Towards more environmentally sustainable dietary guidance for population and planetary health

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The studies presented in this thesis were conducted at the Department of Health Sciences, Vrije Universiteit Amsterdam, within the Amsterdam Public Health Research Institute, the Netherlands.

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MooDFOOD PREVENTING DEPRESSION THROUGH FOOD

PROMISS Nutrition for healthy ageing

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CHAPTER 1
General introduction

1. This thesis

The food we eat affects our health and the health of our planet [1]. In Europe and increasingly other places around the world, poor quality diets marked by low amounts of vegetables, fruit, and whole grains, high amounts of refined carbohydrates, fats, sodium, added sugars, red and processed meat, and excessive calories represent one of the greatest public health burdens of our day [2]. Besides negative health impacts such as obesity and diet-related non-communicable diseases, current diets have adverse environmental impacts, ranging from climate change to biodiversity loss to depletion of natural resources [3]. While evidence for healthier and more sustainable diets is mounting, it is clear that there is no "one-size-fits-all" solution and that more information on different contexts, including nutritional needs and health considerations of specific subpopulations, is needed to unleash the nurturing power of our food and diets for the betterment of human and planetary health [1,4-6].

As part of the search for strategies to improve the health of populations within sound environmental limits, this thesis explores individual- and diet-level factors related to sustainable nutrition among two subpopulations in Europe, namely overweight adults with subsyndromal depressive symptoms and older adults. This thesis contributes to the evidence-base for the development of *environmentally sustainable* dietary strategies to prevent depression and enhance healthy aging within two respective European-wide projects, MooDFOOD (Multi-country cOllaborative project on the rOle of Diet FOod-related behavior, and Obesity in the prevention of Depression) and the PROMISS project (PRevention Of Malnutrition In Senior Subjects in the EU). The insights of this thesis highlight the importance of incorporating environmental sustainability into dietary guidance and can contribute to the development of dietary strategies that simultaneously promote population health and the health of our planet.

2. Food, health and the environment

Today's food systems, which encompass all elements (environment, infrastructures, institutions, actors, etc.) and activities that are related to the journey of food from farm to fork as shown in Figure 1, are having profound impacts on the environment and human society in many ways [7,8]. Not only is the global food system a major source of environmental harm, it is generating social inequalities and inequities and failing to deliver a healthy, affordable, and inclusive diet to a growing world population [9]. The environmental and societal challenges of our time necessitates public health and nutrition practitioners to consider how the broader food system affects the natural environment as well as diets, nutrition and health outcomes of populations [6].

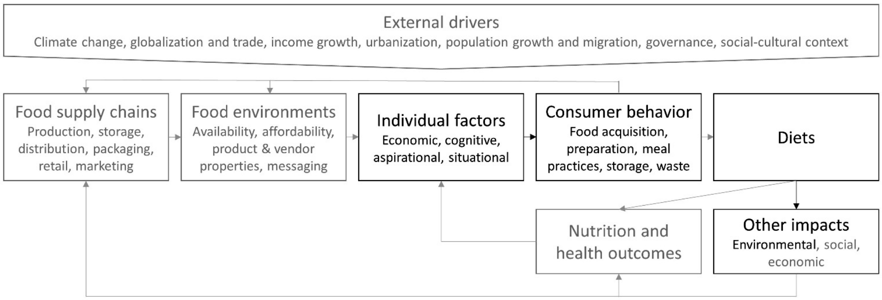

Figure 1. Food systems framework, simplified from Fanzo et. al [8], which was adapted from the framework developed by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security [7]. Components in black represent the focus of this thesis.

2.1. Environmental impacts of the food system

The global food system, which includes each step of a food's journey from farm to fork, is identified as one of the key drivers of climate change, responsible for about one third of anthropogenic greenhouse gas emissions (GHGE) worldwide [10,11]. Greenhouse gases are emitted at each stage of a food's lifecycle, via conversion of forests and grasslands, crop and livestock production processes such as fertilizer application and enteric fermentation, combustion of fossil fuels in food supply chain (e.g. from manufacturing fertilizer and farm equipment to industrial food processing, packaging, transportation, refrigeration, and retail), and decomposition of food waste in landfills [10]. In addition to climate change, the food system is a dominant player in almost all the systems that regulate the stability of our planet. According to the planetary boundaries concept [12], food production is compromising the "safe operating space for humanity" for five Earth system processes, including biosphere integrity (driving biodiversity loss), biogeochemical flows (with excess nitrogen and phosphorous from fertilizers polluting soils and waterways), land-use change, freshwater use, and climate change [13]. Globally, agriculture is estimated to use 40% of Earth's ice-free land, account for 70% of freshwater withdrawals, and contribute 32% of global terrestrial acidification and 78% eutrophication [14-16]. Expansion of agricultural land is the largest driver of deforestation, accounting for 80% of deforestation worldwide [17]. This exploitation of natural resources and pollution have a direct impact on biodiversity on land and in water, with food production threatening >70% of birds and mammals that are listed as threatened with extinction by the International Union for Conservation of Nature [18,19]. This plus the use of pesticides and other agro-chemical pollutants have been identified as the major cause to the declining insect population, having detrimental consequences for pollinators and food production [20]. Further, approximately 34% of the world's marine fish stocks are overfished and 60% are fully exploited [21]. Meanwhile, roughly one third of all food that is produced for human consumption is lost or wasted, having tremendous environmental, economic and societal implications [22]. When food is wasted, not only are resources used and greenhouse gases emitted in vain, but disposal and decomposition in landfills create additional environmental impacts [23].

With a growing and more affluent world population, the environmental impacts across the food system are expected to increase [13].

2.2. Nutrition and health outcomes

Food provides energy and nutrients which can promote and nurture human health, yet the current food system is delivering nutrient-poor, energy-rich diets that sustain high levels of malnutrition. Inequalities in the food system have led to more than 1.3 billion people not having regular access to nutritious and sufficient food while an additional 746 million people experiencing hunger in 2019 [9]. Acute malnutrition and increasing hunger exists alongside an unprecedented rise in overweight, obesity, and diet-related noncommunicable diseases due to unhealthy diets and high availability of cheap ultra-processed food and beverages [1,9,24]. A global transition to diets high in energy-dense and nutrient-poor processed foods and meats has contributed to 1.9 billion adults and 340 million children being overweight or obese in 2016 [25]. Unhealthy diets are the largest global burden of disease, posing high risks to morbidity and mortality [2].

Nutrition and health outcomes of all populations will also be affected by climate change and environmental degradation, directly through affecting food production and nutrient composition of foods and indirectly through altering social and economic forces [26]. The consequences of undernutrition, overweight, obesity, and climate change are related and interactive [3]. The poor and socially disadvantaged populations are likely to be disproportionally impacted, widening existing equity gaps in nutrition and health outcomes [6]. While the effects of global warming on food security are already being noticed, with more frequent and intense heat waves and extreme precipitation events affecting crop yields, rising temperature of oceans and consequently ocean acidification decreasing fishery yields, water scarcity, etc., the risks are projected to become greater as global warming reaches 1.5^{o}C [27] .

2.3. Pivotal role of diets

Diets are underlying and linking the nutritional health of populations and the environmental sustainability of food systems. The amount of food people eat and the food choices they make have a direct impact on their health and the environment. Overconsumption of energy not only contributes to overweight and obesity, but also strongly correlates with the environmental impact of diets [28-30]. Just like different foods have different health impacts, they have different impacts on the environment [31]. Animal-based foods in particular play an important role in the diet's overall environmental impact [32-34]. In general, animal-based food products, and especially meat and dairy, have a higher total environmental footprint compared to food deriving from plants, owing to the significant amounts of land, water, and feed required by livestock and their inefficiency to convert feed into human-edible food [16,35-37]. At a global level, production of animal-based food contributes about 72-78% to total GHGE of the agricultural sector [4]. However, there are significant differences among the different animal products, with ruminant meats (e.g. beef, lamb) having a much larger impact compared to pig and poultry meats due to enteric fermentation and higher feed conversion ratio [16]. When it comes to health, higher consumption of red and processed meat is associated with higher risk of cardiovascular disease, certain types of cancers, and premature death [38-40]. There are also significant differences in impacts of plant products, with nuts inducing more water stress as compared to grains and legumes [16]. Differences in health and environmental impacts of various food products imply differences in the health and environmental impacts of whole diets [1,34]. Identifying win-wins and trade-offs between nutrition and environmental sustainability of diets is therefore important to identify dietary changes that can simultaneously reduce the environmental impact of diets and improve nutritional health of populations [34].

2.4. Individual-level factors shaping consumer food-related behavior

Consumers' food choices are complex and influenced by many factors, including macro-level factors like culture and economics, and individual differences including biological (e.g. appetite), physiological and psychological (e.g. mood), cognitive (e.g. attitudes, motivations), and social norms (e.g. family and peers) factors [41,42]. Furthermore, consumer food behavior is shaped by food environments which include product availability, accessibility, price, convenience, and marketing [43,44]. Two diet-related behaviors that would yield a large reduction to the environment impact of diets include reducing meat consumption and reducing food waste [45]. A rich body of literature reveals the complexity of these behaviors which is described below.

Concern about the health and environmental impacts of meat consumption has led to considerable efforts to identify opportunities and barriers for consumers to reduce meat consumption. The most commonly reported food-related behaviors that people think would have a beneficial impact on the environment are avoiding excessive packaging, purchasing locally produced food, eating seasonal, eating organic food and reducing food waste [46-48]. The environmental impact of dietary change is generally underestimated [48]. Low consumer awareness of the environmental impact of meat production and low willingness to reduce meat consumption is prevalent in much of Europe [49]. Consumers' positive perception of meat (e.g. taste, pleasure, nutritious, familiarity), tradition, social norms, and lack of culinary skills have been found to be barriers to change meat consumption behavior [50,51]. Further, food choice motives such as sensory appeal, price, and convenience have been found to impede willingness whereas food choice motives health and sustainability have been found to facilitate a change in meat consumption [52].

Consumer food waste behavior is equally complex and multifaceted [53,54]. Although food waste is perceived as a problem by consumers, household-level food waste remains rampant [54]. Various theoretical perspectives on food waste exist. One relies on the theory of planned behavior, which suggests that food waste behavior is determined by intention, which is influenced by subjective norm, perceived behavioral control, and attitude towards the behavior [55]. This framework is most commonly applied when investigating food waste behavior [56-61]. However, this socio-psychological framework can only partly predict intention and to a lesser extent actual behavior, explained by the attitude-behavior gap [57,62,63]. In contrast, several studies have demonstrated that food-related behaviors, such as planning and shopping routines, when added or compared to the theory of planned behavior, are more important indicators than intention for the amount of food wasted [57,58]. Household routines such as planning, shopping, storing, cooking, eating, and managing leftovers play a decisive role in food waste generation, as at each stage food may be assessed with regards to their edibility [64]. Consumers are likely to assign importance of food to various goals, like being a good provider and ensuring food safety, and some goals may conflict with the goal for sustainable food consumption or food waste reduction [59].

3. Sustainable diets for population and planetary health

It is clear that a transition to more sustainable diets is needed to reconcile food production and consumption with population and planetary health. If dietary patterns do not change, it is projected that diet-related health costs linked to mortality and diet-related noncommunicable diseases will exceed USD 1.3 trillion per year by 2030 [9], and catastrophic climate change will ensue [65]. While technological advances of food production have suggested to reduce the environmental impact of diets [4,66], technological mitigation can only reduce the impact of our food system to a certain extent and would not address the health issues related to the food system [5,65]. Much evidence underscores the need for significant changes to what is currently consumed and to how we handle food waste to reduce the total environmental impact of our current and future food system [1,4,5,67].

3.1. Definition

The concept of sustainable nutrition was first introduced in 1986 by Gussow and Clancy, who argued the need for diets that not only support human health but also the health of the natural environment to ensure the long-term food and nutrition security [68]. However, it wasn't until the last decade that this concept gained traction, when more evidence became available indicating the extent to which current methods and levels of food production and consumption are contributing to nutritional and health problems and exceeding the planetary boundaries for a safe operating space for humanity [12,69]. In 2010, the Food and Agriculture Organization of the United Nations and Bioversity International attained a consensus definition of sustainable diets as the following:

> "*Sustainable diets are diets with low environmental impacts that contribute to food and nutrition security and to healthy lives for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable, are nutritionally adequate, safe, and healthy, and optimize natural and human resources*" [70].

