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Consumer resistance diminishes environmental gains of dietary change

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E-mail: o.a.taherzadeh@cml.leidenuniv.nl**Keywords:** dietary environmental footprint, EAT-Lancet diet, product substitution, willingness to change, consumer behaviour, partial adoptionSupplementary material for this article is available [online](#)**Abstract**

The environmental gains of dietary change are often assessed in relation to average national diets, overlooking differences in individual consumption habits and people's willingness to change. This study combines microdata on food intake and consumer behaviour to elicit the likely environmental gains of dietary shifts. We focus on the Netherlands owing to the country's ambition to halve its dietary footprint by 2050. Linking food recall survey data from a cross-section of the population ($n = 4313$), life cycle inventory analysis for 220 food products, and behavioural survey data ($n = 1233$), we estimate the dietary footprints of consumer groups across water, land, biodiversity and greenhouse gas (GHG). We find that meat and dairy significantly contribute to the dietary GHG footprint (59%), land footprint (54%), and biodiversity footprint (59%) of all consumer groups and that male consumers impose a 30%–32% greater burden than women across these impact areas. Our scenario analysis reveals that simply replacing cow milk with soy milk could reduce the GHG, land and biodiversity footprints by $\approx 8\%$ if widely adopted by the Dutch adult population. These footprints could be further reduced to $\approx 20\%$ with full adoption of the EAT-Lancet diet but with a significantly increased blue water footprint. However, when incorporating gender- and age-specific willingness to reduce meat and dairy consumption, the environmental gains resulting from partial adoption of the No-Milk diet and EAT diet diminish to a mere $\approx 0.8\%$ and $\approx 4.5\%$, respectively. Consequently, consumer motivation alone is insufficient to realise the significant environmental gains often promised by dietary change. Yet, substituting high-impact food products offers a near-term opportunity to accelerate a rapid sustainable dietary transition. Future studies on sustainable dietary transition must incorporate consumer behaviour to fully comprehend the lock-in of food consumption patterns and targeted policy action required to secure a sustainable food future.

1. Introduction

Dietary change has emerged as a focal priority to deliver a rapid transition to a sustainable and healthy food system. Target 16 of the Global Biodiversity Framework addresses the important role that consumers play in reducing the impact of food production and calls for better information about the consequences of their dietary choices

[1]. Numerous studies have illustrated that shifting to less resource-intensive food consumption patterns in high-income countries, such as plant-based diets, has tremendous potential to curtail food system impacts on land use [2–6], climate [7–11], biodiversity [12–15], and nutrient pollution [3, 16, 17]. However, such studies rely on nationally averaged food consumption data, lacking details on dietary habits between different consumer

groups and their willingness to adopt alternative diets.

A new generation of models that operate at the scale at which food system decisions are taken is needed to fully comprehend the potential environmental gains achieved by dietary shifts. Recent studies have sought to address this gap, offering a more granular understanding of the environmental footprint of food consumers, their motivations for adopting or forgoing a sustainable diet [18–23], and how these motivations might shape their adoption of alternative diets [19, 24–26]. Several studies have used food affordability to determine the preferable scope of, and barriers to, a sustainable dietary transition, in individual countries [27–29], and globally [26, 30, 31]. Coupling food expenditure data and nutritional energy of food items, Meinilä and colleagues [32] derive food consumption archetypes of consumers towards this end. Kramer and colleagues [33] ascribe popularity to foodstuffs based on their current intake levels by consumer sub-groups. Allenden and colleagues [34] provide the first such integration of reported dietary adoption into environmental and nutritional impact assessment of national dietary transitions. Nevalainen and colleagues [35] examine Finnish dietary substitution preferences within a similar vein. Such analysis is needed to provide better estimates of the impact reduction potential of dietary transitions and the scale of intervention required to deliver rapid food transitions. Yet, studies that combine behavioural insights of consumer groups with micro-level assessments of dietary environmental footprints are limited in number [36].

To address the paucity of actor-level and behaviour-based environmental footprinting of dietary change, this study combines consumer behaviour and footprint analysis to provide more realistic estimates of consumers' willingness to mitigate food environmental impacts in their food choices. We focus on the Netherlands for several reasons. Although its agricultural system is among the most efficient in Europe in terms of yield per unit of land [37], the Netherlands' agricultural sector contributes 14% to domestic greenhouse gas (GHG) emissions, 40% to domestic land use [38], and 70% to domestic nitrogen emissions [39], making its food system a key target sector to improve the sustainability of the Dutch economy. The current Dutch diet can also be considered largely unhealthy, with over half of the population being either underweight, overweight, or obese [40, 41], emphasising the need for change. As part of the strategic response to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services recommendation to significantly change current consumption and production patterns [42], the Dutch government has set an ambitious target of halving the environmental footprint of its food consumption by 2050 [43], with

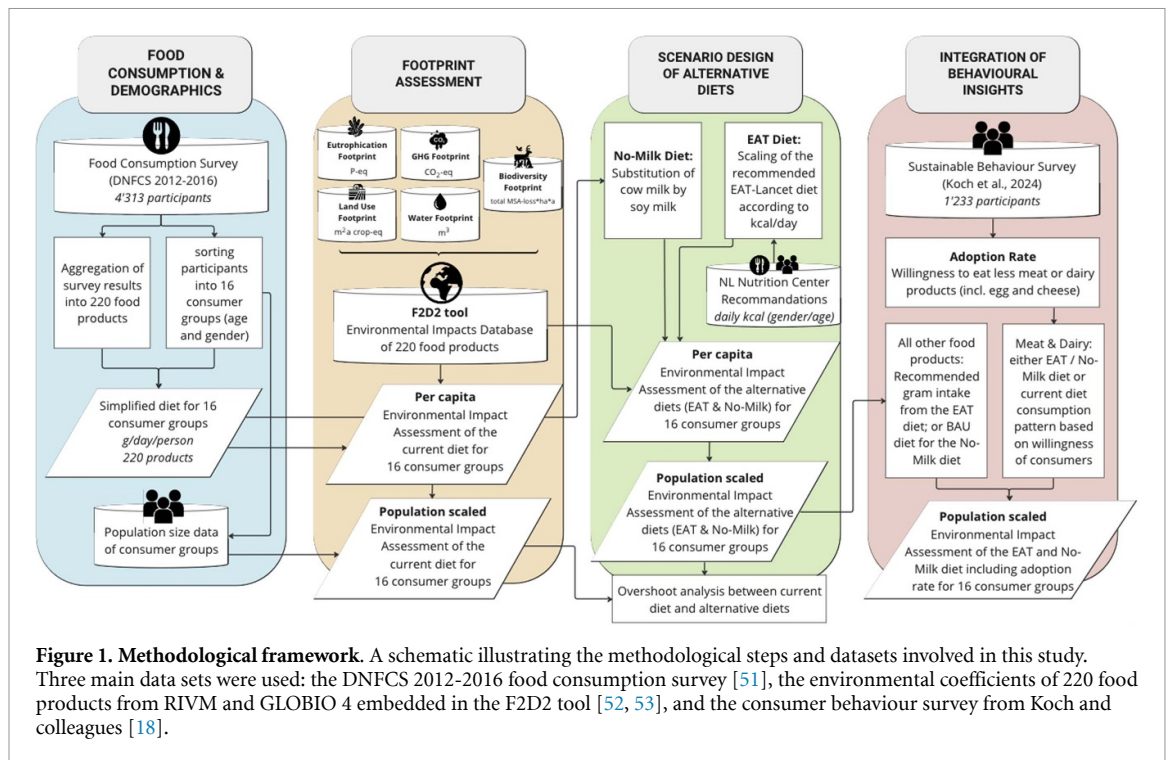
dietary transition identified as a key strategy towards this end [44, 45]. Studies have indicated that consumers' dietary shift holds greater potential for mitigating the environmental impacts of food systems than altering agricultural processes [2, 44]. Previous studies in the Netherlands have estimated that shifting to a sustainable diet could reduce both the current GHG and land footprints by $\approx 33\%$, as opposed to a mere $\approx 5\%$ with more efficient agricultural production alone [38].

