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Assessing the Health and Environmental Benefits of a New Zealand Diet Optimised for Health and Climate Protection

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Abstract: Population diets have impacts on both human and planetary health. This research aims to optimise a New Zealand (NZ) version of the EAT-Lancet diet and to model the impact of this diet on population health if it was adopted in NZ. The optimisation methods used mathematical equations in Excel to ensure: population diets met the nutritional recommendations; diet-related greenhouse gas (GHG) emissions did not exceed the NZ GHG boundary; and diet costs did not exceed baseline costs of the average diet. The EAT-Lancet diet was also directly mapped onto the NZ adult nutrition survey food groups, as another estimate of a NZ EAT-Lancet diet. Both diets were modelled using a DIET multi-state life-table model to estimate lifetime impacts on quality adjusted life years (QALYs), ethnic health inequities and health system costs. The optimised diet differed greatly from baseline intake with large amounts of fruits and vegetables, some fish but no beef, lamb, pork or poultry. Modelling nationwide adoption of the NZ EAT-Lancet diets generated large health savings (approximately 1.4 million QALYs), and health system cost savings (around NZD 20 billion). A healthy, climate-friendly, cost-neutral diet is possible for NZ and, if adopted, could provide large health gain, cost savings and reductions in ethnic health inequities.

Keywords: diet; climate; greenhouse gas emissions; health impact; health inequities

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1. Introduction

Diet is an important risk factor for cardiovascular disease, diabetes and various cancers [1], with an appreciable reduction in disease burden expected should population diets shift towards healthier patterns. High intakes of sodium and low intakes of whole grains and fruits are the leading dietary risk factors for global death [1] with obesity, another diet-related risk factor, leading to further incidence of chronic disease.

Unhealthy diets and obesity are major causes of health loss in NZ [2]. NZ diets are low in fruit and vegetables and contribute to high rates of overweight and obesity [3]. Poor diet is also responsible for ethnic health inequities in NZ. Māori (Indigenous population) are less likely to meet guidelines for recommended servings of fresh fruit and vegetables and processed meat than the general population [3], dietary practices which are risk factors for non-communicable diseases [1].

Alongside the health consequences directly associated with a poor diet, the health effects of environmental degradation are widely apparent and could pose extreme risks to human health in the coming decades. These stem from disruptive climate change, land degradation and biodiversity loss among others [4] and are likely to cause a variety of direct and indirect health effects [5]. A recent Lancet Commission described the interrelated combination of obesity, undernutrition and climate change as a global syndemic [6].

Shifts in diet away from processed foods and towards more vegetables, legumes, whole grains and fruit are likely to have health and environmental co-benefits [7]. In 2019, the EAT-Lancet Commission published a paper on healthy diets from sustainable food systems where they proposed an international reference diet based on Rockström et al.'s planetary boundaries [8]. Rockström et al. outlined the nine planetary boundary limits within which we expect that humanity can operate safely [9]. Six of these are greatly affected by food production (climate change, biodiversity loss, freshwater use, interference with the global nitrogen and phosphorus cycles, and land-system change). The EAT-Lancet Commission proposed a 'Great Food Transformation' including a global reference diet to bring these six key earth system processes within safe operating boundaries. The reference diet is high in vegetables, legumes, whole grains, fruit and plant sources of protein and low in animal sources of protein.

The results of the EAT-Lancet Commission are consistent with the international literature which shows sustainable diets are high in unprocessed plant-based foods and low in animal-based foods [10,11]. Much of this research is on GHG emissions [10,12–14] with less attention given to the other planetary boundaries [15]. However, synergies have been shown between dietary impacts on GHG emissions and on other planetary boundaries such as land use and water use [15,16].

EAT-Lancet takes a global perspective and notes that their framework does not provide a plan for translating the proposed global targets to national targets. The development of a country specific version of the EAT-Lancet diet is an important research gap. This research translates the global approach to a national diet for NZ and could also provide a template for other countries to replicate.

This research aims to estimate, using optimisation methods, a NZ-specific version of the EAT-Lancet diet that remains within the NZ-specific boundary for GHG emissions while meeting key nutritional requirements. The optimised NZ diet, along with the 'EAT-Lancet base scenario' (where the EAT-Lancet diet was directly mapped onto the NZ adult nutrition survey food groups) were modelled as theoretical changes to NZ population dietary intakes. The impact of these changes on health gain in QALYs, ethnic health inequities, health system costs and costs to the individual were assessed to illustrate the total gain that is possible through shifting to sustainable diets. It is essential to consider these multiple outcomes when implementing policy in the context of climate change and the obesity epidemic, which have been identified as the paramount health challenges of our time [6].