In addition to health and environment, this definition adds three equally important guiding principles – equity, socio-cultural values, and economy. For the purpose of this thesis, we largely focus on the health and environmental aspects of sustainable diets (which we use interchangeably with sustainable nutrition), as well as socio-cultural values in terms of cultural acceptability and individual preferences, as we are primarily interested in formulating *environmentally sustainable* and *culturally acceptable* recommendations that promote *population health*.

3.2. Environmental impacts of dietary change

Amid concerns over the health and environmental implications of current diets, increasingly more research is incorporating environmental sustainability with nutrition to identify alternative dietary patterns that are more health promoting for both humans and the natural environment [71,72]. The environmental impact of hypothetical change from current to alternative, theoretical diets is often assessed in dietary scenarios, which are mainly derived from simulations or mathematical optimization [73,74]. With the former, predefined diets such as the Mediterranean diet, diets aligned to national food-based dietary guidelines, and diets based on exclusion of entire food categories (e.g. pescatarian, vegetarian and vegan diets) have been shown to generally perform better compared to current diets in terms of nutritional and environmental outcomes [32,71,75]. With the latter, optimization of diets with simultaneous improvements in health and sustainability have shown the need to reduce consumption of animal foods and discretionary foods and increase consumption of fruits and vegetables, whole grains, legumes, fish, and nuts [76,77]. Such research on the sustainability of various dietary patterns highlight the existence of both co-benefits and trade-offs between nutrition and environmental impacts [30]. For instance, a complete removal of meat and animal-based foods (i.e. vegan diet) has shown to have the lowest environmental impact, but it poses nutritional risks [78,79]. While a reduction in meat consumption can have benefits for both health and the environment especially in places where meat is overconsumed [80], the path to achieve this is not unequivocal. To recommend appropriate solutions, more information is needed on different contexts, including dietary needs of specific subpopulations.

3.3. Nutritional needs and health considerations of specific subpopulations

3.3.1. Overweight adults with subsyndromal depressive symptoms

Depression is a common mental health problem, affecting more than 264 million people worldwide and ranking as one of the top contributors of disability-adjusted life years [81,82]. A meta-analysis of longitudinal studies found that overweight and obesity increase the risk of onset of depression, while depression increases the risk for developing obesity [83]. In order to reduce the global disease burden of depression and to stop this vicious cycle of overweight, obesity, and depression, researchers are pointing to diet as a modifiable risk factor [84]. Epidemiological studies have found that better adherence to higher quality diets is associated with reduced onset of depressive symptoms [85]. In particular, the Mediterranean diet – characterized by high consumption of fruits, vegetables, nuts, whole grains, and legumes; moderate consumption of low-fat dairy, fish, poultry, eggs, and olive oil; and limited intake of red and processed meat and discretionary foods – has been associated with reductions in depression incidence [86,87]. Therefore promoting a Mediterranean-style dietary pattern was hypothesized to prevent depression in overweight and obese individuals with subsyndromal depressive symptoms [88]. The environmental impact of promoting a Mediterranean-style dietary pattern in overweight and obese individuals with subsyndromal depressive symptoms is investigated in this thesis.

3.3.2. Older adults

All societies in the world are rapidly aging. In Europe, it is estimated that the older adult population aged 65 years and older will increase by 42.3% and the working-age population will decrease by 9.5% between 2020 and 2050, posing challenges with regards to health care, long-term care, and social expenditures [89]. One in five persons is already aged 65 years or above in the EU, with the majority living independently in the community [90,91]. For older people to remain independent, it is important that they are living in good health. To support the health and independence of a growing older population, prevention of decline in nutritional and functional status among community-dwelling older adults is essential.

To this end, researchers have been revisiting the protein needs of older adults aged 65 years and older. Adequate protein intake is important for the maintaining muscle mass, strength, and physical function and promoting overall health and wellbeing [45,92,93]. Several short-term metabolic and observational studies suggest that older adults aged 65 years and older need to consume more protein compared to younger adults to maintain adequate muscle mass and strength [92,94-96], although evidence from randomized controlled trials is not conclusive [97]. Nevertheless several expert groups propose an increase of the recommended daily allowance (RDA) of protein from 0.8 g/kg body weight (BW)/day to 1.0-1.2 g/kg BW/day for older adults [98-100]. The environmental impact of such dietary advice is investigated in this thesis. Further, attitudes towards alternative protein sources and specific dietary changes needed to increase protein intake in an environmentally friendly way among older adults is addressed.

3.4. Role of dietary guidance

Dietary guidance refers to the provision of recommendations on food choices and dietary patterns that meet requirements for essential nutrients and protect against the development of food-related noncommunicable disease [101]. Dietary guidance is traditionally developed through the lens of health promotion and disease prevention and comes in many forms, including diet counselling of individuals and provision of dietary guidelines by national and international institutions and scientific organizations. The potential role that dietary guidance can play in supporting consumers on not only how to make healthier food choices, but also more environmentally sustainable food choices, has been long acknowledged [1,68,102].

The Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) have developed several guiding principles to achieve healthy and environmentally sustainable diets [103]. They underscore the need to establish a representative baseline of current diets of specific population groups to identify dietary changes that have the greatest positive impact on both health and the environment [103]. Further, they highlight the importance of developing food-based dietary guidelines that define context-specific sustainable diets by taking into account social, cultural, economic, and environmental circumstances. Aligned with FAO and WHO's guiding principles, this thesis takes a holistic approach to diets, considering the nutritional needs of specific subpopulations, the environmental impact of food consumption, and the adaptability to European cultural contexts, to inform the development of dietary guidance for European subpopulations and planetary health.

4. Aim and outline of this thesis

The present thesis is embedded within two European-wide projects, namely the MooDFOOD project and the PROMISS project. Both projects involve a multidisciplinary consortium that have undertaken extensive research into the potential of diet in preventing depression (MooDFOOD) and enhancing healthy aging (PROMISS) with the aim of developing evidence-based dietary strategies that are effective, feasible, and *environmentally sustainable* in the prevention of depression and malnutrition, respectively. A description of these projects and the datasets used can be found in Box 1.

Box 1. Description of EU projects and datasets used in this thesis
MooDFOOD
The MooDFOOD project (Multi-country cOllaborative project on the rOle of Diet FOod-related behavior, and Obesity in the prevention of Depression) was a 5-year multidisciplinary research project funded by the Seventh Framework Program of the European Commission (grant number 613598). The MooDFOOD project aimed to investigate how food intake, nutrient status, food-related behavior, and obesity are link to the development of depression [104]. The research described in this thesis was performed using data from a survey conducted in Denmark and Spain and a randomized controlled trial that were part of the MooDFOOD project. ***Survey in Denmark and Spain*** In total, 3,034 respondents from Denmark and Spain completed an online questionnaire that was distributed by Qualtrics, a panel service agency, in June and July 2014. The main purpose of the survey was to explore food-related behavior and mental well-being, which has been described elsewhere [105]. The questionnaire contained measures on food-related behaviors, self-reported food waste, and socio-demographics. Data from the survey were used for **Chapter 2.** ***MooDFOOD trial*** The MooDFOOD trial was a 2 x 2 factorial randomized controlled prevention trial that included 1,025 overweight adults with subsyndromal symptoms of depression in four European countries (Germany, Spain, United Kingdom, and the Netherlands). Full details of the trial design and protocol can be found elsewhere [106]. The trial was designed to investigate the feasibility and effectiveness of two different nutritional strategies for the prevention of depression: multi-nutrient supplementation and food-related behavioral activation therapy applying Mediterranean-style dietary guidelines. Dietary intake data were collected using an online self-administered food frequency questionnaire (FFQ) at baseline, 6 months, and 12 months. Dietary data were linked to environmental data described in Box 2. Data from the MooDFOOD trial were used for **Chapter 6**.

Box 1. Description of EU projects and datasets used in this thesis (continued)
PROMISS
The **PROMISS** project (PRevention Of Malnutrition In Senior Subjects in the EU) was a 5-year multidisciplinary research project funded by Horizon 2020, the Research and Innovation Program of the European Union (EU) (grant number 678732). The PROMISS project aimed to contribute to the prevention of malnutrition and to support active and healthy aging in community-dwelling older adults. The research described in this thesis was performed using data from two consumer surveys, one ancillary study to a population-based cohort study (i.e. the Longitudinal Aging Study Amsterdam), and a randomized controlled trial that were part of the PROMISS project. *Consumer surveys* Two consumer surveys were conducted among older adults aged 65 years and older living in five European countries (Finland, Poland, Spain, the Netherlands, United Kingdom), the first in June 2017 and the second in June 2019. The first survey aimed to quantify attitudes and preferences of older adults with regard to dietary and physical activity characteristics and included 1,825 respondents. The second survey aimed to quantify acceptance and preferences of various dietary strategies and included 2,500 respondents. Data from the 2017 survey were used for **Chapter 3** and data from the 2019 survey were used for **Chapter 4**. *Nutrition and Food-related Behavior ancillary study of the Longitudinal Aging Study Amsterdam (LASA)* Dietary intake data were collected during the 2014-2015 Nutrition and Food-related Behavior ancillary study of LASA from 1,439 older adults aged 55 years and older by means of a FFQ which was based on the Dutch version of the HELIUS FFQ [107-109]. Dietary data was linked to environmental data described in Box 2. Data from this study were used for **Chapter 5**. *PROMISS trial* The PROMISS trial was a randomized controlled trial that included 276 community-dwelling older adults with low habitual protein intake from the Netherlands and Finland. The main aim of the trial was to test the (cost-)effectiveness of personalized dietary advice aiming at increasing protein intake on physical functioning [110]. Dietary intake data were collected by means of a combination of three food diaries and 24-hour recalls at baseline, 3-month follow-up, and 6-month follow-up. Dietary data were linked to environmental data described in Box 2. Data from the PROMISS trial were used for **Chapter 7**.

The overall aim of this thesis is to evaluate the environmental impact of health-oriented dietary guidance and provide insight into how to make such guidance more environmentally sustainable. We explore individual-level factors that may influence food choice and food-related behavior, including personal factors (e.g. socio-demographics), psychographic factors (e.g. attitudes and preferences), and life situation (e.g., health status), to identify opportunities and challenges to achieving healthier and more sustainable diets. In addition, we investigate the environmental impact of dietary change suggested to prevent depression and enhance healthy aging in free-living individuals and identify dietary changes needed to simultaneously meet nutrition and sustainability goals using diet optimization methods.

Summarized in Figure 2, this thesis consists of two main objectives and addresses the following research questions:

Objective 1: To identify individual-level factors that pose as opportunities and challenges to achieving more environmentally sustainable food-related behavior

1. What socio-demographic characteristics are predictors of food waste behavior? (Chapter 2)
2. What is older adults' acceptability to consume alternative, more sustainable protein sources and what factors influence their level of acceptability? (Chapter 3)
3. Are there different patterns of meat consumption among older adults and what factors explain these differences? (Chapter 4)

Objective 2: To assess the environmental impact of dietary change due to health-oriented dietary guidance

4. What dietary changes are needed to increase protein in an environmentally sustainable way in older adults? (Chapter 5)
5. What is the effect of health-oriented diet interventions on food consumption and the environmental impact of the diet? (Chapter 6 and Chapter 7)

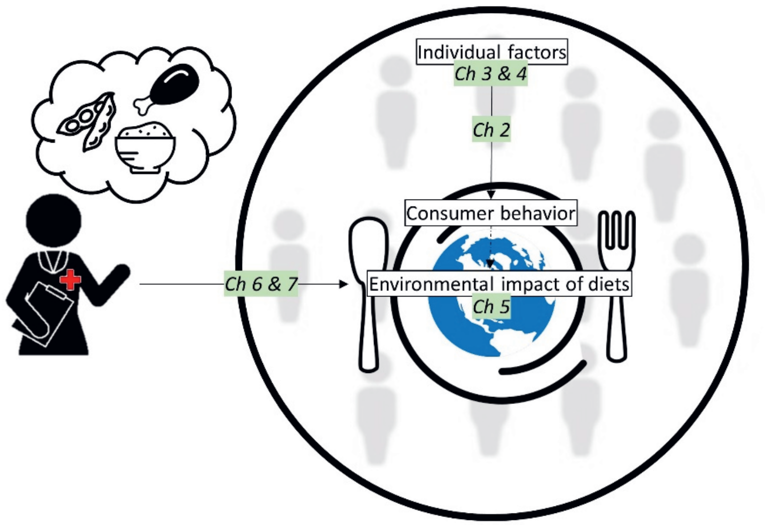

Figure 2. Schematic framework of this thesis. Chapters 2, Chapter 3 and Chapter 4 explore personal and psychographic factors influencing food choice and food-related behavior. Chapter 5 poses several modelled diets optimized for nutrition and sustainability. Chapter 6 and Chapter 7 investigate the effect of diet interventions on the food consumption and the environmental impact of the diet.

