: Example of life cycle approach

Why assess the impact?

There are different motives to assess the impact of a product. Some examples are: decouple environmental impact from growth, reduce resource depletion and create novel products (for example alternative protein sources, energy efficient solutions), establish cost reduction, raise public awareness and involvement (for example regarding deforestation, sustainable fishing, healthy and sustainable nutrition), adaptation of healthy lifestyles.

Steps of an LCA

In order to review all the inputs and outputs and calculate the environmental impacts various steps need to be undertaken. The International Organisation for Standardisation (ISO) provides guidelines related to LCA (ISO 14040 and 14044 (ISO 14040 2006; ISO 14044 2006). Four different steps are proposed, each of them is explained in more detail.

1. Goal & Scope definition

The first step of goal and scope definition involves the stating and justification of the whole study. First, the goal of the study is explained, together with its primary intentions, followed by the intended audience and the involved parties of the study. In order to define the goal of the study the following questions need to be answered: 'What is the reason for carrying out the study?', 'What is the intended application?' and 'What is the targeted audience of the deliverables?'.

The scope definition phase establishes the main characteristics of the whole study. What to analyse and how? The product system is introduced and the scope of the analysed product system is explained (e.g. cradle-to-grave or cradle-to-gate). Hereby, the following items are important to outline: function, functional unit, alternatives and reference flow(s) of the product(s). Eventually, the results and comparison will be based on the reference flow(s).

2. Inventory analysis: Data collection

The life cycle inventory (LCI) stage estimates the consumption of resources and quantifies the waste flows and emissions caused or attributable to the tray's life cycle. LCA, each and every flow should be followed until its economic inputs and outputs have all been translated into environmental interventions (=emission or resource), from economy to environment or vice versa. To do this, three different system boundaries need to be defined:

Economy-environmental system boundary: describes which processes belong to the economy and environment.

Cut-off: discusses the processes that are irrelevant or not taken into consideration during the whole LCA study.

Allocation: assigning the environmental impacts of multifunctional systems. Three different multifunctional processes exist: coproduction, recycling and combined waste processing. In each of the scenarios the environmental impacts need to be allocated over de different functional flows. The allocation method can either based of physical properties of the flows (mass or energy content), economic value or substitution (avoided product).

At this stage data needs to be collected and modelled. This forms the main part of the LCA studies. It gives inputs

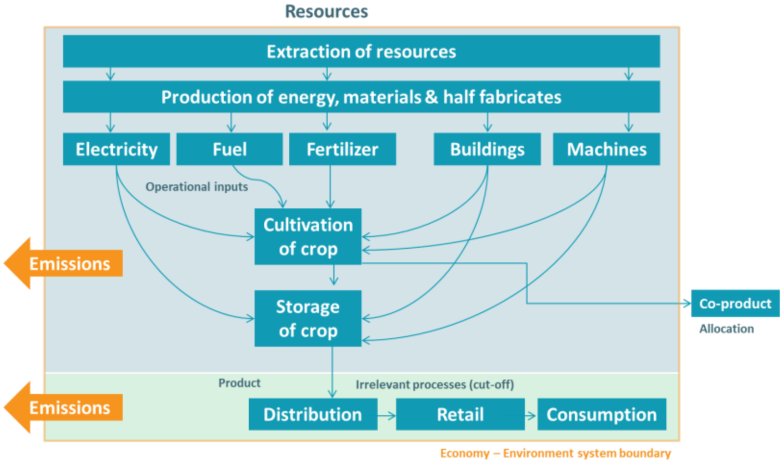


Figure AII2: Example of the cradle-to-gate system boundaries that is applied for agricultural products

for the Life Cycle Impact Assessment and gives feedback to the initial scope setting. The collected data consists preferably of primary data for the most important processes, the so-called fore-ground processes. Economic flows of these foreground processes are connected to so-called background processes to include inventory data from up- and downstream processes. Background databases can be used for this purpose, examples include Agri-footprint®, ELCD and Ecoinvent database. Result of the LCI is the inventory table, an extensive list of environmental interventions.

3. Impact assessment

During the life cycle impact assessment (LCIA) the inventory tables from the LCI are used to determine the environmental impact of reference flows for different impact categories. This is done by first selecting the impact categories that are relevant for the study. This depends on the type and goal & scope of the study. More information about impact categories, in the next paragraphs.