2. Materials and Methods

2.1. Optimising a Healthy, Sustainable Diet

Optimisation methods were used to develop a NZ sustainable healthy diet using the baseline NZ diet, as of the last representative Adult Nutrition Survey (ANS) (2008/09), as a starting point [17]. These methods use mathematical equations that ensure: population micronutrient (and some macronutrient) intakes at least meet the nutritional recommendations; that total fat, saturated fat, sugar and sodium do not exceed the nutritional recommendations; and that diet-related GHG emissions do not exceed the NZ boundary (the GHG emission Planetary Boundary scaled to the NZ context based on comprehensive NZ data) [18]. In addition to GHG emissions not exceeding this threshold, minimising GHG emissions was also the main target of the optimisation. The diets were also optimised to ensure the cost to the consumer did not exceed the baseline costs of the average diet (details below) while still meeting the GHG emissions and nutritional adequacy constraints.

Optimisation: Optimisation was carried out in Microsoft Excel using a template model used in previous work [19]. An Excel add in, "Solver" was used to optimise the intake of food groups by weight (grams(g)). The solver function works with a group of cells, called decision variables (e.g., fruit in g). Solver adjusts the values in the decision variable cells to satisfy the limits on constraint cells and produce the desired result for the objective cells (e.g., Total sugar content of the diet).

Optimisation was carried out on the baseline (2008/09) dietary intake for Māori males, Māori females, non-Māori males and non-Māori females [17]. Within each of the individual Excel sheets for each population group the baseline intake was available for 185 separate

ANS food groups. These are based on the 31 broad adult nutrition survey food groups with those food groups related to the food based dietary guidelines being split out into their more detailed food groups (e.g., Peas/beans/corn). The other food groups were included as the broader categories (e.g., Bread based dishes). This gives the optimisation model more options to choose from without exceeding the maximum options the solver function can work with (200, see Table S1 for the list of food groups included, including those at the more detailed level and the broader level).

These multiple constraints were applied to the gram intake of food groups at the same time. We used GHG emissions as a worked example here. The total GHG emissions was constrained to stay below the NZ GHG boundary. GHG associated with food production (per gram of food group) was multiplied by the consumption of each food group and emissions were summed to give the total over the day. This total was then compared with the constraints (i.e., NZ GHG boundary) during the solver process and the gram intake of each food group was shifted until the emissions met the constraint.

Nutritional constraints: The recommended dietary intakes (RDI) from the 'Nutrient reference values (NRV) for Australia and NZ' (https://www.health.govt.nz/publication/nutrient-reference-values-australia-and-new-zealand, accessed on 23 May 2022) were used to determine the nutritional constraints. This is the average daily intake level of a particular nutrient that is sufficient to meet the requirements of nearly all healthy individuals in a particular life stage and gender group. Where RDIs were not available, Average Intakes (AI) from the NRV, or relevant recommendations from the World Health Organization, Food and Agriculture Organisation or the UK Scientific Advisory Committee on Nutrition were used. Nutrition recommendations often varied by age and sex but not by ethnicity. To account for the different nutrient recommendations by age the recommendations were weighted by the number of people in the NZ population at each age group to give an estimate that could be applied to all ages within the four sex-by-ethnicity groups used in the optimisation (Table S2).

The nutrient content for the food groups outlined above are based on the average nutrient content of specific foods eaten in the ANS and the overall nutrient content is weighted based on the amount consumed of each specific food in the overall survey (not broken down by sex and ethnicity).

Nutritional constraints were applied to keep optimised intake above the recommendations for specific macronutrients and micronutrients (protein, polyunsaturated fat, fibre, calcium, iron, zinc, selenium, phosphorus, potassium, vitamin C, folate, niacin, riboflavin, thiamine, vitamin B6, vitamin B12, vitamin A, vitamin D, vitamin E, and iodine, see Table S2 for recommendations used). Constraints were set to ensure optimised diets did not exceed the recommended maximum intakes for sodium, total fat, saturated fat and total sugars. Dietary energy was constrained to between 90% and 110% of baseline intakes (equal to a standard deviation of 5% of the mean assuming a normal distribution). A series of optimisation scenarios were carried out, outlined below. The aim was to pro-vide a comprehensive picture of what kinds of optimised diets might be possible in a NZ context.

- 'All nutrients scenario': All macronutrients and micronutrients with NZ or international nutrient recommendations (RDI or other) used as constraints: protein, polyunsaturated fat, fibre, calcium, iron, zinc, selenium, phosphorus, potassium, vitamin C, folate, niacin, riboflavin, thiamine, vitamin B6, vitamin B12, vitamin A, vitamin D, vitamin E, iodine, sodium, total fat, saturated fat and total sugars (N = 24)
- Micronutrients scenario: calcium, iron, zinc, selenium, phosphorus, potassium, vitamin C, folate, niacin, riboflavin, thiamine, vitamin B6, vitamin B12, vitamin A, vitamin D, vitamin E, iodine and sodium (N = 18)
- Key nutrients scenario: Micronutrients of potential concern in a sustainable (low red meat and dairy) diet (N = 6: protein, vitamin B12, vitamin D, calcium, iron, and zinc) [20–22].