The first objective is addressed in Chapter 2, Chapter 3, and Chapter 4. In Chapter 2, socio-demographic predictors of food waste behavior in Denmark and Spain are described. The chapter provides a new measurement model of food waste behavior that combines food-related behaviors found to influence the amount of food wasted at the consumer level with self-reported food waste, providing a broader perspective on food waste.

Chapter 3 reports the level of acceptance to consume alternative, more sustainable protein source and explores potential determinants of acceptance among older adults aged 65 years and older from five European countries. Chapter 4 builds on the previous chapter and identifies and describes consumer segments based on meat consumption and liking among older adults from the same five European countries.

The second objective is addressed in Chapter 5, Chapter 6, and Chapter 7. Chapter 5 identifies dietary changes needed to increase protein intake in an environmentally sustainable way in older adults in the Netherlands. To this end, diet optimization methods were employed to model several high-protein diets with minimized departure from habitual intake in cumulative steps. Dietary changes and the environmental impact thereof were identified to isocalorically meet a high-protein diet while maintaining or improving the nutritional adequacy of the diet, without taking environmental sustainability into account. We then applied stepwise constraints to identify dietary changes needed to adhere to the Dutch food-based dietary guidelines and reduce diet-associated GHGE.

In Chapter 6 and Chapter 7, the environmental impact of health-oriented diet interventions in randomized controlled trials was assessed. In Chapter 6, changes in food consumption and the environmental impact of diets was compared between overweight adults with subsyndromal depressive symptoms who received a diet intervention promoting the Mediterranean diet and those who did not receive the intervention. The environmental impact of the diet was assessed using GHGE, land use, fossil energy use, and pReCiPe. Chapter 7 explores the effect of dietary advice aiming at increasing protein intake on food consumption and the environmental impact of the diet among community-dwelling older adults in the Netherlands. The environmental impact of the diet was assessed using GHGE, land use, terrestrial acidification, freshwater and marine eutrophication, and blue water use. More information about the environmental data used in this thesis can be found in Box 2.

A general discussion of the main findings of this thesis and its conclusion are provided in Chapter 8. Methodological considerations and implications for future research and practice are addressed.

Box 2. Environmental data used in this thesis

The environmental impact of food consumption was estimated with life cycle analysis (LCA), a methodological framework for assessing the environmental impacts over the entire life cycle of a product, from cultivation to consumption and final disposal [111]. All relevant information across the life cycle of a food was collected as Life Cycle Inventory (LCI) data using the ReCiPe 2016 Midpoint v1.00 method by Blonk Consultants (Gouda, The Netherlands) [112,113]. The LCA system boundaries were from cradle to grave, indicating all steps from primary production, processing, packaging, distribution, retail, transportation, storage, food preparation, cooking, and incineration of waste products. Transport between all phases, except from retail to consumer was included. The LCA had an attributional approach and hierarchical perspective and were performed following the ISO 14040 and 14044 guidelines. The functional unit was mass related, meaning the environmental impact is explained per 100g of food product. The default allocation used is economic allocation which is when the environmental impact is divided between co-products based on fraction of the financial revenue of each co-product. This type of allocation is commonly used for LCAs of agricultural and food products. These LCA data were linked to dietary data described in Box 1 to calculate the environmental impact of the whole diet.

Environmental impact indicators

This thesis made use of several environmental impact indicators, including:

- greenhouse gas emissions (GHGE; kg CO^2-eq),
- land use (LU; m^{2}*y),
- fossil energy use (FEU; MJ),
- terrestrial acidification (kg SO_2-eq),
- freshwater eutrophication (kg P-eq),
- marine eutrophication (kg N-eq), and
- blue water use (m^3).

GHGE and LU are the most commonly used indicators to describe the environmental impact of food and diets [114] and was used **Chapter 5**, **Chapter 6** and **Chapter 7**. In **Chapters 5** and **Chapter 6**, fossil energy use was considered, and was aggregated with GHGE and LU in **Chapter 6** to calculate an overall environmental score, or the pReCiPe score. In **Chapter 7**, we included the indicators terrestrial acidification, freshwater eutrophication, marine eutrophication, and blue water use to get a more nuanced insight, especially because blue water use has opposing associations between diets and GHGE [115].

References

1. Willett W, Rockstrom J, Loken B, Springmann M, Lang T, Vermeulen S et al (2019) Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems. Lancet 393 (10170):447-492. https://doi.org/10.1016/s0140-6736(18)31788-4
2. Afshin A, Sur PJ, Fay KA, Cornaby L, Ferrara G, Salama JS et al (2019) Health effects of dietary risks in 195 countries, 1990–2017: A systematic analysis for the Global Burden of Disease Study 2017. The Lancet 393 (10184):1958-1972. https://doi.org/10.1016/S0140-6736(19)30041-8
3. Swinburn BA, Kraak VI, Allender S, Atkins VJ, Baker PI, Bogard JR et al (2019) The global syndemic of obesity, undernutrition, and climate change: The Lancet Commission report. The Lancet 393 (10173):791-846. https://doi.org/10.1016/S0140-6736(18)32822-8
4. Springmann M, Clark M, Mason-D'Croz D, Wiebe K, Bodirsky BL, Lassaletta L et al (2018) Options for keeping the food system within environmental limits. Nature. https://doi.org/10.1038/s41586-018-0594-0
5. Garnett T (2011) Where are the best opportunities for reducing greenhouse gas emissions in the food system (including the food chain)? Food Policy 36:S23-S32. https://doi.org/10.1016/j.foodpol.2010.10.010
6. Fanzo J, Bellows AL, Spiker ML, Thorne-Lyman AL, Bloem MW (2020) The importance of food systems and the environment for nutrition. Am J Clin Nutr 113 (1):7-16. https://doi.org/10.1093/ajcn/nqaa313
7. HLPE (2017) Nutrition and food systems. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. Rome.
8. Fanzo J, Haddad L, McLaren R, Marshall Q, Davis C, Herforth A et al (2020) The Food Systems Dashboard is a new tool to inform better food policy. Nature Food 1 (5):243-246. https://doi.org/10.1038/s43016-020-0077-y
9. FAO (2020) The state of food security and nutrition in the world: Transforming food systems for affordable healthy diets. Food and Agriculture Organization of the United Nations, Rome.
10. Tubiello FN, Rosenzweig C, Conchedda G, Karl K, Gütschow J, Xueyao P et al (2021) Greenhouse gas emissions from food systems: building the evidence base. Environ Res Lett 16 (6):065007. https://doi.org/10.1088/1748-9326/ac018e
11. Crippa M, Solazzo E, Guizzardi D, Monforti-Ferrario F, Tubiello FN, Leip A (2021) Food systems are responsible for a third of global anthropogenic GHG emissions. Nature Food. https://doi.org/10.1038/s43016-021-00225-9
12. Rockström J, Steffen W, Noone K, Persson Å, Chapin Iii FS, Lambin EF et al (2009) A safe operating space for humanity. Nature 461:472. https://doi.org/10.1038/461472a
13. Campbell BM, Beare DJ, Bennett EM, Hall-Spencer JM, Ingram JSI, Jaramillo F et al (2017) Agriculture production as a major driver of the Earth system exceeding planetary boundaries. Ecol 22 (4). https://10.5751/ES-09595-220408
14. IPCC (2019) Climate Change and Land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Intergovernmental Panel on Climate Change (IPCC), Geneva, Switzerland.
15. Foley JA, Ramankutty N, Brauman KA, Cassidy ES, Gerber JS, Johnston M et al (2011) Solutions for a cultivated planet. Nature 478:337-342. https://doi.org/10.1038/nature10452
16. Poore J, Nemecek T (2018) Reducing food's environmental impacts through producers and consumers. Science 360 (6392):987-992. https://doi.org/10.1126/science.aaq0216

17. Hosonuma N, Herold M, De Sy V, De Fries RS, Brockhaus M, Verchot L et al (2012) An assessment of deforestation and forest degradation drivers in developing countries. Environ Res Lett 7 (4):044009. https://doi.org/10.1088/1748-9326/7/4/044009
18. IPBES (2019) Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. IPBES secretariat, Bonn, Germany.
19. IUCN (2017) IUCN Red List Threat Species (Version 2016-5). International Union for Conservation of Nature, Gland, Switzerland.
20. Sánchez-Bayo F, Wyckhuys KAG (2019) Worldwide decline of the entomofauna: A review of its drivers. Biological Conservation 232:8-27. https://doi.org/10.1016/j.biocon.2019.01.020
21. FAO (2020) The State of World Fisheries and Aquaculture 2020. Sustainability in action. Rome.
22. FAO (2011) Global food losses and food waste - Extent, causes and prevention. Food and Agriculture Organization of the United Nations (FAO), Rome.
23. Birney CI, Franklin KF, Davidson FT, Webber ME (2017) An assessment of individual foodprints attributed to diets and food waste in the United States. Environ Res Lett 12 (10):105008. https://doi.org/10.1088/1748-9326/aa8494
24. Popkin BM, Corvalan C, Grummer-Strawn LM (2020) Dynamics of the double burden of malnutrition and the changing nutrition reality. The Lancet 395 (10217):65-74. https://doi.org/10.1016/S0140-6736(19)32497-3
25. WHO (2021) Obesity and overweight: Key facts. https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight. Accessed 15 July 2021
26. Salm L, Nisbett N, Cramer L, Gillespie S, Thornton P (2021) How climate change interacts with inequity to affect nutrition. WIREs Climate Change 12 (2):e696. https://doi.org/10.1002/wcc.696
27. Hoegh-Guldberg O, Jacob D, Taylor M, Guillén Bolaños T, Bindi M, Brown S et al (2019) The human imperative of stabilizing global climate change at 1.5°C. Science 365 (6459). https://doi.org/10.1126/science.aaw6974
28. Hendrie GA, Baird D, Ridoutt B, Hadjikakou M, Noakes M (2016) Overconsumption of energy and excessive discretionary food intake inflates dietary greenhouse gas emissions in Australia. Nutrients 8 (11):690. https://doi.org/10.3390/nu8110690
29. Vieux F, Darmon N, Touazi D, Soler LG (2012) Greenhouse gas emissions of self-selected individual diets in France: Changing the diet structure or consuming less? Ecol Econ 75:91-101. https://doi.org/10.1016/j.ecolecon.2012.01.003
30. Macdiarmid JI (2013) Is a healthy diet an environmentally sustainable diet? Proc Nutr Soc 72. https://doi.org/10.1017/S0029665112002893
31. Clark MA, Springmann M, Hill J, Tilman D (2019) Multiple health and environmental impacts of foods. Proc Natl Acad Sci USA 116 (46):23357. https://doi.org/10.1073/pnas.1906908116
32. Aleksandrowicz L, Green R, Joy EJM, Smith P, Haines A (2016) The impacts of dietary change on greenhouse gas emissions, land use, water use, and health: A systematic review. PLOS ONE 11 (11):e0165797. https://doi.org/10.1371/journal.pone.0165797
33. Springmann M, Wiebe K, Mason-D'Croz D, Sulser TB, Rayner M, Scarborough P (2018) Health and nutritional aspects of sustainable diet strategies and their association with environmental impacts: a global modelling analysis with country-level detail. Lancet Planet Health 2 (10):e451-e461. https://doi.org/10.1016/S2542-5196(18)30206-7
34. Tilman D, Clark M (2014) Global diets link environmental sustainability and human health. Nature 515:518-522. https://doi.org/10.1038/nature13959