By enriching existing Dutch dietary footprinting analyses with a wider array of environmental impacts as well as actor-level and behaviour-based information, this study combines surveys on food intake with attitudes towards dietary change and Dutch-specific life-cycle assessment impact inventories to examine (i) how environmental footprints differ between Dutch consumer groups; (ii) the potential environmental benefits resulting from the adult population's full adoption of alternative diets (hereafter 'full adoption'); and (iii) how these environmental gains may be diluted when incorporating behavioural insights into the analysis (hereafter 'partial adoption').

The study examines two dietary adoption strategies: a sustainable and healthy diet (hereafter the 'EAT diet') developed by experts from the EAT-Lancet commission to meet nutritional requirements while minimising environmental impacts [46] and a 'No-Milk' diet, where the groups' current food consumption is maintained but cow milk is substituted by a soy milk alternative. While the EAT diet is preferred in terms of nutrition, it would necessitate a complete overhaul of one's dietary habits, whereas the No-Milk diet is a simple single product substitution, potentially making it a more accessible choice for consumers. One of the key reasons for modelling a No-Milk dietary scenario as opposed to a 'No-Meat' diet is that plant-based milk alternatives are more established and accessible than meat alternatives in Western countries, being the most sold plant-based alternative on the market at present [47–49] and that soy milk offers a similar nutritional protein intake as cow milk [50], which is not necessarily the case of plant-based meat alternatives.

2. Methods

This chapter outlines the data and processes involved in (section 2.1) linking dietary data to environmental impacts (eutrophication, GHG emissions, biodiversity loss, land and blue water footprints) of individuals and consumer groups (section 2.2) estimating the environmental gains of full adoption of both the EAT and No-Milk diets and (section 2.3) integrating behavioural insights to realistically estimate the actual impact reduction potential of partially shifting to the EAT or No-Milk diets. The processes and methods involved in this study are illustrated schematically in figure 1.



2.1. Food recall data and environmental impacts

Individual dietary recall surveys provide granular insights into the population-level consequences of dietary shifts. Recent studies using such datasets reveal notable variation in individual food intake across national populations [36, 54–57], highlighting their utility in dietary environmental footprinting and policy-related analysis. This study employs the Dutch National Food Consumption Survey (DNFCS), conducted by the Dutch National Institute for Public Health and the Environment (RIVM) [51], capturing two 24h dietary recalls between 2012 and 2016 for 4313 children and adults aged between 1 and 79 years old [58]. To link food intake to environmental impacts, a version of the DNFCS 2012–2016 survey made by the Netherlands Environmental Assessment Agency (PBL) that aggregated the 2000+ reported food products into a simplified weighted diet of 220 products was used [59].

The environmental footprint analysis was conducted using four environmental mid-point indicators derived from the RIVM LCI database [51] and Agri-footprint 5.0 [53]: GHG footprint, land footprint, eutrophication footprint, and blue water footprint. Biodiversity characterisation factors from the GLOBIO biodiversity model [15, 60] were employed to calculate the biodiversity footprint of food products. All five environmental footprints were combined in a single modelling tool ('F2D2'), developed by Blonk Consultants and PBL [59]. The F2D2 tool provides environmental impact coefficients for the same 220 food products from the simplified weighted diet of the DNFCS [59], ensuring concordance across the various datasets (2012–2016

DNFCS, RIVM LCI and GLOBIO 4). The impacts assessed include all life cycle stages, from agricultural processes to consumption (including cutting losses, waste, preparation, and disposal) [61], and take into account the sourcing country (i.e. share by import country and domestic production) of products sold in the Netherlands and their country-specific environmental impact intensities [52, 62]. Further details on the RIVM-LCI and GLOBIO-4 indicators are provided in the supplementary material file, sheet 1.

2.1.1. Population scaling of food intake and impacts

This study examines 16 consumer groups distinguished by gender and age (intervals of 10 years from 1 to 80 years old). The footprint assessment of the Dutch diet is first performed on a per capita basis to understand the differences in the environmental impacts of different consumer types. To assess the population-wide impacts of different consumer groups shifting diets, per capita results are scaled to the population size of each group using demographic data from Statistics Netherlands for the year 2016 [63]. The population size of each group can be found in the supplementary material file, sheet 5.

2.2. Scenario design of the EAT and No-Milk diets

We explore the potential environmental benefits associated with the adoption of two alternative diets: the EAT diet, as proposed by Willet and colleagues [46], and a 'No-Milk' diet that replaces cow milk directly consumed (i.e. excluding processed dairy products such as cheese and yoghurt) with soy milk. These diets were chosen to examine the anticipated environmental gains of large-scale dietary shifts and

more simple product-level substitutions within the Netherlands. The scenario analysis excludes the population below 20 years of age due to their lower energy intake ($\approx 15\%$ less calorie intake per day than the rest of the population) and the lack of associated daily nutritional recommendations for young people from the FDBG [64].

The EAT diet is modelled on the median guidelines from the EAT-Lancet Commission, which recommends a mostly plant-based diet adhering to 2500 calories per day [46]. Every food product within the diet was scaled accordingly to match the daily calorie intake recommendation from the FDBG [64] based on gender and age, with women having lower daily calorie intake requirements than men. The EAT-Lancet Commission does not offer any recommendations regarding beverages; thus, beverage intake is kept the same as in the 2012–2016 DNFCS ‘business-as-usual’ (BAU) diet for each consumer group. For the No-Milk diet, cow milk is replaced by 250 g per day of soy milk to align with the recommendations of the EAT-Lancet Commission [46], and the consumption level of all other food products is kept the same as in the BAU diet. The composition of both alternative diets for each of the 16 consumer groups can be found in the supplementary material file, sheet 3–4. The environmental footprints of both alternative diets were computed by multiplying the intake of food in grams per day per person by the product-specific environmental impact coefficients. These per capita results are then scaled up to the population size of each consumer group over a year.