Additional food group constraints were added to ensure that these diets met NZ food based dietary guidelines (updated December 2020) [23]:

- Fruit and vegetable intakes met or exceeded the age- and gender-specific guidelines (in grams/day (g/d))
- Red meat intake did not exceed the 500 g a week guideline
- Total grain intakes met the age- and gender-specific guidelines (the recommendations for this food group are in KJ rather than grams, e.g., Women over 70 years should have 3 serves with a serve being 500 KJ)
- Protein foods met the age and gender specific guidelines (in KJ rather than grams)
- Milk and milk products met the age and gender specific guidelines (in KJ rather than grams)

GHG emissions constraint: A NZ boundary for GHG emissions calculated for the NZ Ministry for the Environment (MfE) by the Stockholm Resilience Centre was used as an upper limit in optimisation [18]. The figure used is the fair share of food system environmental impacts per capita allocation for 2010. The 0.7-ton CO_2-eq/capita/year was divided by 365 to get a daily allocation and then multiplied by 1000 (to convert tons to kg) to give 1.9486 $kgCO_2$-eq/capita/day.

Price constraint: Price of the food consumed was optimised not to exceed the baseline food price (prices for both the baseline diet and the optimised diet were per food group in 2011 NZ dollars). Price of food group per 100 g was obtained from the Nutritrack 2011 database (a brand-specific packaged food database) and attached to the consumption data from the ANS 2008/09 data [17].

Realistic portions constraint: The final constraint applied in this optimisation was to ensure that the amount of food per food group was as realistic as possible. This is necessary as the mathematical optimisation will select as many grams of a specific food group as necessary to meet the optimisation requirements, whether it is realistic for a person to consume these amounts or not. This constraint was applied at the 185-food group level (Table S1) and when the optimisation chose a gram intake that was twice the baseline intake (this threshold was selected after an iterative process starting at ten times baseline intake and reducing it down to twice the baseline intake) then the amount was constrained to only one portion of the food group a day.

2.2. Translating the EAT-Lancet Diet for Modelling

The EAT-Lancet diet provides recommended intakes in both grams and calories (converted to kilojoules, KJ) per day for a range of food groups: Whole grains; tubers or starchy vegetables; vegetables; fruits; dairy foods; protein sources; added fats; added sugars, some with subgroups with specific recommendations (e.g., under protein sources: pork, eggs, tree nuts, etc.). To model the impact of New Zealanders following the EAT-Lancet diet these broad food groups were matched to the 338 food groups from the ANS which are used in the DIET multi-state life-table (MSLT) modelling [24] (details in next section). The main scenario modelled was based on the gram recommendations (referred to as the 'EAT-Lancet base scenario').

To divide the recommended amount of grams in the EAT-Lancet diet (e.g., whole grains) among the ANS modelling food groups (26 in the case of wholegrains), the amounts were weighted by the baseline consumption in the ANS to partially account for NZ food preferences. For the next scenario, the recommended KJ in the EAT-Lancet diet was divided among the ANS modelling food groups based on their baseline KJ contribution within the relevant food group in the baseline ANS diet. The EAT-Lancet diet also stated which of the protein foods were exchangeable with other protein foods. An additional scenario (based on gram recommendations only) was carried out, which treated these exchangeable food groups as one larger food group with the amounts weighted to baseline consumption, to give greater flexibility and to allow the diet to be more like the baseline diet ('EAT-Lancet exchange scenario'). These processes were repeated in all four sex by ethnic groups (Māori or non-Māori) used in modelling.

2.3. DIET Multi-State Life-Table (MSLT) Modelling

The NZ population alive in 2011 (N = 4:4 million) was modelled out to death or until age 110 in the DIET MSLT Model [24]. The model is parameterized with rich national data by sex, age, and ethnicity. The model includes a range of dietary risk factors (high intake of red meat, processed meat, sugar-sweetened beverages, and sodium as well as low intake of fruit, vegetables, and polyunsaturated fat) and nine diseases associated with one or more dietary risk factors: coronary heart disease, stroke, type 2 diabetes and multiple cancers (esophageal, colorectal, ovarian, head and neck, lung and stomach). A change in body mass index (BMI) was ignored in this research as the energy intake of these diets are set during optimisation to between 90% and 110% of baseline intake. If modelling BMI as a risk factor, this prescribed increase/reduction in BMI for the different sex by ethnic groups would drive the health gain seen and there is uncertainty around the likely change in energy intake under these scenarios.

Changes in dietary risk factors resulting from the population switching to eating these optimised diets were combined with disease-specific relative risks obtained from the Global Burden of Disease (GBD) study [25] through population impact fractions that alter the incidence of diet-related diseases in the model. The change in diet related disease incidence contributed to the QALY calculations in two ways. Firstly, for those living with any of these diseases, disease-specific morbidity was assigned in each disease state using disability weights derived from the Global Burden of Disease study [26]. Secondly, with a change in disease incidence comes a change in the number of deaths from the disease. QALYs are a composite measure of these changes in morbidity and mortality. Health system costs associated with incidence, prevalence and death from each of the modelled diseases, and for individuals without disease, were estimated according to a specific protocol [27]. Ethnic inequities in health were quantified through estimating QALYs for Māori and non-Māori separately and presenting the age standardised ratio of per capita QALY gains by ethnicity. We take a health systems perspective and model impacts over the lifetime of the cohort. We use 3% discounting as standard. We used Monte Carlo simulation to estimate uncertainty in the modelling outputs, by drawing randomly from probability distributions about all input parameters, including baseline input parameters specified with uncertainty in Table S3. Detailed modelling methods are included in the technical report [24].