35. Gerbens-Leenes PW, Nonhebel S (2002) Consumption patterns and their effects on land required for food. Ecol Econ 42 (1):185-199. https://doi.org/10.1016/S0921-8009(02)00049-6
36. Westhoek H, Lesschen JP, Rood T, Wagner S, De Marco A, Murphy-Bokern D et al (2014) Food choices, health and environment: Effects of cutting Europe's meat and dairy intake. Global Environ Chang 26:196-205. https://doi.org/10.1016/j.gloenvcha.2014.02.004
37. Alexander P, Rounsevell MDA, Dislich C, Dodson JR, Engström K, Moran D (2015) Drivers for global agricultural land use change: The nexus of diet, population, yield and bioenergy. Global Environ Chang 35:138-147. https://doi.org/10.1016/j.gloenvcha.2015.08.011
38. Guasch-Ferré M, Satija A, Blondin SA, Janiszewski M, Emlen E, O'Connor LE et al (2019) Meta-analysis of randomized controlled trials of red meat consumption in comparison With various aomparison diets on cardiovascular risk factors. Circulation 139 (15):1828-1845. https://doi.org/10.1161/CIRCULATIONAHA.118.035225
39. Zheng Y, Li Y, Satija A, Pan A, Sotos-Prieto M, Rimm E et al (2019) Association of changes in red meat consumption with total and cause specific mortality among US women and men: two prospective cohort studies. BMJ 365:l2110. https://doi.org/10.1136/bmj.l2110
40. Wang X, Lin X, Ouyang YY, Liu J, Zhao G, Pan A et al (2016) Red and processed meat consumption and mortality: dose–response meta-analysis of prospective cohort studies. Public Health Nutr 19 (5):893-905. https://doi.org/10.1017/S1368980015002062
41. Shepherd R (1990) The psychology of food choice. Nutrition & Food Science 90 (3):2-4. https://doi.org/10.1108/eb059291
42. Rozin P (2015) Food Preferences, Psychology and Physiology of. International Encyclopedia of the Social & Behavioral Sciences, 2nd ed. Elsevier, Oxford, UK
43. Chen PJ, Antonelli M (2020) Conceptual models of food choice: Influential factors related to foods, individual differences, and society. Foods 9 (12). https://doi.org/10.3390/foods9121898
44. Herforth A, Ahmed S (2015) The food environment, its effects on dietary consumption, and potential for measurement within agriculture-nutrition interventions. Food Security 7 (3):505-520. https://doi.org/10.1007/s12571-015-0455-8
45. Wood SLR, Alam M, Dupras J (2019) Multiple pathways to more sustainable diets: Shifts in diet composition, caloric intake and food waste. Front Sustain Food Syst 3 (89). https://doi.org/10.3389/fsufs.2019.00089
46. Tobler C, Visschers VHM, Siegrist M (2011) Eating green. Consumers' willingness to adopt ecological food consumption behaviors. Appetite 57 (3):674-682. https://doi.org/10.1016/j.appet.2011.08.010
47. Lea E, Worsley A (2008) Australian consumers' food-related environmental beliefs and behaviours. Appetite 50 (2):207-214. https://doi.org/10.1016/j.appet.2005.07.012
48. Siegrist M, Visschers VHM, Hartmann C (2015) Factors influencing changes in sustainability perception of various food behaviors: Results of a longitudinal study. Food Qual Prefer 46:33-39. https://doi.org/10.1016/j.foodqual.2015.07.006
49. Hartmann C, Siegrist M (2017) Consumer perception and behaviour regarding sustainable protein consumption: A systematic review. Trends Food Sci Tech 61:11-25. https://doi.org/10.1016/j.tifs.2016.12.006
50. Macdiarmid JI, Douglas F, Campbell J (2016) Eating like there's no tomorrow: Public awareness of the environmental impact of food and reluctance to eat less meat as part of a sustainable diet. Appetite 96:487-493. https://doi.org/10.1016/j.appet.2015.10.011
51. Sanchez-Sabate R, Badilla-Briones Y, Sabaté J (2019) Understanding attitudes towards reducing meat consumption for environmental reasons. A qualitative synthesis review. Sustainability 11 (22). https://doi.org/10.3390/su11226295

52. Vainio A, Niva M, Jallinoja P, Latvala T (2016) From beef to beans: Eating motives and the replacement of animal proteins with plant proteins among Finnish consumers. Appetite 106:92-100. https://doi.org/10.1016/j.appet.2016.03.002
53. Aschemann-Witzel J, De Hooge I, Amani P, Bech-Larsen T, Oostindjer M (2015) Consumer-related food waste: Causes and potential for action. Sustainability 7 (6):6457-6477. https://doi.org/10.3390/su7066457
54. Schanes K, Dobernig K, Gözet B (2018) Food waste matters - A systematic review of household food waste practices and their policy implications. J Clean Prod 182:978-991. https://doi.org/10.1016/j.jclepro.2018.02.030
55. Ajzen I (1991) The theory of planned behavior. Organ Behav Hum Decis Process 50 (2):179-211. https://doi.org/10.1016/0749-5978(91)90020-T
56. Graham-Rowe E, Jessop DC, Sparks P (2015) Predicting household food waste reduction using an extended theory of planned behaviour. Resour Conserv Recycl 101:194-202. https://doi.org/10.1016/j.resconrec.2015.05.020
57. Stancu V, Haugaard P, Lähteenmäki L (2016) Determinants of consumer food waste behaviour: Two routes to food waste. Appetite 96:7-17. https://doi.org/10.1016/j.appet.2015.08.025
58. Stefan V, van Herpen E, Tudoran AA, Lähteenmäki L (2013) Avoiding food waste by Romanian consumers: The importance of planning and shopping routines. Food Qual Prefer 28 (1):375-381. https://doi.org/10.1016/j.foodqual.2012.11.001
59. Visschers VHM, Wickli N, Siegrist M (2016) Sorting out food waste behaviour: A survey on the motivators and barriers of self-reported amounts of food waste in households. J Environ Psychol 45:66-78. https://doi.org/10.1016/j.jenvp.2015.11.007
60. Mondéjar-Jiménez J-A, Ferrari G, Secondi L, Principato L (2016) From the table to waste: An exploratory study on behaviour towards food waste of Spanish and Italian youths. J Clean Prod 138:8-18. https://doi.org/10.1016/j.jclepro.2016.06.018
61. Soorani F, Ahmadvand M (2019) Determinants of consumers' food management behavior: Applying and extending the theory of planned behavior. Waste Manag 98:151-159. https://doi.org/10.1016/j.wasman.2019.08.025
62. Vermeir I, Verbeke W (2006) Sustainable food consumption: Exploring the consumer "attitude – behavioral intention" gap. J Agric Environ Ethics 19 (2):169-194. https://doi.org/10.1007/s10806-005-5485-3
63. Kollmuss A, Agyeman J (2002) Mind the Gap: Why do people act environmentally and what are the barriers to pro-environmental behavior? Environ Educ Res 8 (3):239-260. https://doi.org/10.1080/13504620220145401
64. Evans D (2011) Beyond the throwaway aociety: Ordinary domestic practice and a sociological approach to household food waste. Sociology 46 (1):41-56. https://doi.org/10.1177/0038038511416150
65. Clark MA, Domingo NGG, Colgan K, Thakrar SK, Tilman D, Lynch J et al (2020) Global food system emissions could preclude achieving the 1.5° and 2°C climate change targets. Science 370 (6517):705-708. https://doi.org/10.1126/science.aba7357
66. Béné C, Oosterveer P, Lamotte L, Brouwer ID, de Haan S, Prager SD et al (2019) When food systems meet sustainability – Current narratives and implications for actions. World Dev 113:116-130. https://doi.org/10.1016/j.worlddev.2018.08.011
67. Rockström J, Edenhofer O, Gaertner J, DeClerck F (2020) Planet-proofing the global food system. Nature Food 1 (1):3-5. https://doi.org/10.1038/s43016-019-0010-4
68. Gussow JD, Clancy KL (1986) Dietary guidelines for sustainability. J Nutr Educ 18 (1):1-5. https://doi.org/10.1016/S0022-3182(86)80255-2
69. Dernini S (2019) Sustainable diets: A historical perspective. In: Ferranti P, Berry EM, Anderson JR (eds) Encyclopedia of Food Security and Sustainability. Elsevier, Oxford, pp 370-373. https://doi.org/10.1016/B978-0-08-100596-5.22075-1

70. Burlingame B, Dernini S (2012) Sustainable diets and biodiversity: Directions and solutions for policy, research and action. FAO Headquarters, Rome.
71. Hallström E, Carlsson-Kanyama A, Börjesson P (2015) Environmental impact of dietary change: a systematic review. J Clean Prod 91:1-11. https://doi.org/10.1016/j.jclepro.2014.12.008
72. Perignon M, Vieux F, Soler L-G, Masset G, Darmon N (2017) Improving diet sustainability through evolution of food choices: review of epidemiological studies on the environmental impact of diets. Nutr Rev 75 (1):2-17. https://doi.org/10.1093/nutrit/nuw043
73. Mertens E, van't Veer P, Hiddink GJ, Steijns JMJM, Kuijsten A (2017) Operationalising the health aspects of sustainable diets: a review. Public Health Nutr 20 (4):739-757. https://doi.org/10.1017/S1368980016002664
74. Nelson ME, Hamm MW, Hu FB, Abrams SA, Griffin TS (2016) Alignment of healthy dietary patterns and environmental sustainability: A systematic review. Adv Nutr 7 (6):1005-1025. https://doi.org/10.3945/an.116.012567
75. van Dooren C, Marinussen M, Blonk H, Aiking H, Vellinga P (2014) Exploring dietary guidelines based on ecological and nutritional values: A comparison of six dietary patterns. Food Policy 44:36-46. https://doi.org/10.1016/j.foodpol.2013.11.002
76. Gazan R, Brouzes CMC, Vieux F, Maillot M, Lluch A, Darmon N (2018) Mathematical optimization to explore tomorrow's sustainable diets: A narrative review. Adv Nutr 9 (5):602-616. https://doi.org/10.1093/advances/nmy049
77. Vieux F, Privet L, Soler LG, Irz X, Ferrari M, Sette S et al (2020) More sustainable European diets based on self-selection do not require exclusion of entire categories of food. J Clean Prod 248:119298. https://doi.org/10.1016/j.jclepro.2019.119298
78. Chai BC, van der Voort JR, Grofelnik K, Eliasdottir HG, Klöss I, Perez-Cueto FJA (2019) Which diet has the least environmental impact on our planet? A systematic review of vegan, vegetarian and omnivorous diets. Sustainability 11 (15):4110. https://doi.org/10.3390/su11154110
79. Bakaloudi DR, Halloran A, Rippin HL, Oikonomidou AC, Dardavesis TI, Williams J et al (2021) Intake and adequacy of the vegan diet. A systematic review of the evidence. Clin Nutr 40 (5):3503-3521. https://doi.org/10.1016/j.clnu.2020.11.035
80. Springmann M, Spajic L, Clark MA, Poore J, Herforth A, Webb P et al (2020) The healthiness and sustainability of national and global food based dietary guidelines: modelling study. BMJ 370:m2322. https://doi.org/10.1136/bmj.m2322
81. Vos T, Lim SS, Abbafati C, Abbas KM, Abbasi M, Abbasifard M et al (2020) Global burden of 369 diseases and injuries in 204 countries and territories, 1990-2019: a systematic analysis for the Global Burden of Disease Study 2019. The Lancet 396 (10258):1204-1222. https://doi.org/10.1016/S0140-6736(20)30925-9
82. WHO (2020) Depression: Key facts. https://www.who.int/news-room/fact-sheets/detail/depression. Accessed 15 July 2021
83. Luppino FS, de Wit LM, Bouvy PF, Stijnen T, Cuijpers P, Penninx BWJH et al (2010) Overweight, obesity, and depression: A systematic review and meta-analysis of longitudinal studies. Arch Gen Psychiatry 67 (3):220-229. https://doi.org/10.1001/archgenpsychiatry.2010.2
84. Marx W, Moseley G, Berk M, Jacka F (2017) Nutritional psychiatry: the present state of the evidence. Proc Nutr Soc 76 (4):427-436. https://doi.org/10.1017/s0029665117002026
85. Molendijk M, Molero P, Ortuño Sánchez-Pedreño F, Van der Does W, Angel Martínez-González M (2018) Diet quality and depression risk: A systematic review and dose-response meta-analysis of prospective studies. J Affect Disord 226:346-354. https://doi.org/10.1016/j.jad.2017.09.022