2.3. Integration of behavioural insights: partial adoption scenarios

To integrate behavioural insights, we incorporate data from an online survey by Koch and colleagues [18] that has been carried out among a representative sample of the Dutch adult population, exploring individuals’ willingness to adopt a wide range of sustainable behaviours. The data collection took place in September and October 2021 via the Kantar NIPObase panel [65]. A full explanation and description of this survey is available from Koch and colleagues [18]. One section of the survey (completed by 1233 participants) assessed individuals’ willingness to engage in sustainable behaviours regarding food, assuming no extra costs or accessibility barriers. In this sub-sample of the survey, we see a slight over-representation of women (55.9%) compared to the Dutch population (see supplementary file, sheet 6). However, this is not a problem for the analysis, as we applied the willingness data on a per capita basis to the different consumer groups. For this study, we used data on two specific question areas: the willingness to consume no or little amounts of meat and the willingness to consume no or little amounts of dairy products. These items

were measured on a scale of 1 (low willingness) to 4 (high willingness). For this study, we processed the data in a two-step process. First, we recoded ‘willingness’ to a dichotomous scale. Answers 1–2 (low to medium–low willingness) were recoded into ‘not willing’ and 3–4 (medium–high to high willingness) to ‘willing’. Second, we organised the survey results by the 16 consumer groups (gender and age) to combine the willingness data with food consumption patterns and their associated environmental impacts. The willingness to eat either less meat or dairy per consumer group expressed as a dietary adoption rate, can be found in the supplementary material file, sheet 6.

To the best of our knowledge, no data are available on the willingness of Dutch consumers to eat more vegetables or plant-based products. However, we assume that non-animal products do not face the same resistance as meat or dairy products (i.e. some groups might be resistant to eating significantly less meat but are open to increasing their vegetable intake as they are not required to forgo consumption). Therefore, the adoption rate derived from the survey of Koch and colleagues [18] is only applied to meat and dairy products consumption for the partial adoption of the EAT diet scenario, and only to cow milk for the partial adoption of the No-Milk diet. For the partial adoption scenario of the No-Milk diet, it is assumed that soy milk and cow milk have similar protein intake and therefore BAU consumption for other food products (e.g. vegetables, legumes, etc) is modelled. In contrast, BAU consumption of non-animal products does not fully compensate for the nutritional deficit from reduced animal protein intake in the partial adoption scenario of the EAT diet. Within this scenario, we align the food intake of non-animal products with the EAT-Lancet recommendations to ensure adequate nutrition for each consumer group.

To obtain the footprints of the partial adoption scenarios, the adoption rate is applied directly to the environmental impact contributions of meat and dairy products, rather than at the consumption level (i.e. grams of food consumed per day). For instance, to determine the results for the partial adoption of the EAT diet for female consumers aged between 21 and 30, we know that 51% of them are willing to eat less meat, but only 19% are willing to reduce their dairy intake (see supplementary file for the adoption rate of all consumer groups, sheet 6). We then build upon the footprints computed earlier in the full adoption of the EAT diet for all non-animal food products for this particular consumer group, and incorporate the footprint contribution of meat and dairy products as follows: 51% of the total population of this consumer group is assigned the meat footprint of the EAT diet, while the remaining 49% is assigned the meat footprint of the BAU diet. The same procedure is

applied to dairy products using the appropriate adoption rate.

3. Results

This section presents the results of the Dutch diet footprint analyses under three different approaches: section 3.1, determining the current footprint of the 2012–2016 diet of 16 consumer groups and highlighting the high-impact groups; section 3.2, estimating the potential environmental gains of adopting two alternative diets; and section 3.3, assessing the potential environmental gains of dietary shifts considering the adoption rates of different consumer groups.

3.1. Footprint analysis of the current diet

The GHG footprint modelling of Dutch food consumption aligns with previous studies that found similar results for climate (between 2 and 5 kg CO₂-eq per capita, per day) and blue water dietary footprints (0.08–0.14 m³ per capita, per day) (see [66, 67]). Our results indicate that there has been a negligible reduction in the dietary GHG footprint of the Netherlands compared with results from the 2007–2010 DNFCs (by $\approx 1.5\%$ from the estimated 4.1 kg CO₂-eq per person per day then [45]). A contribution analysis was conducted to evaluate the environmental impacts attributed to different food groups and to identify the main drivers. This analysis, presented in figure 2, shows that animal products significantly contribute to the eutrophication footprint (38%), GHG footprint (59%), land footprint (54%), and biodiversity footprint (59%). The main driver of the blue water footprint was the consumption of non-alcoholic beverages (31%) and fruits (13%). This impact is particularly driven by the high consumption of juices in the Netherlands, with an average daily per capita consumption of 105 g ($\approx 2\times$ the EU average [68]). This finding is also consistent with a previous study that found that fruit juices contributed the most (13%) to the blue water footprint of the Dutch diet [66].