The GHG emissions associated with the food groups used in the optimisation and the DIET MSLT modelling were from a previously developed NZ-specific life-cycle assessment (LCA) database [10]. It was developed by modifying cradle to point-of-sale reference emissions estimates from an established UK database [28] to the NZ context. Each NZ ANS food group was matched to a NZ-specific LCA (if available) or a food category from the reference UK LCA database and emissions estimates were assigned accordingly. UK emissions estimates were modified to be more relevant to the NZ context by modifying GHG emissions associated with transportation and electricity usage.

Scenario and sensitivity analyses: The 'all nutrients scenario', which meets the most optimisation criteria, and the 'EAT-Lancet base model' were modelled as the base cases. We carried out a routine equity analysis for Māori in which potential health gains are "valued" similarly between Māori and non-Māori [29]. The modelling results of the 'micronutrients scenario' and the 'key nutrients scenario' were included in the scenario and sensitivity analysis table (Table S5). The 'EAT-Lancet exchange scenario' and 'EAT-Lancet KJ scenario' were modelled as additional scenarios. The 'all nutrients scenario' and the 'EAT-Lancet base scenario' were also both modelled with no discounting.

3. Results

3.1. Optimisation Results

For the 'all nutrients scenario', 'micronutrients scenario' and 'key nutrients scenario', solutions were found with constraints added to up to 30 food groups to keep optimised intake at realistic amounts.

For the 'all nutrients scenario', GHG emissions were optimised to between 1.79 kgCO$_2$-eq and 1.87 kgCO$_2$-eq, just under the NZ boundary threshold (Table 1). This scenario represented between 42% of baseline emissions for Māori males to 63% of baseline emissions for non-Māori females. The price of the optimised diets ranged from 70% of baseline diets in Māori males to 88% of baseline diets in Māori females. The energy intake varied between 90% of baseline energy intake in males to 110% in females, which was the full range of the optimisation restrictions. The total grams of the diet (excluding non-alcoholic beverages) ranged from 106% of baseline intakes in non-Māori males to 132% in Māori females.

Table 1. Descriptions of the optimised diets for the 'all nutrients', 'micronutrients' and 'key nutrients' scenarios for the four demographic groups.

	GHG Emissions (% of Baseline)	Price (% of Baseline)	Energy Intake (% of Baseline)	Total Grams of Diet, Excluding Beverages Except Milk (% of Baseline) *
All nutrients scenario				
Total population **	1.83 (54%)	$12.82 (79%)	8778 (100%)	1548 (118%)
Māori males	1.87 (42%)	$13.83 (70%)	10,000 (90%)	1640 (109%)
Māori females	1.79 (62%)	$12.57 (88%)	8542 (110%)	1514 (132%)
non-Māori males	1.85 (46%)	$13.13 (71%)	9104 (90%)	1580 (106%)
non-Māori females	1.82 (63%)	$12.40 (87%)	8292 (110%)	1507 (128%)
Micronutrients scenario				
Total population **	1.66 (49%)	$16.42 (100%)	9358 (106%)	1480 (112%)
Māori males	1.66 (37%)	$18.65 (94%)	10,515 (95%)	1594 (106%)
Māori females	1.95 (67%)	$14.36 (100%)	8542 (110%)	1562 (136%)
non-Māori males	1.65 (41%)	$18.58 (100%)	10,406 (103%)	1590 (106%)
non-Māori females	1.62 (56%)	$14.32 (100%)	8292 (110%)	1338 (113%)
Key nutrients scenario				
Total population **	1.59 (47%)	$14.29 (87%)	8704 (99%)	1265 (96%)
Māori males	1.60 (36%)	$16.02 (81%)	10,000 (90%)	1424 (95%)
Māori females	1.95 (67%)	$11.36 (79%)	7581 (98%)	1283 (112%)
non-Māori males	1.59 (39%)	$15.02 (81%)	9108 (90%)	1285 (86%)
non-Māori females	1.53 (53%)	$13.81 (96%)	8292 (110%)	1215 (103%)

* excluding non-alcoholic beverages (while still including milk). This was to allow for a useful comparison between baseline intake (which included water) and the optimised diet (which does not include water, as it had no optimisation criteria set against it). ** This is a population weighted result based on the sex by ethnic group results, rather than it being optimised for the total population.

For the 'micronutrients scenario', GHG emissions were optimised to between 37% and 67% of baseline emissions. The price of the optimised diets ranged from 94% of baseline diets in Māori males to 100% of baseline diets in all other sub-groups. The energy intake varied between 95% of baseline energy intake in Māori males to 110% in females. The total grams of the diet ranged from 106% in males to 136% in Māori females.