86. Altun A, Brown H, Szoeke C, Goodwill AM (2019) The Mediterranean dietary pattern and depression risk: A systematic review. Neurol Psychiatry Brain Res 33:1-10. https://doi.org/10.1016/j.npbr.2019.05.007
87. Psaltopoulou T, Sergentanis TN, Panagiotakos DB, Sergentanis IN, Kosti R, Scarmeas N (2013) Mediterranean diet, stroke, cognitive impairment, and depression: A meta-analysis. Ann Neurol 74 (4):580-591. https://doi.org/10.1002/ana.23944
88. Bot M, Brouwer IA, Roca M, Kohls E, Penninx BWJH, Watkins E et al (2019) Effect of multinutrient supplementation and food-related behavioral activation therapy on prevention of major depressive disorder among overweight or obese adults with subsyndromal depressive symptoms: The MooDFOOD Randomized Clinical Trial. JAMA 321 (9):858-868. https://doi.org/10.1001/jama.2019.0556
89. European Commission (2017) The 2018 Ageing Report: Underlying assumptions & projection methodologies. European Economy Institutional Papers. European Union, Luxembourg.
90. Eurostat (2017) Population structure and ageing. https://ec.europa.eu/eurostat/statistics-explained/index.php/Population_structure_and_ageing#Past_and_future_population_ageing_trends_in_the_EU. Accessed 15 March 2019
91. Stula S (2012) Living in old age in Europe. Current developments and challenges. Working Paper No. 7 of the Observatory for Socio-political Developments in Europe. Working Paper No. 7 of the Observatory for Sociopolitical Developments in Europe, Berlin, Germany.
92. Lemieux FC, Filion ME, Barbat-Artigas S, Karelis AD, Aubertin-Leheudre M (2014) Relationship between different protein intake recommendations with muscle mass and muscle strength. Climacteric 17 (3):294-300. https://doi.org/10.3109/13697137.2013.829440
93. Deer RR, Volpi E (2015) Protein intake and muscle function in older adults. Curr Opin Clin Nutr Metab Care 18 (3):248-253. https://doi.org/10.1097/MCO.0000000000000162
94. Moore DR, Churchward-Venne TA, Witard O, Breen L, Burd NA, Tipton KD et al (2015) Protein ingestion to stimulate myofibrillar protein synthesis requires greater relative protein intakes in healthy older versus younger men. J Gerontol A 70 (1):57-62. https://doi.org/10.1093/gerona/glu103
95. Katsanos CS, Kobayashi H, Sheffield-Moore M, Aarsland A, Wolfe RR (2005) Aging is associated with diminished accretion of muscle proteins after the ingestion of a small bolus of essential amino acids. Am J Clin Nutr 82 (5):1065-1073. https://doi.org/10.1093/ajcn/82.5.1065
96. Isanejad M, Mursu J, Sirola J, Kröger H, Rikkonen T, Tuppurainen M et al (2016) Dietary protein intake is associated with better physical function and muscle strength among elderly women. Br J Nutr 115 (7):1281-1291. https://doi.org/10.1017/S000711451600012X
97. Health Council of the Netherlands (2021) Evaluation of dietary reference values for protein. Background document to: Dietary reference values for protein 2021/10. Health Council of the Netherlands, The Hague.
98. Bauer J, Biolo G, Cederholm T, Cesari M, Cruz-Jentoft AJ, Morley JE et al (2013) Evidence-based recommendations for optimal dietary protein intake in older people: A position paper from the PROT-AGE study group. J Am Med Dir Assoc 14 (8):542-559. https://doi.org/10.1016/j.jamda.2013.05.021
99. Deutz NEP, Bauer JM, Barazzoni R, Biolo G, Boirie Y, Bosy-Westphal A et al (2014) Protein intake and exercise for optimal muscle function with aging: Recommendations from the ESPEN Expert Group. Clin Nutr 33 (6):929-936. https://doi.org/10.1016/j.clnu.2014.04.007

100. Richter M, Baerlocher K, Bauer JM, Elmadfa I, Heseker H, Leschik-Bonnet E et al (2019) Revised reference values for the intake of protein. Ann Nutr Metab 74 (3):242-250. https://doi.org/10.1159/000499374
101. Tapsell LC, Neale EP, Satija A, Hu FB (2016) Foods, nutrients, and dietary patterns: Interconnections and implications for dietary guidelines. Adv Nutr 7 (3):445-454. https://doi.org/10.3945/an.115.011718
102. Garnett T, Mathewson S, Angelides P, Borthwick F (2015) Policies and actions to shift eating patterns: What works? A review of the evidence of the effectiveness of interventions aimed at shifting diets in more sustainable and healthy directions. Food Climate Research Network (FCRN) at the Environmental Change Institute, University of Oxford, Oxford.
103. FAO; WHO (2019) Sustainable Healthy Diets. FAO: Rome, Italy; WHO: Geneva, Switzerland.
104. Cabout M, Brouwer IA, Visser M, Consortium tM (2017) The MooDFOOD project: Prevention of depression through nutritional strategies. Nutr Bull 42 (1):94-103. https://doi.org/10.1111/nbu.12254
105. Winkens LHH, van Strien T, Brouwer IA, Penninx BWJH, Visser M, Lähteenmäki L (2018) Associations of mindful eating domains with depressive symptoms and depression in three European countries. J Affect Disord 228:26-32. https://doi.org/10.1016/j.jad.2017.11.069
106. Roca M, Kohls E, Gili M, Watkins E, Owens M, Hegerl U et al (2016) Prevention of depression through nutritional strategies in high-risk persons: rationale and design of the MooDFOOD prevention trial. BMC Psychiatry 16 (1):192. https://doi.org/10.1186/s12888-016-0900-z
107. Visser M, Elstgeest LEM, Winkens LHH, Brouwer IA, Nicolaou M (2020) Relative validity of the HELIUS food frequency questionnaire for measuring dietary intake in older adult participants of the Longitudinal Aging Study Amsterdam. Nutrients 12 (7):1998. https://doi.org/10.3390/nu12071998
108. Winkens LHH, van Strien T, Barrada JR, Brouwer IA, Penninx BWJH, Visser M (2018) The Mindful Eating Behavior Scale: Development and psychometric properties in a sample of Dutch adults aged 55 years and older. J Acad Nutr Diet 118 (7):1277-1290.e1274. https://doi.org/10.1016/j.jand.2018.01.015
109. Wijnhoven HAH, Elstgeest LEM, de Vet HCW, Nicolaou M, Snijder MB, Visser M (2018) Development and validation of a short food questionnaire to screen for low protein intake in community-dwelling older adults: The Protein Screener 55+ (Pro55+). PLOS ONE 13 (5):e0196406. https://doi.org/10.1371/journal.pone.0196406
110. Reinders I, Wijnhoven HAH, Jyväkorpi SK, Suominen MH, Niskanen R, Bosmans JE et al (2020) Effectiveness and cost-effectiveness of personalised dietary advice aiming at increasing protein intake on physical functioning in community-dwelling older adults with lower habitual protein intake: rationale and design of the PROMISS randomised controlled trial. BMJ Open 10 (11):e040637. https://doi.org/10.1136/bmjopen-2020-040637
111. (JRC) JRC (2010) ILCD Handbook: General Guide for Life Cycle Assessment—Detailed Guidance. European Commission. Joint Research Centre, Institute for Environment and Sustainability, Ispra, Italy.
112. Huijbregts M, Steinmann Z, Elshout P, Stam G, Verones F, Vieira M et al (2016) ReCiPe 2016: A harmonized life cycle impact assessment method at midpoint and endpoint level Report I: Characterization. National Institute for Public Health and the Environment, Bilthoven, The Netherlands.
113. van Paasen M, Braconi N, Kuling L, Durlinger B, Gual P (2019) Agri-Footprint 5.0 Part 1: Methodology and basic principles. Blonk Consultants, Gouda.

114. van Dooren C, Aiking H, Vellinga P (2018) In search of indicators to assess the environmental impact of diets. Int J LCA 23 (6):1297-1314. https://doi.org/10.1007/s11367-017-1371-2
115. Vellinga RE, van de Kamp M, Toxopeus IB, van Rossum CTM, de Valk E, Biesbroek S et al (2019) Greenhouse gas emissions and blue water use of Dutch diets and its association with health. Sustainability 11 (21):6027. https://doi.org/10.3390/su11216027

PART I

Individual-level factors that pose as opportunities and challenges to achieving more environmentally sustainable food-related behavior

CHAPTER 2

Socio-demographic predictors of food waste behavior in Denmark and Spain

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Abstract

Food waste generated at the household level represents about half of the total food waste in high-income countries, making consumers a target for food waste reduction strategies. To successfully reduce consumer food waste, it is necessary to have an understanding of factors influencing food waste behaviors (FWB). The objective of this study was to investigate socio-demographic predictors of FWB among consumers in two European countries: Denmark and Spain. Based on a survey involving 1518 Danish and 1511 Spanish consumers, we examined the associations of age, sex, education, marital status, employment status, and household size with FWB. By using structural equation modeling based on confirmatory factor analysis, we created the variable FWB from self-reported food waste and two activities that have been correlated with the amount of food wasted in previous studies: namely, shopping routines and food preparation. Results show that being older, unemployed, and working part-time were associated with less food waste behavior in both countries. In Denmark, being male was associated with more food waste behavior, and living in a household with four or more people was associated with less food waste behavior. These results underscore the modest role of socio-demographic characteristics in predicting food waste behavior in Europe.

1. Introduction

One-third of food produced for human consumption—approximately 1.3 billion tons per year—gets lost or wasted globally [1]. This amounts to a considerable waste of the resources that are used in food production, such as cropland, water, energy, and fertilizers, as well as the large amounts of greenhouse gas emissions associated with food production and food waste disposal [2]. Not only does food waste lead to unnecessary and avoidable environmental degradation such as soil erosion and biodiversity loss, it induces economic losses and perpetuates social inequalities due to lower wages across the food system, higher food prices, and the widening of the food access gap [3,4]. Food waste occurs at all points throughout the food supply chain, but in Europe, the majority (53%) of the total food waste is generated at the household level, totaling about 47 million tons of food waste in 2012 [5]. As households, and thus consumers, produce the most food waste, it is important to know which factors influence consumer-level food waste to tackle the aforementioned environmental, economic, and social issues.

Consumer-related food waste is a complex and multi-faceted issue that is influenced by cultural, social, political, economic, and geographic drivers, as well as cognitive, motivational, and structural factors, food-related behaviors, and food habits [6,7]. The theory of planned behavior [8] is the more frequently applied theoretical framework that has been used to explain or predict consumer-level food waste [9-13]. The theory suggests that behavior is determined by intention, which is influenced by subjective norm, perceived behavioral control, and attitude [8]. Yet, intention does not correspond well with behavior in all cases. Several studies have demonstrated that food-related behaviors such as planning and shopping routines, when added or compared to the theory of planned behavior, are more important indicators than intention for the amount of food wasted [10,11].