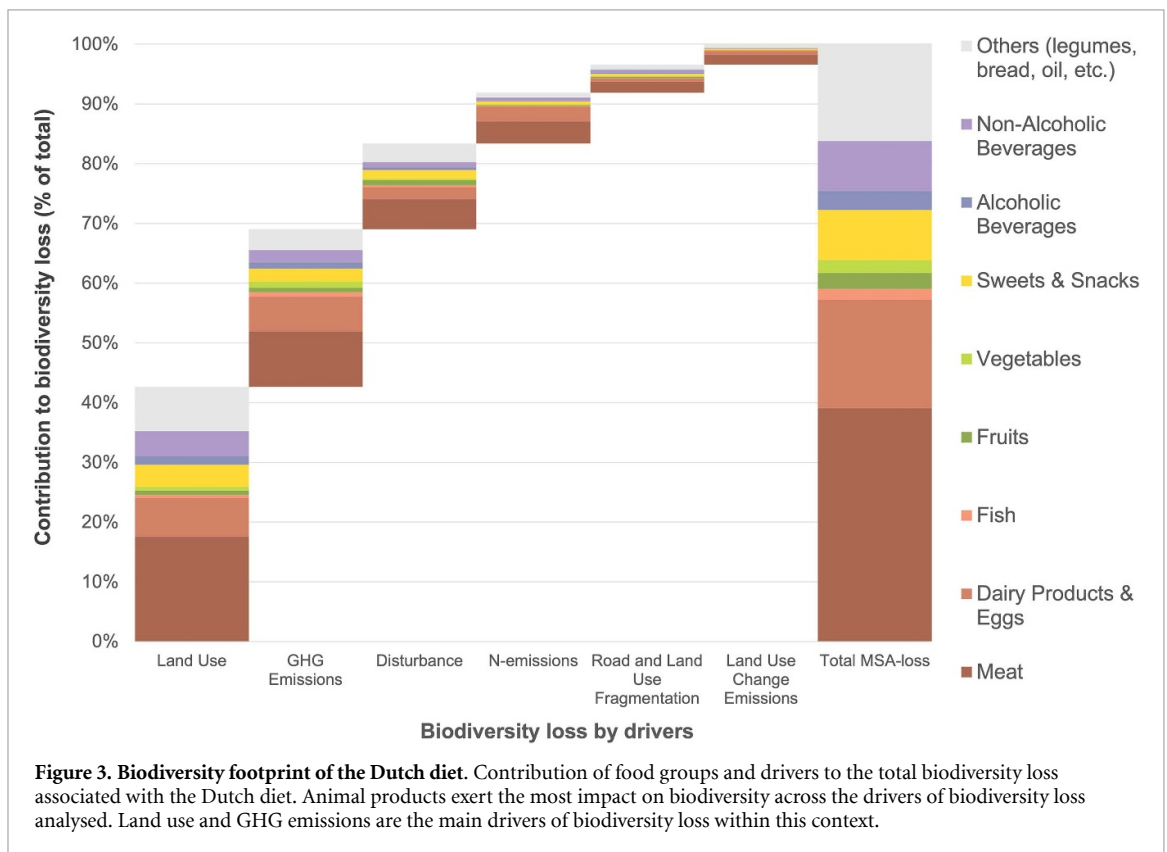
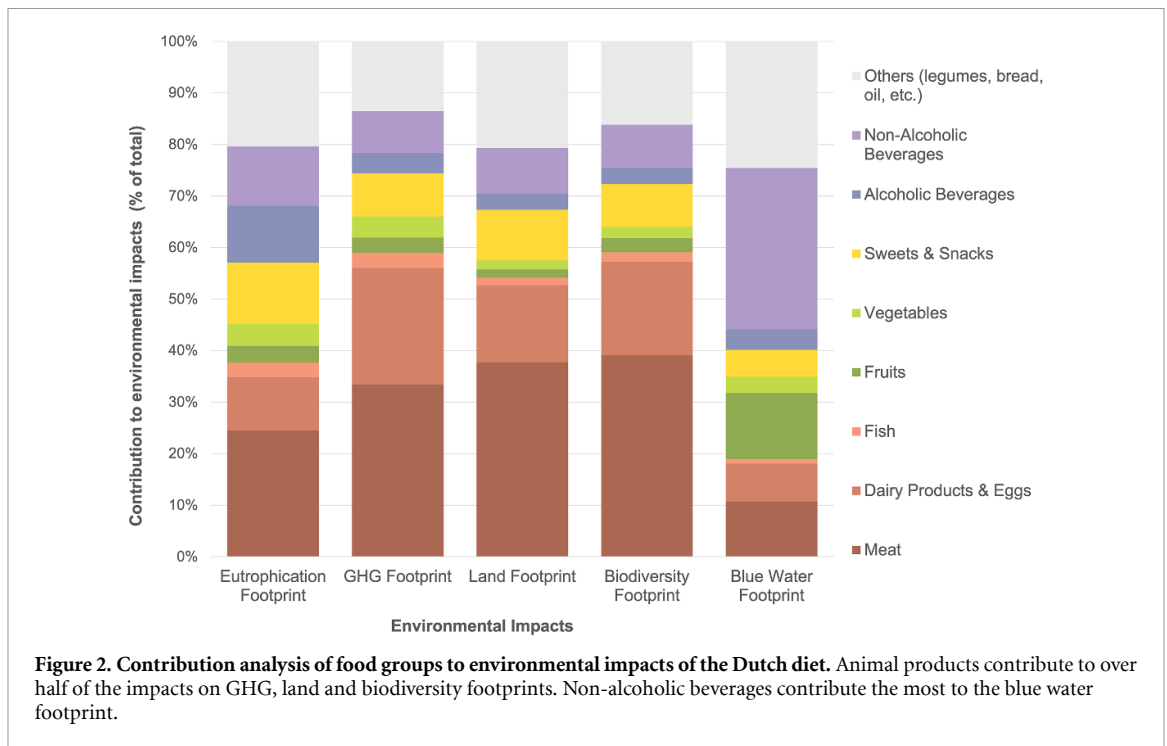
When focusing on the pressures contributing to total biodiversity loss, following the GLOBIO 4 methodology [60], animal products also play a predominant role in driving biodiversity loss. This is primarily attributed to their significant GHG emissions, extensive land-use requirements, and consequential impacts on biodiversity, as illustrated in figure 3.

Figure 4 depicts the relative per capita environmental impact of 16 distinct consumer groups compared with the population median within a single environmental impact category. The absolute value results for each consumer group can be found in the supplementary material file, sheet 7. Our findings indicate relatively homogeneous per capita consumption patterns across age groups within a binary gender category, except children (until 20 years old), which

is due to their low consumption level overall. Scaling the environmental footprint results to the Dutch population (depicted in figure 5), we find that the male consumer group aged between 51 and 60 exhibits the highest overall environmental footprint ($\approx 45\%$ above the national average) and contributes $\approx 10\%$ to total domestic environmental impacts, across all environmental footprints modelled. In comparison with their female equivalent age group (51–60), the male consumer group greatly exceeds (25%–30%) their eutrophication, GHG, and land footprints. Overall, all male consumer groups exhibit a footprint that surpasses by $\approx 30\%$ that of female consumers across all environmental impact categories, except for water consumption, where their impacts are more closely aligned. This difference can be attributed to the higher daily consumption in grams across the male population and their higher consumption of high-impact foods such as meat (on average 36% more) or dairy products (16% more). Regarding the blue water footprint, female consumers have a large impact due to their higher consumption of high-impact foods, such as fruits and juices.

To better understand gendered differences in the environmental footprint of consumer groups, we conducted a calorie-weighted analysis between the dietary environmental footprints of male and female groups. We found that men have overall still a higher impact than women across all environmental footprints (on average 4% more) except for their water footprint. At the consumer group level, women aged 51 to 70 have a higher environmental impact per daily kilocalorie intake than men in similar age groups (on average 4.6% more, see the supplementary material for the absolute results, sheet 7). While the results consistently indicate that men have a greater environmental footprint than women, the extra environmental burden attributed to men is less notable when utilising kilocalories as the functional unit (FU). This emphasises the importance of conducting footprinting studies using a variety of functional units beyond mass and volume, and incorporating nutritional considerations, which represent the fundamental purpose of food [69–72].

In contrast, we find homogeneous environmental impacts across consumer groups by education level, suggesting that education level has little influence on the dietary environmental footprints of Dutch consumers (see supplementary material file for the results, sheet 8). A two-way ANOVA test was performed to validate this finding, using the group-level footprints and group characteristics available in the absence of individual participant-level data at this resolution. On a per capita basis, the influence of education on environmental impact does not appear as significant as gender, as shown in table 1. The full results of this statistical analysis can be found in the supplementary material file, sheet 9. Due to



these considerations, we opted not to centre the main analysis on consumer groups categorised by education levels. Furthermore, applying the FDBG recommendations for daily gram intake [64] for the dietary change scenarios to education-level consumer groups is not feasible due to the intertwining of age within education levels.

3.2. Potential environmental gains from adopting alternative diets

Figure 6 illustrates the potential environmental gains of the entire population adopting either the EAT or the No-Milk diet, expressed as a percentage relative to the BAU diet. The results indicate that the environmental gains from adopting the EAT diet are