Next step is to translate the inventory table into impact indicator results (impact categories). This is usually performed using specialized software, like Simapro. The following steps are performed to get from the inventory table to impact category results. This can be best explained using the impact category “climate change” as example, but works similarly for all impact categories.

Classification – the software classifies the emitted greenhouse gasses from the inventory table. Hereby all, non-greenhouse gasses are lest out from the analysis for this impact category.

Characterisation – the impact of each greenhouse is calculated based on the mass and potency of the greenhouse gas in respect to the indicator unit. The indicator unit for global warming at mid-point level is kg CO2-equivalents. Each kg of emitted carbon dioxide is 1 kg CO2-eq., however methane is a more potent greenhouse gas and each kg of emitted methane is equivalent to 25 kg of CO2. The potency of the greenhouse gasses or “characterisation factors” for greenhouse gasses are derived from IPCC and updated from time to time.

Normalisation – this is an optional step to compare the significance of the footprint to the total impact of the world or European region. This can give an idea about the significance of the category impact.

Weighting - this is an optional step to aggregate indicator results of various impact categories into a single score. However, weighting has always been a controversial issue in LCA studies (Finnveden, Eldh, and Johansson 2006) and is therefore usually not performed.

4. Interpretation

The final phase of the LCA discusses the overall result from the previous steps. Interpretation begins with a consistency and completeness check to determine the soundness of the study. The contribution and sensitivity analysis helps to bolster the robustness of the results in preparation of the discussion and conclusion of the report. Each of the four optional steps are discussed in more detail.

Consistency check: the objective of the consistency check is to determine whether assumptions, methods, models and data are consistent with the goal and scope of the study.

Completeness check: ensure that the information and data used for this study are available and complete.

Contribution analysis: illustrates the main contributing processes for each impact category. This helpful in understanding the product system(s) better.

Sensitivity analysis: assesses the influence on the results of variations in process data, model choices and other variables. During the sensitivity analysis some of the important parameters are deliberately changed in order to determine the robustness of the results.

What follows is the discussion and the conclusion of the main research question for the study.

Presenting results in LCA studies

LCA results can be shown in multiple ways, at midpoint and at endpoint level. Midpoint are considered to be a point in the environmental cause-effect chain mechanism of a particular impact category (See Figure), prior to the endpoint at which characterization factors can be calculated to reflect the relative importance of an emission or extraction in a life cycle inventory (Bare et al. 2000). Both midpoint and endpoint level indicators have complimentary merits and limitations. Results at mid-point indicators are argued to be more certain but can have lower relevance for decision support. Whereas endpoint indicators are considered to have higher relevance but lower certainty.

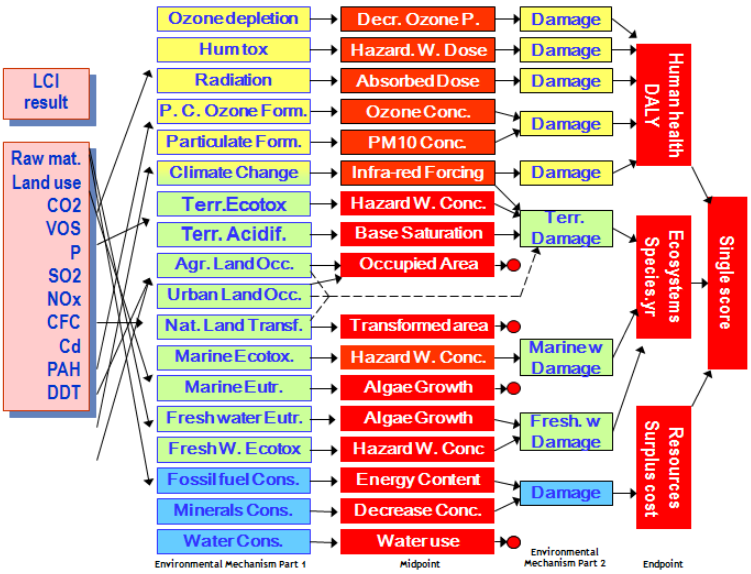


Figure AII3: Graphic illustration of basic differences between the midpoint and the endpoint results (Goedkoop et al. 2013)

Because endpoints have lower certainty and involves the controversial process of weighting different impact categories, mid-points are always used to present results of LCA studies performed by Blonk Consultants. As default, impact categories from ReCiPe (version 1.13) are used to present results, using the hierarchical version. ReCiPe is chosen, since it is the most recent and harmonized indicator approach available in life cycle impact assessment. Optionally the mid-point results can be aggregated into a single score end-point result using the ReCiPe endpoint method.