For the 'key nutrients scenario', GHG emissions were calculated to be between 36% (Māori males) and 67% (Māori females) of baseline emissions. The price of the optimised diets ranged from 79% of baseline diets in Māori females to 96% of baseline diets in non-Māori females. The energy intake varied between 90% of baseline energy intake in males to 110% in non-Māori females. The total grams of the diet ranged from 86% in non-Māori males to 112% in Māori females.

3.2. Selected Food Groups in Optimisation Scenarios

Figure 1 presents the population weighted average amount of broad food groups in each of the three scenarios for the whole NZ population, for any food group that has more than 50 g/person/day. Baseline intake from the ANS, for these food groups, is included in this figure. All three scenarios include large amounts of 'Fruit' and 'Vegetables' and moderate amounts of 'Bread'. There are some differences between the scenarios with the 'all nutrients' and 'micronutrient' scenarios having large amounts of 'Dairy products and alternatives', mainly due to large increases in 'Soy yoghurt' (Table S4). The 'all nutrients' and 'key nutrients' scenarios have moderate amounts of 'Milk' (although less than baseline intake).

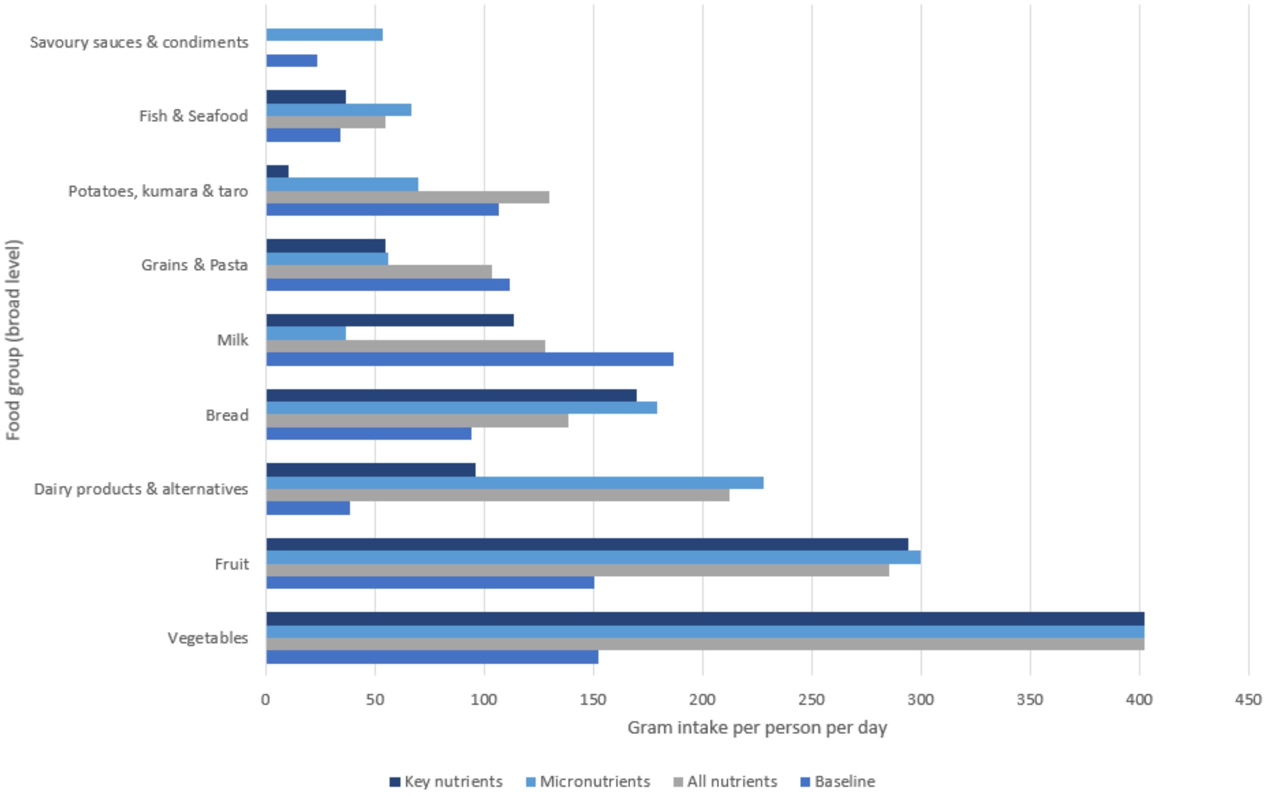

Figure 1. Intake of broad food groups providing 50 g or more to one of the scenarios (excluding baseline) for each optimisation scenario.

Figure 2 follows the same format as Figure 1 but shows results for the detailed food groups. The 'all nutrients' scenario has a much higher intake than the other scenarios for 'Other pomme fruit' (e.g., Nashi pear), 'Oranges', and 'Calcium-enriched milk' and a much higher intake than the 'key nutrients' scenario for 'Mature legumes and pulses' and 'Soy yoghurt'. All three scenarios have much higher intakes than baseline for 'Carrots', 'Onions, garlic and leeks', 'Yams' and 'Canned salmon'. The 'micronutrients' and 'key nutrients' scenarios have much higher intakes of 'Mature legumes and pulse products and dishes', 'Meat substitute and dishes', 'Bananas', 'Pear', 'Evaporated and condensed milk' and 'Novelty ice cream' (e.g., on a stick) than both baseline and the 'all nutrients' scenarios.