Furthermore, a sociological approach to food waste has highlighted the importance of the social and material contexts of everyday food waste practices, pointing out that factors such as time, domestic divisions of labor with regard to food shopping and preparation, and infrastructures of provision influence food waste behavior (FWB), but may be beyond the control of consumers [14,15]. Consequently, factors related to socio-demographics such as sex and employment status may influence food provisioning practices, leading to food waste [16]. However, evidence suggests that socio-demographic characteristics have weak predictive power of food waste [10,17]. Previous studies have found socio-demographics to explain only 7–13% of the variance regarding intention to reduce and perceived behavioral control to avoid household food waste [12,18]. Despite the limited predictive power, correlations between age, sex, employment status, income, household size and composition, and amount of food wastes have been found, but the strength and direction of the relationships vary between studies [7]. In addition, such studies have examined the correlations between socio-demographic characteristics and self-reported food waste, but have not looked at these alongside food-related behaviors that are known to influence food waste.

Self-reported food waste is a major limitation in most studies, as it may suffer from social desirability and hypothetical bias, and consequently, may deviate from actual behavior [19,20]. However, more objective techniques to measure food waste, such as waste composition analysis or diary-based methods, are timely and financially costly [20,21]. Thus, some researchers have focused on food waste as an aggregate of food-related behaviors rather than on self-reported food waste as an outcome. For instance, Mondejar-Jiménez et al.'s outcome regarding 'positive behavior toward food waste' consisted of food-related activities that have been found to influence the amount of food wasted at the consumer level, namely reusing leftovers, understanding the date labels on foods, and making a shopping list [13]. As there is limited literature using such an outcome to explore factors influencing food waste behavior, further investigation into its application is warranted.

The objective of this study was to investigate socio-demographic predictors of FWB among consumers in two European countries, namely Denmark and Spain. In Denmark, it is estimated that the average household wastes about 183 kg food per year [22], while in Spain, it is estimated that the average household wastes about 71.2 kg food per year [23]. By employing a similar approach to Mondejar-Jiménez et al., this study tries to move beyond using self-reported food waste as the exclusive measure of this behavior. The results presented in the paper can add to the existing literature on the role that socio-demographics play in predicting food waste behavior.

2. Materials and Methods

2.1. Procedure and Sample

Data collection was carried out with Qualtrics—a panel service agency—in June and July 2014. An online questionnaire was made available to a randomly selected sample of panelists in Denmark and Spain. The questionnaire was developed in English, translated to Danish and Spanish, and distributed through online platforms to Danish and Spanish respondents, respectively. Qualtrics follows the European Society for Opinion and Marketing Research (ESOMAR) principles in their data collection activities and panel management. The respondents had to confirm their willingness to participate in the study, and their data was handled with anonymity and confidentiality in accordance with the provisions of the Declaration of Helsinki [24].

In total, 3034 respondents completed the questionnaire, with 1522 respondents from Denmark and 1512 respondents from Spain. Of the 3034 respondents who completed the questionnaire, five had missing data for age, and were excluded from this study. Thus, 1518 Danish respondents and 1511 Spanish respondents had complete details for all the relevant variables. Table 1 provides a summary of the socio-demographic characteristics of the respondents included in this study. The majority of the respondents were responsible to some extent for the provision of food in their household: 76% in both countries were responsible for deciding what food to cook/prepare for household meals, 83% in Denmark and 90% in Spain were responsible for food shopping, and 76% in Denmark and 79% in Spain were responsible for cooking and preparing food.

Table 1 Socio-demographic characteristics of sample in Denmark (N=1518) and Spain (N=1511).

Characteristic	Denmark	Spain
Age (years), mean	50.1	37.0
Sex		
Female	48.4%	48.8%
Male	51.6%	51.2%
Education [1]		
Low	24.1 %	11.3%
Middle	40.8 %	34.4%
High	35.1 %	54.3%
Employment status [2]		
Full time	42.0%	53.1%
Part time	11.1%	14.8%
Unemployed	13.6 %	32.2%
Retired	33.2 %	Not asked
Marital status [3]		
Married/living with partner	59.5%	60.3%
Single	40.5%	39.7%
Household size (number of persons)		
1	29.1%	7.9%
2	43.8%	23.5%
3	11.4%	30.3%
4	10.5%	27.9%
5+	5.1%	10.3%

[1] Low includes lower primary to lower secondary school, middle includes upper secondary school to additional training; higher includes Bachelor or other higher education. [2] Full time if working a minimum of 30 hours per week, part-time if working between 15 and 29 hours per week. [3] Single includes widowed, divorced and separated. [6] Categories are married or separated; never married, widowed or divorced.

2.2. Measures

The questionnaire contained measures on food-related behaviors, self-reported food waste, and socio-demographics. The study was a part of a larger survey on food-related behavior and mental well-being, which has been described elsewhere [25]. This study reports the findings related to food-related behaviors that are likely to increase food waste and how they are linked to socio-demographic characteristics. The used measures, described below, were selected based on earlier findings of behaviors that have been linked to reported food waste, and are reported in Table 2.

2.2.1. Food-related behaviors and self-reported food waste

The food-related behaviors that were assessed included planning routines, shopping routines, practices related to handling leftovers and food beyond its best-before date, and food preparation (Table 2). Planning routines consisted of two items, referring to the planning of shopping trips and meals [10]. Shopping routines were measured with four items concerning the excess purchase of food [26]. Leftover management was measured with two items about reusing leftovers and throwing out products that are beyond the best-before date. Food preparation was assessed with one item concerning preparing/cooking more food than needed. These variables were measured by having respondents rate their agreement to statements using a 7-point Likert scale in the Danish questionnaire and a 5-point Likert scale in the Spanish questionnaire.

Self-reported food waste consisted of five items, referring to food waste in general and four specific food sub-categories, namely milk and other dairy products, fresh fruits and vegetables, meat and fish, and bread and other bakery products [11], and was measured by having respondents report how often they throw away the food in a regular week (not at all; less than 1/10th; more than 1/10th but less than 1/4 ; more than 1/4 but less than 1/2; more than 1/2).

2.2.2. Socio-Demographics

Respondents were asked to indicate their age, sex, education, employment status, marital status (married or living with partner; single; widowed; divorced; or separated), and household size (1; 2; 3; 4; 5; or 6+). The following categories of education were created: low includes lower primary to lower secondary school, middle includes upper secondary school to additional training; and higher includes Bachelor or other higher education. Full-time employment was defined in the questionnaire as a minimum of 30 hours work per week, while part-time employment was defined as between 15 and 29 hours work per week. In addition, those who reported to be widowed, divorced, or separated were considered as single in this study. Since only a few people reported to live in a household with 6+ people (19 in Denmark and 24 in Spain), we grouped them with those who reported to live in a household of 5 people.

2.3. Statistical Analysis

All analyses were done separately for each country and were run in RStudio version 1.1.383 (RStudio Inc., Boston, Massachusetts, USA). Descriptive statistics were conducted to report the socio-demographic characteristics of the sample, respondents' agreement toward food-related behaviors, and self-reported food waste in general and by food sub-category.

2.3.1. Modeling Food Waste Behavior

Before we were able to examine the socio-demographic predictors of FWB, we needed to model FWB, as it was not directly measured. Similar to Mondejar-Jiménez et al.'s 'positive behavior toward food waste' [13], we created FWB out of self-reported food waste and four food-related activities that have been found to influence the amount of food wasted at the consumer level (Figure 1).

From the food-related behavior perspective, food waste emerges along the chain of events related to household food provisioning, and has been shown to be related to various practices, such as food planning, shopping, storing, cooking, eating, and managing leftovers [14,27]. For instance, making shopping lists [28] and eating leftovers [10] has been associated with less food waste, while buying unintended food products when shopping [10] and throwing out food beyond the best-before date [29] has been associated with more food waste. The food-related activities that we included in our model of FWB are planning routines, shopping routines, food preparation, and practices related to handling leftovers and food beyond its best-before date (Table 2). These activities, which occur at different stages in the chain of events related to household food provisioning, were chosen and combined with self-reported food waste to have a comprehensive measure of FWB.

We modeled FWB using confirmatory factor analysis (CFA). CFA allowed us to test our hypothetical model of FWB as a latent variable (LV) in a simultaneous analysis of the entire system of variables to determine the extent to which it is consistent with the data [30]. The path diagram of the hypothesized measurement model is shown in Figure 1, with a description of the latent variables and indicators in Table 2. The first loading of a LV was set to 1 to give the LV an interpretable scale.

Table 2. Latent variables and indicators in the hypothesized measurement model of food waste behavior.

Latent variables (LV)	Indicators (Q)
LV1: Planning routines	Qp1. The shopping trips are usually planned in advance (shopping lists are made, inventories are checked, etc.).[1] Qp2.The home meals are usually planned a couple of days ahead.[1]
LV2: Shopping routines	Qs1. In general, I buy too much food when shopping (e.g. more than I end up using). Qs2. I often buy unintended food products when shopping. Qs3. I often buy food in packages that are too big for my needs. Qs4. I usually buy higher amounts of food when they offer good value for money.
LV3: Leftover management	Ql1. I always throw out products that are beyond the best-before date. Ql2. I always reuse leftovers.[1]
LV4: Self-reported food waste	How much… would you say that you throw away, of what you buy and/or grow, in a regular week? Qfw1. Food Qfw2. Milk and other dairy products Qfw3. Fresh fruits and vegetables Qfw4. Meat and fish Qfw5. Bread and other bakery products
LV5: Food waste behavior (FWB)	LV1. Planning routines LV2. Shopping routines LV3. Food leftover management LV4. Self-reported food waste Qc1. Food preparation: Too much food is often cooked/prepared for a meal.

[1] Scale was reversed for analyses.

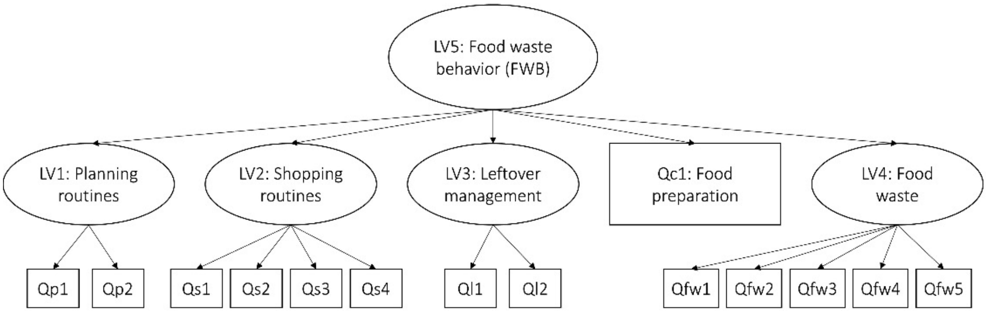

Figure 1. Hypothesized measurement model of food waste behavior. Ovals represent latent variables (LV) and rectangles represent indicators (Q) or single questions described in Table 2.

We evaluated model validity by considering acceptable levels of goodness-of-fit for the measurement model and assessing construct validity. Goodness-of-fit was considered to be satisfactory when comparative fit index (CFI) values were close to the cut-off value of 0.95, and root mean square error approximation (RMSEA) values were close to the cut-off value of 0.06 [31]. Item reliability was assessed by considering loadings greater or equal to 0.7 [32]. Convergent validity was demonstrated when the average variance extracted (AVE) was at least 0.5 and construct reliability (CR) was at least 0.7 [33]. Discriminant validity was assessed by determining inter-construct correlation, and comparing it to the maximum threshold of 0.85 [34]. To see if results could be compared between the two countries, we also tested for measurement invariance (MI). MI was assessed by evaluating the fit of increasingly constrained models using the chi-square difference test [35]. The following types of invariance were tested: i) configural invariance (the baseline model) to test whether or not the same items measure the constructs across countries; ii) metric invariance to determine whether respondents in the two countries attribute the same meaning to the latent constructs (factor loadings were set equal across groups); iii) scalar invariance to determine whether respondents in the two countries attribute the same meaning to the latent constructs and to the levels of the underlying items (factor loadings and intercepts set equal across groups); and iv) full uniqueness MI to determine whether the latent constructs are measured identically in the two countries (factor loadings, intercepts, and residuals set equal across groups) [35]. While full MI commonly does not hold, we also tested for partial metric invariance by setting one factor loading equal across groups, and for partial scalar invariance by setting one factor loading and one intercept equal. If partial MI is established, then valid inference regarding the difference between latent constructs for each country can be made [36].