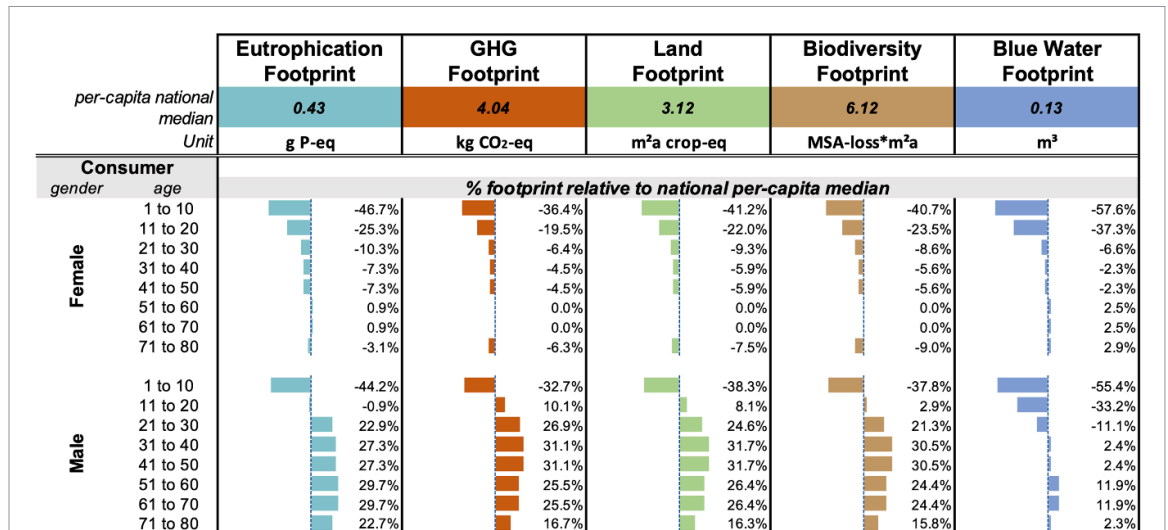


Figure 4. Per-capita environmental footprint per day of consumer groups in relation to the national median. Comparison of daily dietary environmental footprints of consumer groups in relation to the footprint of a single typical Dutch individual (defined by the per capita median environmental footprint of the entire population). The findings underscore that men exhibit a higher footprint than the national average and surpass that of women. The population, encompassing both males and females, below 20 years of age generally demonstrates a significantly lower per capita dietary environmental footprint compared to the adult population. This discrepancy can be attributed notably to their lower daily energy intake, as noted by the Dutch food-based dietary guidelines.

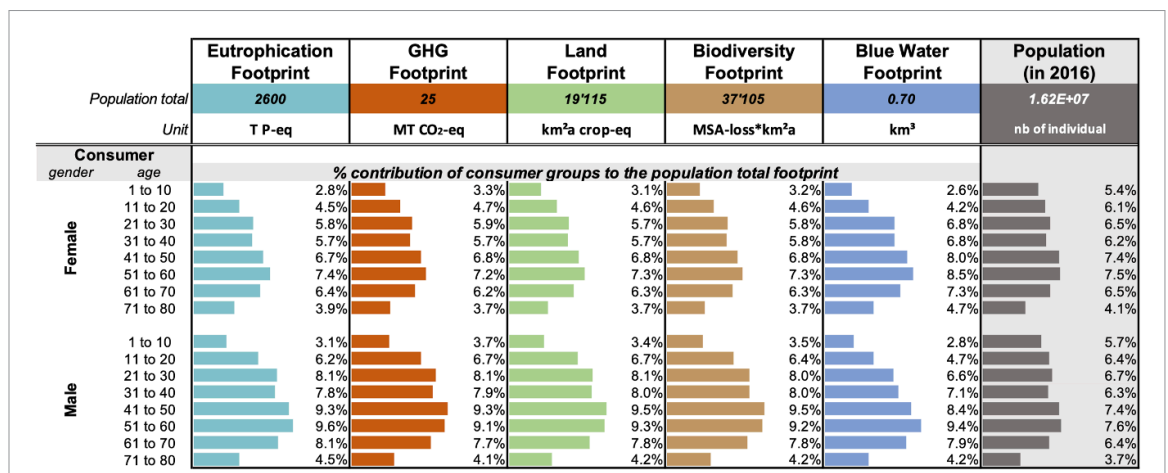


Figure 5. Contribution of consumer groups to the total Dutch dietary environmental footprint in 2016. Contribution (%) of each consumer group to the overall national footprint per year for each environmental indicator. The results indicate that no individual group distinctly exhibits a significantly higher footprint than another when the corresponding population size of groups is taken into account. Additionally, the results show that the footprint of each consumer group is intrinsically linked to the population size of that group (i.e. a group with a larger population will typically have a higher footprint). The population total excludes the individuals above 80 years old.

2–3 times larger compared with the No-Milk diet for the GHG, land and biodiversity footprints, but may lead to some important trade-offs in the blue water footprint. Given that the EAT diet is predominantly plant-based and entails an increased intake of fruits and nuts, which have a high blue water footprint, its adoption results in an increased water consumption overall, a finding consistent with recent observations from the dietary environmental footprinting literature [73–75]. Our estimates indicate that a full adoption of the EAT diet among the highest impact group: male consumers aged 41 to 50 can lead to a 28% reduction of their GHG footprint (as opposed

to 9.2% with the No-Milk diet). Conversely, it can also result in a 15.6% increase in their blue water footprint (as opposed to reducing it by 1.2% with the No-Milk diet). If the EAT diet is fully adopted by the entire Dutch population, we estimate that we can reduce the food-related GHG footprint by 20.5% (representing 3% of the total Dutch GHG emissions [76]), the biodiversity footprint by 21.1%, the land footprint by 19.9% and the eutrophication footprint by 6.5%, but it can increase the blue water footprint by 7.6% (the results of both diets in absolute values are available in the supplementary material file, sheet 10).

Table 1. Results of two-way ANOVA analysis for environmental footprints by gender and education level. Across all environmental footprints, the two-way ANOVA analysis reveals that gender exhibits a more significant influence than education, as defined by a *P*-value lower than 0.05. However, for the Blue Water footprint, education appears to have a slightly more pronounced influence (*p* = 0.080)

	<i>P</i> -value (significant level < .05)	
	Gender	Education level
Eutrophication footprint	0.004	0.109
GHG footprint	0.012	0.940
Land footprint	0.005	0.667
Biodiversity footprint	0.007	0.892
Blue water footprint	0.694	0.080