3.3. DIET MSLT Modelling Results

Table S4 presents the grams per food group of the 32 broad food groups of all modelled scenarios, alongside baseline intake which serves as business as usual (BAU) in the DIET MSLT modelling. Table 2 presents how the different dietary intake of the two diets translates into a change in dietary risk factors used in the modelling. The 'all nutrients scenario' has a greater increase in fruit intake than the 'EAT-Lancet base scenario' and a similar increase in vegetable intake. It has a similar decrease in red and processed meat, approximately 100 g a day for both diets and both have about 110 g per day decrease in sugar sweetened beverage intake. The 'EAT-Lancet base scenario' has a large increase in nuts and seeds (44 g/d) compared to just 8 g/d in the 'all nutrients scenario'. The 'EAT-Lancet base scenario' has a greater decrease in sodium and a greater increase in polyunsaturated fat intake.

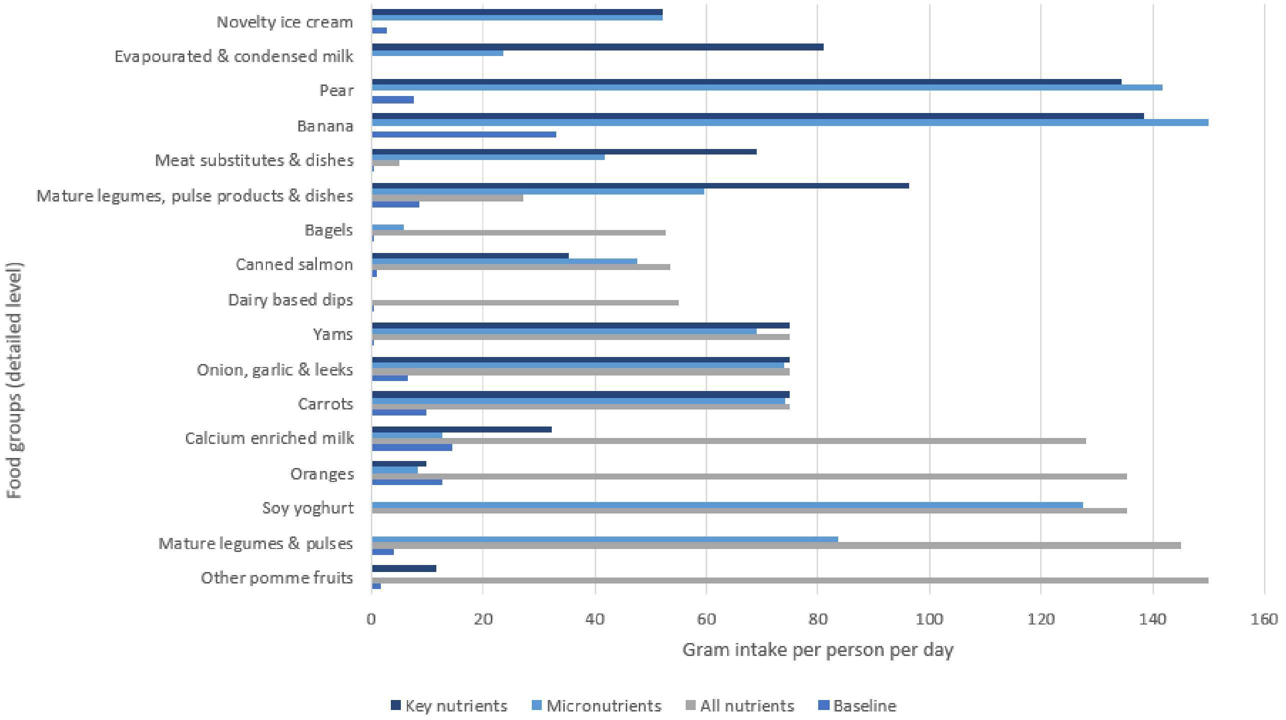

Figure 2. Intake of detailed food groups providing 50 g or more to one of the scenarios (excluding baseline) for each optimisation scenario.

Table 2. Change in dietary risk factors for optimised 'all nutrients scenario' and the 'EAT-Lancet base scenario'.

	Optimised Sustainable NZ Diet (Percent of Baseline Intake)	**EAT-Lancet Diet (Percent of Baseline Intake)**
Δ Fruit (g/day)	135.4 (90%)	50.2 (33%)
Δ Vegetables (g/day)	250.1 (164%)	266.8 (175%)
Δ Red meat (g/day)	−53.1 (−100%)	−45.3 (−85%)
Δ Processed meat (g/day)	−56.7 (−91%)	−60.8 (−97%)
Δ SSB (g/day)	−109.3 (−100%)	−109.2 (−100%)
Δ Nuts and seeds (g/day)	8.4 (137%)	43.9 (712%)
Δ Sodium (mg/day)	−453.5 (−21%)	−611.6 (−29%)
Δ PUFA (% of total energy)	2.7 (53%)	7.7 (150%)

Δ: change in; SSB: sugar sweetened beverages; PUFA: Polyunsaturated fatty acids.