2.3.2. Regression Analyses

After testing our hypothesized measurement model of FWB, structural equation modeling (SEM) was conducted to test the latent variable FWB (LV5) as the dependent variable in regression analyses with the following socio-demographic characteristics as independent variables: age, sex, education level, employment status, marital status, and household size. A backward selection procedure was conducted in which all the socio-demographic predictors of interest were included in the first regression model, and only the statistically significant predictors remained in the final regression model. A *p*-value above the cut-off point of 0.1 was used to remove variables.

3. Results

3.1. Food-related behaviors and self-reported food waste of respondents

Figure 2 presents the level of agreement of waste-promoting and waste-reducing (italicized) food-related behaviors by country separately. It appears that the majority of respondents in both countries either somewhat disagree, disagree, or strongly disagree with the statements 'In general, I buy too much food when shopping' and 'I often buy food in packages that are too big for my needs', and somewhat agree, agree, or strongly agree with the statements 'Shopping trips are usually planned in advance', 'I usually buy higher amounts of food when they offer good value for money', and 'I always reuse leftovers'.

Figure 3 illustrates the amount of food and food sub-categories reported to have been wasted in a regular week for each country separately. Approximately 20% respondents in Denmark and 22% in Spain indicated throwing away more than 10% of food in a regular week, whereas 80% in Denmark and 78% in Spain reported not throwing away any food or less than 10% of food in a regular week. When looking at the specific food sub-categories, more than 10% of bread and other bakery products were reported to be thrown away by about one-third of respondents in both countries, with fresh fruits and vegetables the second most susceptible food sub-category reported to be thrown away in a regular week in both countries. In Denmark, meat was the least susceptible food sub-category reported to be thrown away in a regular week, while in Spain, milk and other dairy products was the least susceptible sub-category.

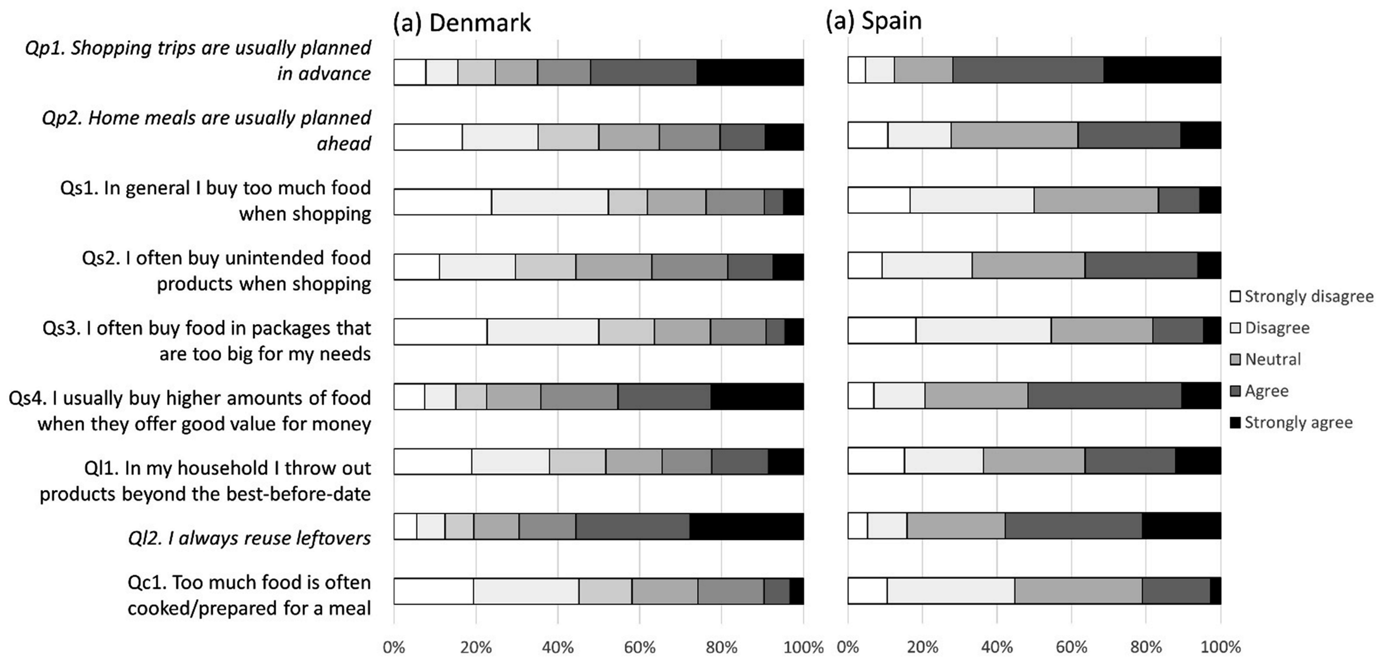

Figure 2. Level of agreement of statements on waste-reducing (italicized) and waste-promoting food-related behaviors in respondents in (**a**) Denmark (N = 1518) and (**b**) Spain (N = 1511).

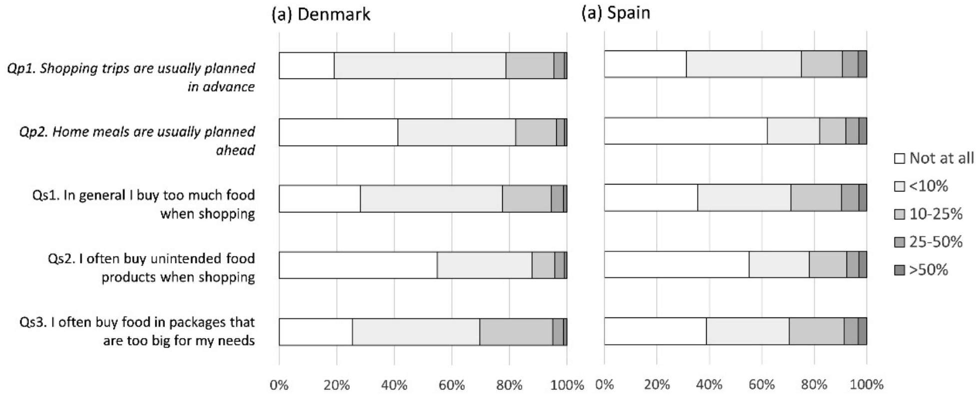

Figure 3. Self-reported food waste in Denmark (N=1518) and Spain (N=1511) (%). Results of survey question: "How much… [see bar for category] would you say that you throw away, of what you buy and/or grow, in a regular week?".

Evaluating the measurement model of FWB revealed that two constructs were problematic: planning routines and leftovers management. The measurement model resulted in negative variance for the first item under planning routines (Qp1) for Denmark, while the measurement model did not converge for Spain. When the measurement of planning routines (LV1) was removed from the measurement model, CFA showed a satisfactory fit of the measurement model for both countries. However, when composite reliability and construct validity were assessed, leftover management (LV3) fell below the cut-off point of 0.7 or greater for CR (0.343 for Denmark and 0.170 for Spain) and 0.50 or greater for AVE (0.207 for Denmark and 0.107 for Spain), and thus was removed from the model. An item (Qs4) under shopping routines (LV2) resulted a poor loading for both countries, but remained in the model because removing it worsened the goodness-of-fit of the model. As illustrated in Figure 4, the resulting measurement model for FWB was satisfactory, as indicated by the CFA overall goodness-of-fit indices (Table 3), with CFI values close to the cut-off value of 0.95 and RMSEA values close to the cut-off value of 0.06 [31]. All the items had significant loadings ($p < 0.001$), and CR and AVE were close to or above their respective cut-off values [33]. The discriminant validity was also satisfactory, with the inter-construct correlation between the remaining first-order LVs (i.e. shopping routines and self-reported food waste) below the threshold of 0.85 (0.445 for Denmark and 0.395 for Spain). Based on the fit indices of the increasingly constrained models used to test for measurement invariance, the chi-square difference tests showed that partial metric invariance holds for the measurement model between Denmark and Spain ($\Delta\chi^2 = 1.176$, d = 1, $p = 0.278$).

3.2. Prediction analysis

Table 4 shows the full and final prediction model for Denmark and Spain. Age, sex, employment status, and household size were found to be associated with FWB in Denmark, with 7.3% of the variance of FWB explained by these predictors combined.

Being older was associated with less FWB, and being male was associated with more FWB. Compared to those with a full-time job, working part-time or being unemployed or retired were associated with less FWB. Marital status and level of education were not associated with FWB. Compared to living in a single-person household, living in a household with four people was associated with more FWB. The structural equation model for Denmark converged well, and its fit was satisfactory (χ^2 = 505.61, df 114, p < 0.001, RMSEA = 0.048, CFI = 0.927).

Age and employment status were found to be associated with FWB in Spain, with 8.1% of the variance of FWB explained by these predictors combined. Being older, working part-time, and being unemployed were associated with less FWB. Marital status, household size, and level of education were not associated with FWB. The structural equation model for Spain converged well, and its fit was satisfactory (χ^2 = 358.98, df 60, p < 0.001, RMSEA = 0.057, CFI = 0.961).

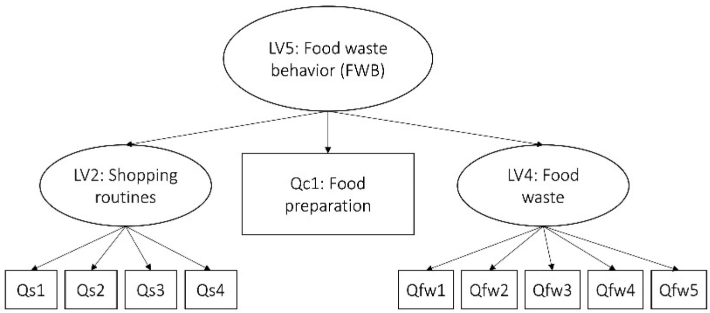

Figure 4. Final measurement model of food waste behavior. Ovals represent latent variables (LV) and rectangles represent indicators (Q) or single questions described in Table 3.

Table 3. Fit indices and reliability measurements of the final measurement model of food waste behavior for Denmark (DK) and Spain (SP).[1]

Latent Variables (LV) and Indicators (Q)	Factor Loadings; *CR; AVE*[2]	
	DK (N = 1518)	SP (N = 1511)
LV2: Shopping routines	*0.707; 0.403*	*0.745; 0.430*
Qs1. In general, I buy too much food when shopping (e.g., more than I end up using).	0.847	0.792
Qs2. I often buy unintended food products when shopping.	0.639	0.637
Qs3. I often buy food in packages that are too big for my needs.	0.682	0.687
Qs4. I usually buy higher amounts of food when they offer good value for money.	0.251	0.469
LV4: Self-reported food waste	*0.851; 0.534*	*0.918; 0.692*
How much… would you say that you throw away, of what you buy and/or grow, in a regular week?		
Qfw1. Food	0.746	0.844
Qfw2. Milk and dairy products	0.715	0.862
Qfw3. Fresh fruits and vegetables	0.738	0.844
Qfw4. Meat and fish	0.741	0.882
Qfw5. Bread and other bakery products	0.720	0.739
LV5. Food waste behavior	*0.737; 0.486*	*0.724; 0.477*
LV2. Shopping routines	0.796	0.847
LV4. Self-reported food waste	0.683	0.505
Qc1. Food preparation: Too much food is often cooked/prepared for a meal.	0.598	0.677

[1] Goodness of fit indices: Denmark: χ^2 = 144.6, df 33, $p < 0.001$, RMSEA = 0.047, CFI = 0.978; Spain: χ^2 = 285.9, df 33, $p < 0.001$, RMSEA = 0.071, CFI = 0.967. [2] Construct reliability (CR) and average variance extracted (AVE) of each latent variable are italicized.