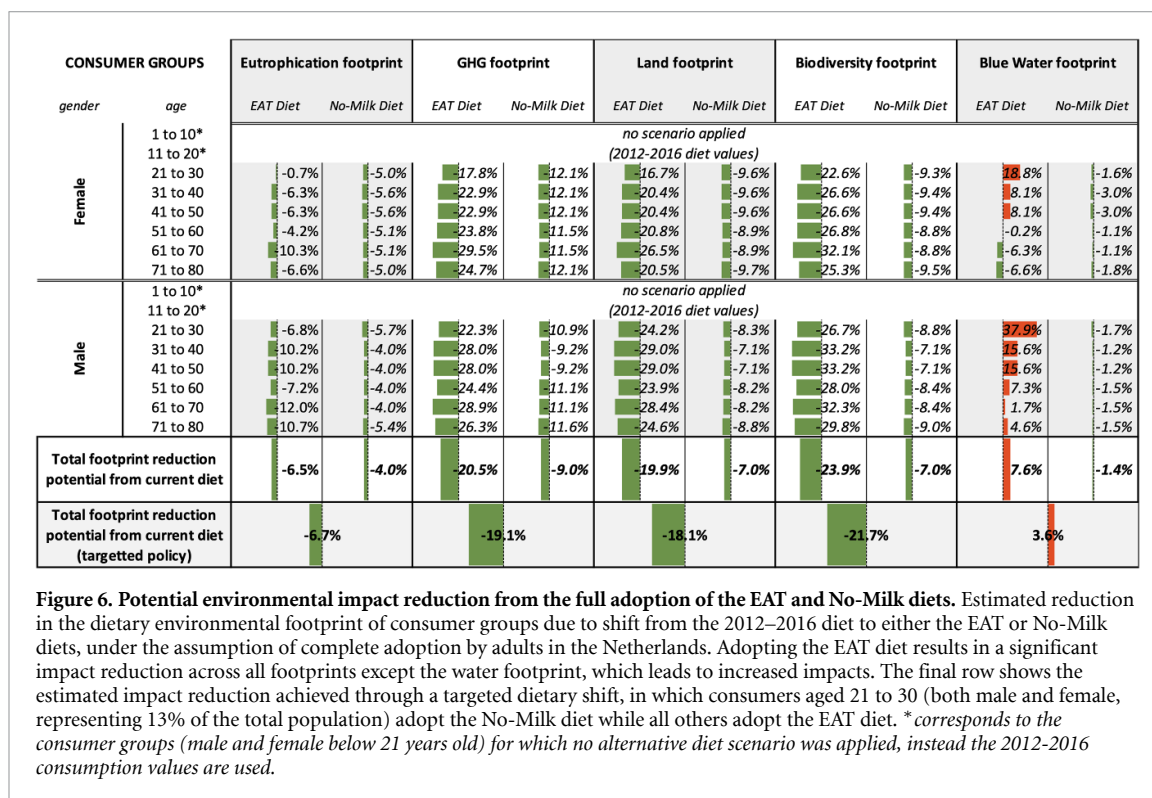


Figure 6. Potential environmental impact reduction from the full adoption of the EAT and No-Milk diets. Estimated reduction in the dietary environmental footprint of consumer groups due to shift from the 2012–2016 diet to either the EAT or No-Milk diets, under the assumption of complete adoption by adults in the Netherlands. Adopting the EAT diet results in a significant impact reduction across all footprints except the water footprint, which leads to increased impacts. The final row shows the estimated impact reduction achieved through a targeted dietary shift, in which consumers aged 21 to 30 (both male and female, representing 13% of the total population) adopt the No-Milk diet while all others adopt the EAT diet. *corresponds to the consumer groups (male and female below 21 years old) for which no alternative diet scenario was applied, instead the 2012–2016 consumption values are used.

These findings highlight that implementing a uniform policy does not necessarily result in the most significant reduction of environmental impacts. Specifically, the analysis reveals that consumer groups between 21 and 30 years old might significantly increase their blue water footprint by adopting the EAT diet. Our analysis shows that directing specific demographic groups (i.e. males and females aged 21 to 30, constituting 13% of the total population) to adopt the No-Milk diet while others adopt the EAT diet would yield the most substantial environmental benefits. This approach achieves impact reductions comparable to those of the EAT diet, while simultaneously mitigating trade-offs in the blue water footprint, as shown in figure 6, (see supplementary material file, sheet 11, for the absolute value results).

3.3. Integrating behavioural insights into the adoption of the EAT diet

To date, the investigation of environmental gains associated with dietary shifts has ignored the motivations of consumers in relation to food choice,

implying equal and frictionless barriers for consumers to adopt alternative diets. This study provides more realistic estimates of the environmental gains anticipated in dietary transition scenarios by incorporating the willingness to adopt alternative diets. The results reveal that the environmental gains from adopting the EAT diet, considering the willingness to eat less meat and dairy products are significantly lower ($\approx 4.5\times$) than with a full adoption. Figure 7 shows the relative impact reduction from the BAU diet by partially adopting the EAT diet (the absolute results can be found in the supplementary material file, sheet 12). Figure 8 presents a comparison of the estimated footprint reduction potential of the entire Dutch population derived from various scenario analyses: full adoption (i.e. all consumers shift to the alternative diet) of the EAT and the No-Milk diets and partial adoption (i.e. only a portion of the consumers fully shift to the alternative diet) of the EAT and No-Milk diets. The large disparity between environmental gains anticipated from full and partial dietary shifts highlights the importance of incorporating

CONSUMER GROUPS		Eutrophication footprint		GHG footprint		Land footprint		Biodiversity footprint		Blue Water footprint	
gender	age	EAT Diet	No-Milk Diet	EAT Diet	No-Milk Diet	EAT Diet	No-Milk Diet	EAT Diet	No-Milk Diet	EAT Diet	No-Milk Diet
Female	1 to 10*	no scenario applied									
	11 to 20*	(2012-2016 diet values)									
	21 to 30	6.6%	0.9%	-5.2%	-2.3%	-4.2%	1.8%	-8.0%	1.7%	21.8%	-0.3%
	31 to 40	2.6%	-1.2%	-7.4%	-2.5%	-5.6%	-2.0%	-9.4%	-1.9%	11.6%	-0.6%
	41 to 50	6.0%	-0.6%	-1.5%	-1.2%	-0.1%	-1.0%	-3.1%	-1.0%	12.9%	-0.3%
	51 to 60	5.0%	-0.4%	-7.0%	-1.0%	-5.1%	-0.8%	-8.6%	-0.8%	3.7%	-0.1%
	61 to 70	-1.1%	-0.6%	-2.8%	-1.4%	-10.9%	-1.1%	-4.1%	-1.1%	-2.3%	-0.1%
	71 to 80	2.4%	-0.9%	-8.7%	-2.2%	-4.9%	-1.8%	-8.6%	-1.8%	-2.9%	-0.3%
Male	1 to 10*	no scenario applied									
	11 to 20*	(2012-2016 diet values)									
	21 to 30	5.8%	-1.2%	-1.6%	-2.3%	-3.5%	-1.7%	-4.3%	-1.8%	44.8%	-0.4%
	31 to 40	3.4%	-0.6%	-3.9%	-1.5%	-5.7%	-1.1%	-6.6%	-1.1%	22.6%	-0.2%
	41 to 50	2.8%	-0.6%	-5.0%	-1.4%	-6.7%	-1.1%	-7.5%	-1.1%	22.3%	-0.2%
	51 to 60	4.2%	-0.4%	-3.3%	-1.1%	-3.7%	-0.8%	-5.2%	-0.8%	13.0%	-0.2%
	61 to 70	-0.8%	-0.5%	-8.6%	-1.3%	-8.9%	-1.0%	-0.7%	-1.0%	7.4%	-0.2%
	71 to 80	3.0%	-0.5%	-3.0%	-1.0%	-1.5%	-0.7%	-4.5%	-0.8%	11.3%	-0.1%
Total footprint reduction potential from current diet		2.8%	-0.6%	-4.4%	-1.3%	-4.3%	-1.0%	-6.1%	-2.5%	12.0%	-0.2%

Figure 7. Potential environmental impact reduction assuming partial adoption of the EAT and No-Milk diets. Estimated environmental gains from the partial adoption of the EAT and No-Milk diets in comparison with the current 2012–2016 diet, integrating age- and gender-specific dietary adoption rates, as defined in section 2.3. Partial adoption of the EAT diet does not lead to as significant an impact reduction compared with full adoption, with notably increased trade-offs in the water and eutrophication footprints. * corresponds to the consumer groups (male and female below 21 years old) for which no alternative diet scenario was applied, instead the 2012-2016 consumption values are used.