Both modelled sustainable healthy diets produce large health gains when the whole of the NZ population is modelled to follow them: 1.4 million QALYs for both diets (Table 3). These are accompanied by large cost savings to the health system at NZD 19.7 billion (in NZD 2011 value) for the 'optimised sustainable NZ diet' and NZD 20.5 billion for the 'EAT-Lancet base scenario'. QALY gains are between 26% and 30% higher in males than in females. QALY gains for Māori increase by around 35% when the equity analysis is applied for both diets. Age standardised per capita QALY gains are 70% and 90% higher in Māori than in non-Māori and this increases to 140% and 160% when the equity analysis is applied. Table S5 shows the health gain and cost savings in the subsequent 10 and 20 years. Health gains and cost savings were approximately 5% and 13% of lifetime health gains and cost savings in the subsequent 10 years and were 19% and 36% in the subsequent 20 years.

Compared to the 'all nutrients scenario', health gain is very similar for the 'micronutrients scenario' and the 'key nutrients scenario', as are cost savings (Table S6). Age standardised per capita health gains are 90% higher for Māori in both the 'micronutrients scenario' and the 'key nutrients scenario'. The 'all nutrients scenario' with no discounting gives the expected larger health gains and cost savings but only a 50% higher health gain for Māori (compared to non-Māori) when future health gain is valued the same as current health gain (0% discounting). When the more flexible version of the EAT-Lancet diet is modelled ('EAT-Lancet exchange scenario') estimated benefits expressed in Table S6 are very similar to the 'EAT-Lancet base scenario'. When the 'EAT-Lancet KJ scenario' is modelled health gains and cost savings are approximately 5% lower than the 'EAT-Lancet base scenario'. A similar pattern is seen with the 0% discounting sensitivity analysis as was seen with the 'all nutrients scenario'.

Table 3. Quality adjusted life years (QALYs) and health system cost savings of the optimised 'all nutrients scenario' and the 'EAT-Lancet base scenario'.

	Non-Māori	**Māori**	**Māori**	**Ethnic Groups Combined**	
	Health Gains: QALYs	**Health Gains: QALYs**	**Equity Analysis Health Gains: QALYs ***	**Health Gains: QALYs**	**Net Health System Cost Savings (2011 NZ$ Billion)**
Optimised sustainable NZ diet					
Sex groups combined **	1,057,000 (843,800 to 1,290,900)	313,600 (260,000 to 372,500)	428,900 (349,200 to 517,600)	1,370,600 (1,107,600 to 1,664,000)	$19.7 (14.8 to 25.1)
Men	621,500	167,500	228,600	789,000	$11.9
Women	435,500	146,000	200,400	581,600	$7.8
Per capita ***	283.3 (345.2)	465.1 (600.7)	636.2 (823.7)	311.1	$4473.8
EAT-Lancet diet					
Sex groups combined **	1,035,200 (829,400 to 1,267,200)	339,600 (279,700 to 406,600)	462,000 (375,500 to 563,800)	1,374,800 (1,110,000 to 1,676,000)	$20.5 (15.5 to 26.3)
Men	609,200	198,500	268,700	807,800	$12.6
Women	426,000	141,100	193,300	567,000	$7.9
Per capita ***	277.5 (337.8)	503.7 (650.3)	685.3 (886.9)	312.1	$4649.7

* potential health gains are "valued" similarly between Māori and non-Māori by assigning non-Māori background mortality and morbidity rates to Māori [29]. ** results for sex groups combined are presented with 95% uncertainty intervals in brackets. *** per capita results are QALYs/1000 people and $/person. QALYs for Non-Māori and Māori are presented with age standardised health gains in brackets.

4. Discussion

Whether recommendations for intakes of all 24 nutrients or just 6 key nutrients were considered in the optimisation, diets which met all constraints were able to be found. These diets had lower GHG emissions with similar food costs and energy intakes as the baseline diets. These scenarios varied greatly from baseline intake with larger amounts of fruits and vegetables, some fish but no beef, lamb, pork, poultry or other meat (with the exception of pies and pasties for males in the 'all nutrients' scenario). Variation was also seen between the optimised scenarios, especially when looking at the detailed food group results. However, except for 'Novelty ice cream', the food groups selected to be more than 50 g were all foods that undergo minimal processing such as 'Fruits', 'Vegetables', 'Soy yoghurt', 'Canned salmon', and 'Calcium-enriched cow's milk'.

The modelling results showed that the optimised diet and the EAT-Lancet diet translated to the NZ context would generate large health savings and health system cost savings, approximately 1.4 million QALYs and around 20-billion-dollar savings. Per capita health gains were also higher for Māori than for non-Māori showing that if shifts towards these healthy sustainable diets could be achieved to the same degree in Māori as in non-Māori, then this would help to reduce health inequities between Māori and non-Māori.