Definitions used in LCA

Following LCA definitions are derived from the LCA handbook (Guinée et al. 2002)

Impact category: a class representing environmental issue of concern to which environmental interventions are assigned, e.g. climate change, loss of biodiversity.

Category indicator: A quantifiable representation of an impact category, e.g. infrared radioactive forcing for climate change.

Category unit: Unit to express the category indicator.

Characterisation factor: a factor derived from a characterisation model for expressing a particular environmental intervention in terms of a common unit of the category indicator.

Characterisation method: a method for quantifying the impact of environmental interventions with respect to a particular impact category; it compromises a category indicator, a characterisation model and characterisation factors derived from the model.

Characterisation unit: used to express the indicator result which is the numerical result of the characterisation step for a particular impact category, e.g. 12 kg CO2-equivalents for climate change.

Impact categories

An LCA evaluates the environmental impact of a product or service. There exist various impact categories, such as climate change, freshwater eutrophication and agricultural land occupation. Table AII1 gives an overview of the impact categories, defined by ReCiPe methodology. In order to transform the extensive list of life cycle inventory results into a limited number of indicator scores the ReCiPe methods has been developed. These indicator scores express the relative severity on an environmental impact category.

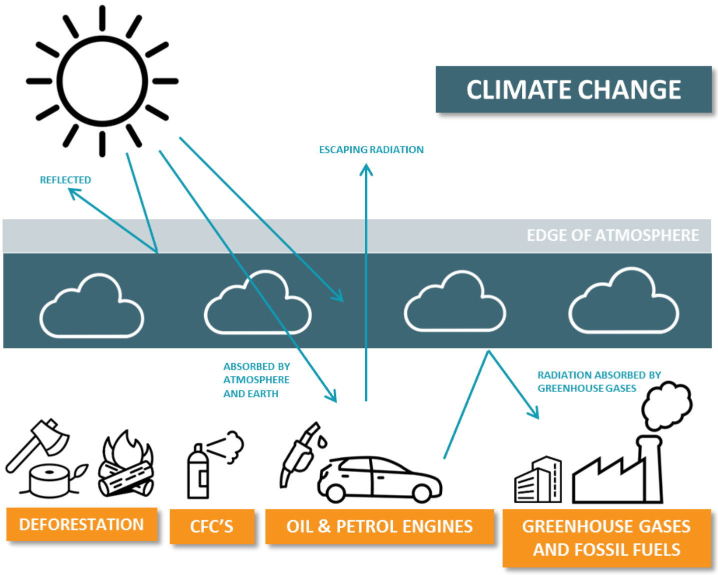
Table AII1: Category indicators, units, characterisation factors, and indicator results for 18 ReCiPe impact categories

Impact category	Category indicator	Indicator unit (mid-point)	Characterisation factor (mid-point)	Indicator unit (mid-point)	End-point	Indicator unit (end-point)
Climate change	infra-red radiative forcing	W*yr/m^2	GWP$_{100}$	kg CO_2 eq.	ü (2x)	DALY + species/yr
Ozone depletion	Stratospheric ozone concentration	ppt*yr	ODP	kg CFC-11 eq.	ü	DALY
Terrestrial acidification	base saturation	yr*m^2	TAP	kg SO_2 eq.	ü	species/yr
Freshwater eutrophication	phosphorus concentration	yr*kg/m^3	FEP	kg P eq.	ü	species/yr
Marine eutrophication	nitrogen concentration	yr*kg/m^3	MEP	kg N eq.		
Human toxicity	hazard-weighted dose	m^2*yr	HTP	kg 1,4-DB eq.	ü	DALY
Photochemical oxidant formation	photochemical ozone concentration	kg	POFP	kg NMVOC	ü	DALY
Particulate matter formation	PM_{10} intake	kg	PMFP	kg PM10 eq.	ü	DALY
Terrestrial ecotoxicity	hazard-weighted dose	m^2*yr	TETP	kg 1,4-DB eq.	ü	species/yr
Freshwater ecotoxicity	hazard-weighted dose	m^2*yr	FETP	kg 1,4-DB eq.	ü	species/yr
Marine ecotoxicity	hazard-weighted dose	m^2*yr	METP	kg 1,4-DB eq.	ü	species/yr
Ionising radiation	absorbed dose	man*Sv	IRP	kBq U235 eq.	ü	DALY
Agricultural land occupation	occupation	m^2	ALOP	$m_2$anually	ü	species/yr
Urban land occupation	occupation	m^2	ULOP	$m_2$anually	ü	species/yr
Natural land transformation	transformation	m^2	NLOP	m_2	ü	species/yr
Water depletion	amount of water	m^3	WDP	m_3		
Metal depletion	grade decrease	kg^{-1}	MDP	kg Fe eq.	ü	$
Fossil depletion	upper heating value	MJ	FDP	kg oil eq.	ü	$