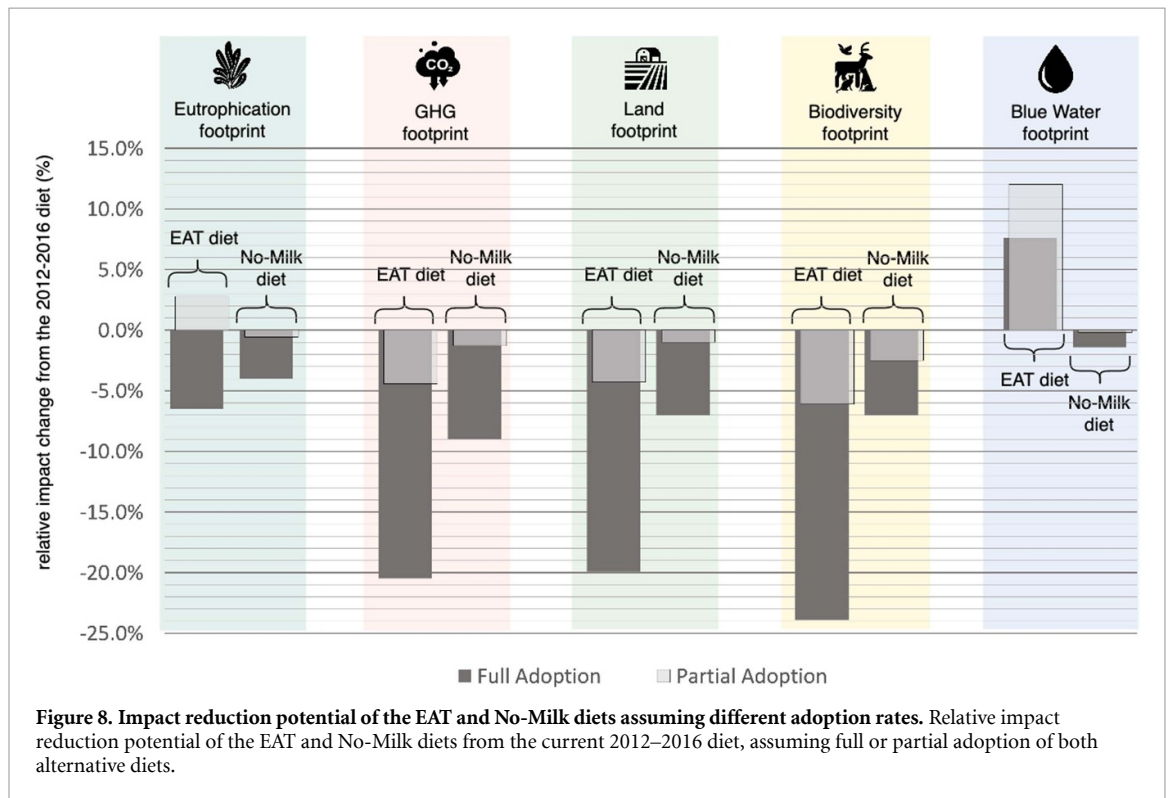


Figure 8. Impact reduction potential of the EAT and No-Milk diets assuming different adoption rates. Relative impact reduction potential of the EAT and No-Milk diets from the current 2012–2016 diet, assuming full or partial adoption of both alternative diets.

consumers’ willingness into dietary environmental footprint analysis.

4. Discussion

This study examines the environmental footprints of Dutch diets across different consumer groups and how motivations for dietary change might curtail these impacts. Our findings demonstrate that animal products contribute substantially to multiple environmental impacts, including GHG emissions,

land use, biodiversity loss, and freshwater eutrophication, aligning with existing literature [2, 44, 45, 75]. When assessing the environmental footprints of specific consumer groups, our findings suggest that age and gender have a more pronounced influence on the disparity in environmental impacts than education level. Male consumer groups appear to have an environmental footprint $\approx 30\%$ higher across all footprints except water when compared with female consumer groups, individuals aged between 51 and 60 exhibit the highest overall environmental footprint.

However, adjusting for calorie intake, we find a closer alignment between the environmental burden of food consumption between male and female groups.

Considering the differentiated environmental impacts of food consumer groups, we observe greater environmental gains when individuals aged between 21 and 30 adopt the No-Milk diet compared to the EAT diet. Ergo, uniform adoption of either one of these diets does not necessarily yield the greatest environmental gains, especially when trying to minimise trade-offs on the blue water footprint. Conversely, a targeted adoption of both diets by consumer groups stands to achieve the hypothetical impact reductions in the GHG, biodiversity and land footprints ($\approx 20\%$) while minimising the increase in the blue water footprint (see figure 6). The food products of the Dutch diet that contribute most to the blue water footprint are fruits and beverages, specifically oranges and orange juice. The Netherlands currently imports most of its oranges from South Africa, Egypt, Spain, and Morocco [77, 78], which rely heavily on blue water for irrigation of citrus fruits [79–81]). These regions also experience high water stress [82], a further impetus to reduce and substitute their consumption in the Dutch diet. Although non-trivial, the blue water footprint of dairy products is found to be relatively low when compared to other food products such as oranges, mangoes, avocados, olives or almonds, owing to the use of local feed crops grown using green water in the conventional dairy sector of the Netherlands, and its high production efficiency [83]. Yet, dairy products contribute significantly towards the land, biodiversity and GHG emissions footprint of the Dutch diet, necessitating shifts in consumption patterns towards dairy alternatives, as illustrated in the No-Milk diet scenario modelled. These findings invite future research on high-impact food product substitution and whether environmental impact reductions from the EAT diet could, for instance, be further maximised by simply replacing certain fruits with less water-intensive products.

When considering consumers' willingness to reduce their meat and dairy consumption, consumer resistance significantly diminishes the anticipated environmental gains of a dietary shift (figure 7). Although we observe a $\approx 4.5\%$ impact reduction potential across the GHG, land, and biodiversity footprints in the EAT diet partial adoption scenario, we also estimate an increase in the eutrophication and water footprints of consumers. This increase is due to the design of the partial adoption scenarios, which (for reasons stated in section 2.3) warrant an increased consumption of non-animal products compared to the BAU diet. These products have a high eutrophication footprint, as shown in figure 2, which results in an overall higher dietary-related eutrophication footprint. The willingness to eat less meat

and dairy obtained from Koch and colleagues' survey [18] is particularly low. This could be attributed to a lack of awareness of the link between meat and environmental impacts or the perception that a meal is incomplete without animal protein [84, 85]. This shows a great potential for education policies to further increase the willingness to eat less meat and dairy products in the Netherlands. However, prior studies show contradicting evidence regarding the potential success of this. In a study of Dutch consumers, individuals were found to display a higher willingness to purchase certain sustainable food products if they knew they had a lower nitrogen footprint [86], while other studies indicate that ecological food labelling and education measures are often ineffective, with consumers typically placing more importance on the availability and price of food [21, 87]. A recent study by Kok and Barendregt [88], also explored the adoption, use, and effect of ecological footprint calculators for food products among Dutch citizens and found that these calculators increase users' awareness of their environmental impact and, in some cases, lead to behaviour change. Kok and Barendregt [88] propose several design recommendations (e.g. improving transparency about impact calculations, showing users the gains of their behaviour change on their footprint, or offering social comparison) to improve these calculators to further increase adoption and continuous engagement with the tool, which they believe could ultimately lead to more sustainable behaviour change.