This package of results clearly illustrates that diets can be tailored to meet nutrient recommendations alongside reducing GHG emissions, without increasing costs to consumers. These diets not only meet nutrient recommendations but are associated with reduced chronic disease resulting in large health benefits to the population. These healthy and climate friendly diets are however very different to the baseline intake, and it will be important to consider how people can be supported to shift their food habits and intakes towards these kinds of diets rather than expect these diets to be adopted completely. It is likely that action and support will be needed at multiple levels, from changes to the food environment through to support for behaviour change, if we are to see meaningful shifts in population dietary intake towards healthy and sustainable diets.

The optimised diets presented here are comparable with those identified in a 2019 review on optimisation to improve nutrition and reduce environmental impacts of diets [11]. The review of 12 optimisation studies found that such dietary patterns were more plant based with reductions in ruminant meats, decreases in just over half of the studies in dairy products but with increases in fish intake in half the studies. Optimised diets also tended to include fewer sweet foods (biscuits, cakes, and desserts), savoury snacks, white bread, and beverages (alcoholic and soda drinks), as seen in the current study.

The current study combines multiple optimisation criteria to generate three optimised healthy, sustainable diets, produces a NZ specific version of the EAT-Lancet diet and models these through to health impacts at a population level. There are however several limitations to this work. There was a limit to the number of optimisation criteria that could be used in Excel (200) so 17 broad food groups were included instead of breaking these down into their 159 more detailed food categories as was done with the other food groups (Table S1). Cultural acceptability was not considered in this optimisation, although the constraint to keep portions of specific foods to a realistic level was based on the baseline intake in the ANS. This national nutrition survey data, also used as the baseline or BAU diet for the modelling, is from 2008/09 and NZ diets are likely to have changed in the intervening time. The NZ health survey has shown a steady decrease in fruit and vegetable intake in adults over this time (https://minhealthnz.shinyapps.io/nz-health-survey-2020-21-annual-dataexplorer/ accessed on 11 July 2022). The impact of shifting diets to these optimised healthy diets may therefore be greater than we have estimated. Energy intake was constrained in the optimization and there was uncertainty around how energy intake would likely change under these scenarios. The effect of these scenarios on body weight was therefore not modelled through to disease incidence. A modelled change in BMI has been shown to have large impacts on health outcomes [30] so if energy intake was lower under these scenarios, then the total health gains would be much larger. An additional limitation of this work is that the base year of the modelling was 2011, with trends on disease incidence, case fatality and remission being applied until 2026. Disease rates may have changed since this time which may alter the impacts of these diets.

It is clear that shifting population food intakes to the EAT-Lancet diet or a diet optimised for health and the climate would confer large health gains, health system cost savings and reductions in health inequities between Māori and non-Māori, alongside reductions in GHG emissions. Previous research has shown that shifting population intake to a vegan diet confers similar health gains (1.5 million QALYs) and cost savings (NZD 20.2 billion in 2011 dollars) and simply shifting the population intake to meet the NZ dietary guidelines would provide large benefits (1.0 million QALYs and NZD 13.9 billion in 2011 dollars) [10]. The challenge for policymakers is selecting the policies and actions that can best support these changes in dietary intake. It is likely that they will need to intervene at multiple levels across the food system to have the impact needed, including improving access to and affordability of healthy sustainable food and using various levers to encourage behaviour change.

Future research in this area could combine the existing optimisation constraints with constraints to keep diets acceptable to the public, considering cultural acceptability of the selected foods. Producing examples of healthy sustainable diets that consumers recognise and can see themselves eating will increase the likelihood of people shifting their intakes towards these diets. Considering the large climate and health benefits of shifting population intake towards these diets, making them acceptable and desirable to consumers is important.

5. Conclusions

This research has outlined examples of sustainable healthy diets that meet dietary recommendations, are no more expensive than the baseline diet, halve their associated GHG emissions and, when modelled, provide large health gain, cost savings and reductions in ethnic health inequities. This provides a strong justification for efforts to support population shifts in dietary intake towards healthy sustainable diets. Resources should be directed to supporting these population shifts in diets through improving the food environment, making healthy sustainable foods easily accessible, affordable and desirable.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su142113900/s1, Table S1: Detailed food groups used in Objective 1 optimisation (those included as broad food categories and not further broken down are highlighted grey); Table S2: Nutrients included in the optimisation scenarios and nutrient recommendations used in optimisation; Table S3: Baseline modelling parameters; Table S4: Food group intake in the baseline diet, optimised NZ diets, and EAT Lancet diets; Table S5: Quality adjusted life years (QALYs) and health system cost savings of the optimised NZ diet and the EAT Lancet diet for the subsequent 10 and 20 years; Table S6: Quality adjusted life years (QALYs), health system cost savings and age standardised per capita ratio of QALYs between Māori and non-Māori for the optimised sustainable diet scenarios and the EAT lancet scenarios.

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