Most ReCiPe mid-point impact categories can be translated to end-point result. First, the environmental impact are grouped into three different domains: human heath, ecosystems and resources. Reference unit at end-point are DALY, species lost per year and surplus cost for each domain respectively. These results can then be further aggregated into a single score (points).

Appendix II Environmental impact categories

Climate change (carbon footprint)



Climate change refers to the change in weather patterns. Climate change heats up the earth slowly and is often called global warming. These changes have an impact on the quality of life on earth. Climate change is caused by various factors, such as biotic processes, plate tectonics, variations in solar radiation received by the earth, volcanic eruptions. Besides that, human activities have significant influence on climate change. Examples are fossil fuel combustion, agriculture and deforestation. These processes result in higher concentration of greenhouse gases (GHG's) in the atmosphere. CO_2 is one of the greenhouse gases (GHG) that has an impact on climate change. Besides that, there exist other greenhouse gases that contribute to global warming, for instance methane and nitrous oxide. These other gases, with an impact on climate change, are also included and expressed in equivalents with the same impact as CO_2. For results at mid-point, carbon dioxide is taken as reference unit, therefore 1 kg of CO_2 is 1 kg CO_2 equivalents. More potent greenhouse gasses include methane (34 kg CO_2-eq/kg) and nitrous oxide (298 kg CO_2-eq/kg). Within LCA studies, for the impact category climate change only human activities are taken into account. At end-point results for global warming are presented in human health effects (DALY) and effects on the environment (species lost per year).

All environmental impact indicators

All indicators used in this study are shortly described in Table 5.

TABLE 5: RECIPE2016 IMPACT INDICATORS

Impact indicator	Description
Climate Change	All inputs or outputs that result in greenhouse gas emissions. The greatest contributor is generally the combustion of fossil fuels such as coal, oil and natural gas. The consequences include increased average global temperatures and sudden regional climatic changes. Climate change is an impact affecting the environment on a global scale. Unit of measurement: Kilogram of Carbon Dioxide equivalent (kg CO2 eq). During the calculations, the global warming potential of all greenhouse gas emissions are compared to the amount of the global warming potential of 1 kg of CO2
Terrestrial acidification	Changes in acidity of the soil are caused by atmospheric deposition of acidic substances. Serious changes are harmful for specific species. In the ReCiPe 2016 methodology three acidifying emissions are taken into account. These emissions are: NOx, NH3 and SO2. NOx is mainly formed during combustion processes. Agriculture is the main source for NH3. Energy combustion (coal) counts mainly for SO2 emissions. Unit of measurement: kilogram SO2 eq.
Freshwater and marine eutrophication.	Eutrophication impacts ecosystems due to substances containing nitrogen (N) or phosphorus (P). These nutrients cause a growth of algae or specific plants and limit growth in the original ecosystem. Eutrophication is an impact which affects the environment at local and regional scale. Unit of measurement: kg N eq for Marine Eutrophication and kg P eq for Freshwater eutrophication.
Land use	Occupation refers to the use of a land cover for a certain period, and it is measured as area-time (m2*yr).
Water use	The withdrawal of water from lakes, rivers or groundwater can contribute to the 'depletion' of available water. Unit of measurement: cubic metres (m3).

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