In the study by Koch and colleagues employed in our analysis [18], participants showcased a low willingness to eat less meat and dairy, despite the assumption of similar affordability and availability of non-meat and non-dairy product alternatives. Thus, low willingness to shift diet even under this condition highlights that the intrinsic willingness of consumers to adopt such diets is likely even lower. The temporal mismatch between the consumption and behavioural surveys adds further uncertainty to the scale of hypothetical dietary change and associated impacts modelled within this study. The food intake survey was collected between 2012 and 2016, while the willingness to change data was collected in 2021. It is possible that diets already shifted during this time. For example, there has been a recent minor trend towards reduced meat consumption. As such, the willingness to eat less meat and dairy from the 2012–2016 baseline diet could in reality be both higher or lower—depending on whether significant diet changes had already taken place. Consideration of additional information on diet shifts in the 2012–2021 decade could help shed light on the significance of this effect.

Several opportunities for future research inquiry emerge from the limitations of this analysis and its

underlying data. These concern (i) higher specificity of environmental impacts of diets and their associated risks, (ii), improved stratification of consumer impacts by socio-demographic characteristics, and (iii) more granular consumer preference data for estimating dietary adoption rates.

The environmental footprints calculated in this study were based on an LCI database [53,61] designed to capture the environmental impacts specific to Dutch food supply chains, at high product resolution. Although superior to environmental accounts developed using averaged or coarse sectoral data (e.g. from global meta-analysis or multi-regional input-output tables), we identify several improvements that could improve the precision and relevance of the LCI database used in this study. First, the sourcing profiles of the Netherlands were derived from bilateral food trade accounts with countries grouped by region, whereas multilateral food trade accounts with country-specific sources would have been preferable to better capture production differences in impact and commodity provenance. Second, associating water and land use with the availability and quality of these resources in sourcing countries can help to distinguish the severity of their use by different sectors in the Dutch food system [89]. Third, the environmental impact coefficients employed in the analysis of water use, land use, eutrophication and GHG emissions [53] do not reflect recent improvements in agricultural efficiency, nor climate-induced yield change [90].

Further stratification of our group-level footprints is necessary to better characterise high- and low-impact consumer groups. In this study, we only focus on gender and age due to the limited socio-demographic attributes reported via the food intake survey of the DNFCs 2012–2016 [51]. However, other strata should be considered for profiling high-impact groups; socio-economic status and ethnic groups are potentially relevant within the Dutch context. Ethnicity, culture or religion of consumer groups play an important role in eating behaviour [91–94] and could have huge implications on the acceptability of meat alternatives and dietary shifts in general [95–97]. Socioeconomic status of consumer groups (e.g. household income or spending levels) is also key to understanding the financial capacity of individuals to partake in dietary change. Within the context of this study, education level, available within the current food intake survey, offers a poor proxy to disaggregate our results along socio-economic lines. However, improvements to the scope of food products covered in household budgetary surveys may offer a promising avenue for coupling socioeconomic assessment of groups with dietary change scenarios.

Dietary adoption rates remain an extant challenge to estimate based on available consumer preference

data. The willingness to change rates used in this study were adopted from Koch and colleagues [18], but these rates were only available for meat and dairy products, not per food item. This posed a limitation to the analyses in our study as these groups were not directly comparable to the changes required in the food groups for the adoption of the No-Milk and EAT diets. For the adoption of the EAT diet, we assumed that changes in all other food groups (not meat/dairy groups) occurred with complete willingness, potentially overestimating the potential environmental benefits. Conversely, we believe that the actual consumer willingness to replace milk with soy drink is likely much higher than the willingness rate adopted here for the No-Milk diet, based on Koch and colleagues [18], as the survey also included cheese and eggs. We thus expect an underestimation of individuals' willingness to shift to plant-based milk, especially as various studies have indicated a drastic increase in the consumption of plant-based milk over the past decade [98–100]. Replacing high-impact food products with already widely accepted alternatives should be studied in more detail in the future as a more feasible route to a near-term sustainable dietary transition. For instance, simply substituting cow milk with soy drink, as demonstrated in this study, has the potential to reduce the GHG, land and biodiversity footprints by $\approx 8\%$. Studying the willingness of consumers to change specific high-impact food items and the corresponding environmental benefits of their substitution is essential to understand further the real environmental benefits that can be achieved from dietary changes. Further studies are needed to gain a more comprehensive understanding of the underlying factors contributing to consumer food preferences in the Dutch context and to identify potential catalysts that could facilitate consumer acceptance of sustainable dietary choices. The role of sociological experiments which study how consumer groups negotiate alternative dietary choices in their everyday life can complement survey-based studies and better distinguish revealed versus stated preferences [101]. As more granular information on the behavioural preferences of food consumption becomes available, a more nuanced assessment of dietary shifts incorporating food-specific adoption rates can be made. Future environmental footprinting studies may also benefit from the dynamic treatment of behaviour change [102], as illustrated by previous behavioural studies such as the s-shaped curve of adoption [103], the theory of planned behaviour [104], and meditating of behavioural effect size [105].

Wide-scale transformation of food consumption patterns remains challenging and unlikely without additional government intervention [24], and even if fully achieved, dietary shifts alone will not be sufficient to reach the objective of halving the Dutch

dietary footprint by 2050, as our results showed. Hence, pursuing changes to food consumption and production practices in tandem is critical. To achieve this systemic change, we must understand the barriers that consumers and farmers face to support a just and sustainable food transition [106, 107]. In contrast to nationally average dietary environmental footprinting analysis, pin-pointing high-impact consumer groups can support triage-based decision support, targeting the substitution of products which contribute most to the environmental footprints of different consumers. Within the context of food consumption, microtargeting of information on sustainable food choice, price incentives, and widened access to low-impact food products offers a viable route towards this end.

5. Conclusion

Overall, the study findings indicate that even in the best-case scenario of full adoption of a more sustainable diet, where the reduction in the GHG, biodiversity, and land use footprints reaches a maximum of $\approx 20\%$, the goal of halving the food footprint in the Netherlands will still not be met. A more realistic analysis of dietary shifts, incorporating adoption rates, further diminishes the reduction potential of dietary shifts to around $\approx 4.5\%$. These results show that consumer motivation alone is insufficient to realise the significant environmental gains promised by dietary change. Yet, substituting high-impact food products offers a near-term opportunity to accelerate a rapid sustainable dietary transition.

The study illustrates the crucial role group-level environmental footprinting plays in uncovering the differentiated roles, impacts, and priority consumption shifts of consumers within a sustainable dietary transition. Such insights are seldom revealed in conventional dietary environmental footprinting analysis, which lacks details of consumer groups, their preferences and their impacts. Such an actor-based approach is critical to ensure effective, realistic and fair pathways for a sustainable food future.

Data availability statement

The diet recall data from the Dutch National Food Consumption Survey (DNFCS) for the years 2012–2016 are accessible upon request from RIVM: <https://www.rivm.nl/en/dutch-national-food-consumption-survey/data-on-request>. The sustainable behaviour survey data employed in the study can be found at <https://doi.org/10.1016/j.spc.2023.12.009>. The aggregated dietary composition and modelled environmental footprints by consumer group can be found in the online supplementary material: <https://doi.org/10.17605/OSF.IO/QBZ4W>.

Sustainable Behaviour Data: The sustainable behaviour survey data utilised in the study conducted

by Koch and colleagues, titled "Circular consumption to reduce environmental pressure: Potential of behavioural change in the Netherlands" (2023), are available upon request by contacting the main author of the study: julia.koch@pbl.nl.

Modeled Final Footprints: The modeled final footprints referenced in this study can be found in the supplementary material and the programming code is available upon request.

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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