Table 4. Associations of socio-demographic characteristics with food waste behavior from multivariable linear regressions for Denmark

Characteristic	Denmark (N = 1518)				Spain (N = 1511)			
	Full Model		Final Model		Full Model		Final Model	
	β[1]	(95% CI)[2]	β	(95% CI)	β	(95% CI)	β	(95% CI)
Age (years)	−0.014***	(−0.020, −0.008)	−0.014***	(−0.020, −0.008)	−0.015***	(−0.019, −0.011)	−0.016***	(−0.019, −0.012)
Sex								
Female (ref)								
Male	0.151**	(0.012, 0.289)	0.160**	(0.022, 0.297)	0.013	(−0.069, 0.095)	–	–
Education								
Low (ref)								
Middle	−0.104	(−0.279, 0.071)	–	–	0.012	(−0.124, 0.148)	–	–
High	−0.049	(−0.230, 0.132)	–	–	−0.055	(−0.188, 0.077)	–	–
Employment status								
Full-time (ref)								
Part-time	−0.206*	(−0.440, 0.027)	−0.207*	(−0.439, 0.025)	−0.096	(−0.215, 0.024)	−0.077	(−0.195, 0.041)
Not employed	−0.284**	(−0.507, −0.060)	−0.278**	(−0.497, −0.059)	−0.264***	(−0.360, −0.167)	−0.237***	(−0.328, −0.145)
Retired[3]	−0.219**	(−0.409, −0.029)	−0.214**	(−0.401, −0.027)	NA	NA		
Marital status								
Married/living with partner (ref)								
Single	−0.016	(−0.236, 0.205)	–	–	0.022	(−0.072, 0.117)	–	–
Household size (number of persons)								
1 (ref)								
2	0.023	(−0.220, 0.226)	0.04	(−0.121, 0.201)	−0.057	(−0.232, 0.117)		
3	0.039	(−0.248, 0.325)	0.05	(−0.191, 0.290)	0.02	(−0.148, 0.187)		
4	0.243	(−0.068, 0.554)	0.254**	(0.005, 0.503)	0.111	(−0.059, 0.280)		
5+	−0.159	(−0.552, 0.203)	−0.147	(−0.474, 0.181)	0.151	(−0.044, 0.347)	–	–

[1] Beta–coefficient (β).* $p < 0.10$, ** $p < 0.05$, *** $p < 0.001$. [2] 95% confidence interval (CI). [3] Not asked (NA) to Spanish respondents.

4. Discussion

Age, sex, employment status, and household size were found to be modest predictors of food waste behavior in Denmark, and age and employment status were found to be modest predictors of FWB in Spain. FWB in this study was measured by shopping routines, food preparation, and self-reported food waste, and thus, these socio-demographic factors predict the likelihood of respondents to buy and cook too much food, as well as throw out food. Similar to previous studies, socio-demographics only explained little of the variance of FWB in both countries [12,18]. Rather, attitudes, values, and other psychographic variables have been previously shown to be more closely related to behavioral outcomes [6,17]. Also, an individual's socio-demographic characteristics may not directly translate to household-level measures [37], limiting the predictive power of socio-demographics. Thus, one may conclude that socio-demographics play a small role in predicting household FWB.

Our results agree with exploratory studies that show age and the amount of food wasted to be negatively correlated [10-12,38]. Adults 65 years of age or older in particular have been found to practice food waste reducing behaviors such as planning meals in advance, and have more knowledge of food waste than younger adults [39,40]. In this study, the Spanish subpopulation of adults aged 65+ was very small, preventing the comparison of this age group with younger adults with regard to their FWB. Our results are also consistent with previous studies that have found a negative association between employment status and amount of food wasted [38,41], which have shown that compared to people working full-time, those not employed tend to waste less food.

Our study resulted in different associations between sex and household size and FWB for Denmark and Spain. While neither were significant predictors of FWB in Spain, they were both significant predictors of FWB in Denmark. The difference in results for household size may stem from the differences in household size between the countries, where the majority reported living in single or two-person households in Denmark, whereas the majority reported living in a household with three or more people in Spain. The present study found that living in a household with four people was associated with more FWB compared to those living in single-person households in Denmark. This finding may be attributed to household dynamics and cultural expectations. For example, those striving to be a 'good' food provider for the family have been found to have more food wasting behaviors in various contexts [12,42]. It has also been found that households with children are more likely to have more food wasting behavior [43], although in this report, household composition was not studied. Being male was associated with more FWB in Denmark, which is similar to findings in the United States and in the European Union (EU) [38,41], but different from Koivupuro et al., who found that males waste less food than females in Finland. This suggests that the relationship between sex and food waste may vary greatly between countries. The researchers in Finland speculated that women may be more likely than men to strive to provide their family with healthy, fresh products with a shorter shelf life, making them more susceptible to generating food waste [16]. However, Secondi et al. found that women on average in the EU appeared to be more conscious of food waste compared to men, which may make them less susceptible to generating food waste [38].

Our model of FWB, which combined food-related behaviors found to influence the amount of food wasted at the consumer level with self-reported food waste, was unique and provides a broader perspective on food waste. While the AVE of the latent variable FWB was just below the cut-off, the degree of convergent validity was similar to Mondejar-Jiménez et al.'s 'positive behavior toward food waste' (AVE = 0.497). As expected, self-reported food waste greatly underestimated the actual amount of food wasted in these countries. We found that 20% of the Danish and 40% of the Spanish respondents reported to throw away *no* food in a regular week. When food waste was collected from a sample of Danish households and when food diaries were kept to record food waste in Spain, it was found that 97% of the sampled households generated food waste in Denmark (i.e., 3% of households produced no food waste) [22], and 80% in Spain (i.e., 20% of households produced no food waste) [44]. In addition to being prone to social desirability and memory bias [20], self-reported food waste is susceptible to underestimation due to an *individual* trying to assess *household* food waste [37]. As the self-reported food waste measure can bias individuals to underestimate the amount of food [20], combining self-reported food waste with other food-related behaviors was our attempt to minimize this bias. This approach is supported by previous research highlighting the complexity of food waste and arguing that food waste is not a single behavior, but rather a result of multiple food-related behaviors that lead to food being thrown away [10,13,39].

There are some strengths and limitations to this study. Strengths include a large sample size compared to previous studies [9,11,13,45] and the inclusion of respondents in two European countries. As partial measurement invariance was established, this study provides insight into country differences. A limitation to this study is that we measured individual behavior as a proxy of household behavior, as this approach has been shown to give an inaccurate representation of the entire household, especially when it comes to a habitual behavior such as food waste [37]. This may be another reason why socio-demographics are found to play a minor role in predicting FWB. Another limitation is the paucity of other possible predictors of FWB that have been shown in earlier studies to influence the likelihood or amount of food wasted. For instance, past research suggests that psychographic factors play a more important role than socio-demographic factors in explaining food waste at the consumer level [6]; however, our survey was designed for another research question, and thus was not designed to conduct a comprehensive study on the predictors of FWB. Also, socio-demographics such as income and household composition have been shown to influence food waste, but were not assessed in this study [46,47]. Furthermore, the data collection and sampling scheme limit the generalizability of the findings to the entire Danish and Spanish populations; thus, study findings should be interpreted taking into account the specific characteristics of the study samples.

Future research should approach food waste from a behavior perspective and conduct a more comprehensive investigation of predictors of food waste behavior. Survey questions measuring food-related behaviors should be pre-tested and piloted to ensure that there are no ambiguities in the questions and the respondents could understand the questions the way they are intended in order to prevent the deletion of items during measurement model assessment. Furthermore, studies should clearly differentiate between individual and household behavior when designing the survey. As it is difficult to measure household behaviors by only asking one individual per household, a suggestion would be to isolate individual food wasting behavior.

5. Conclusions

This study found that age, sex, employment status, and household size predict food waste behavior in Denmark and age and employment status in Spain. The findings support existing knowledge that socio-demographic factors are modest predictors of FWB. The present study contributes to food reduction strategies, as it gives a different perception of food waste incorporating a behavioral approach, and adds evidence from two European countries that socio-demographics should play a modest role in interventions. While food waste reduction strategies may benefit by targeting younger adults and those working full time in both countries—and men and individuals in bigger households in Denmark—strategies should be designed to target food-related behaviors that influence the amount of food wasted.

References

1. FAO (2011) Global food losses and food waste - Extent, causes and prevention. Food and Agriculture Organization of the United Nations (FAO), Rome.
2. Kummu M, de Moel H, Porkka M, Siebert S, Varis O, Ward PJ (2012) Lost food, wasted resources: Global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use. Sci Total Environ 438:477-489. https://doi.org/10.1016/j.scitotenv.2012.08.092
3. HLPE (2014) Food losses and waste in the context of sustainable food systems. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. High Level Panel of Experts (HLPE) on Food Security and Nutrition of the Committee on World Food Security, Rome.
4. FAO (2014) Food wastage footprint - Full-cost accounting. Report by Food and Agriculture Organization of the United Nations. Food and Agriculture Organization of the United Nations (FAO)
5. Stenmarck Å, Jensen C, Quested TE, Moates G (2016) Estimates of European food waste levels. Commissioned by the European Commission in the FUSION project
6. Aschemann-Witzel J, De Hooge I, Amani P, Bech-Larsen T, Oostindjer M (2015) Consumer-related food waste: Causes and potential for action. Sustainability 7 (6):6457-6477. https://doi.org/10.3390/su7066457
7. Schanes K, Dobernig K, Gözet B (2018) Food waste matters - A systematic review of household food waste practices and their policy implications. J Clean Prod 182:978-991. https://doi.org/10.1016/j.jclepro.2018.02.030
8. Ajzen I (1991) The theory of planned behavior. Organ Behav Hum Decis Process 50 (2):179-211. https://doi.org/10.1016/0749-5978(91)90020-T
9. Graham-Rowe E, Jessop DC, Sparks P (2015) Predicting household food waste reduction using an extended theory of planned behaviour. Resour Conserv Recycl 101:194-202. https://doi.org/10.1016/j.resconrec.2015.05.020
10. Stancu V, Haugaard P, Lähteenmäki L (2016) Determinants of consumer food waste behaviour: Two routes to food waste. Appetite 96:7-17. https://doi.org/10.1016/j.appet.2015.08.025
11. Stefan V, van Herpen E, Tudoran AA, Lähteenmäki L (2013) Avoiding food waste by Romanian consumers: The importance of planning and shopping routines. Food Qual Prefer 28 (1):375-381. https://doi.org/10.1016/j.foodqual.2012.11.001
12. Visschers VHM, Wickli N, Siegrist M (2016) Sorting out food waste behaviour: A survey on the motivators and barriers of self-reported amounts of food waste in households. J Environ Psychol 45:66-78. https://doi.org/10.1016/j.jenvp.2015.11.007
13. Mondéjar-Jiménez J-A, Ferrari G, Secondi L, Principato L (2016) From the table to waste: An exploratory study on behaviour towards food waste of Spanish and Italian youths. J Clean Prod 138:8-18. https://doi.org/10.1016/j.jclepro.2016.06.018
14. Evans D (2011) Beyond the throwaway society: Ordinary domestic practice and a sociological approach to household food waste. Sociology 46 (1):41-56. https://doi.org/10.1177/0038038511416150
15. Evans D (2011) Blaming the consumer – once again: the social and material contexts of everyday food waste practices in some English households. Crit Public Health 21 (4):429-440. https://doi.org/10.1080/09581596.2011.608797
16. Koivupuro H-K, Hartikainen H, Silvennoinen K, Katajajuuri J-M, Heikintalo N, Reinikainen A et al (2012) Influence of socio-demographical, behavioural and attitudinal factors on the amount of avoidable food waste generated in Finnish households. Int J Consum Stud 36 (2):183-191. https://doi.org/10.1111/j.1470-6431.2011.01080.x

17. Falasconi L, Cicatiello C, Franco S, Segrè A, Setti M, Vittuari M (2019) Such a shame! A study on self-perception of household food waste. Sustainability 11 (1). https://doi.org/10.3390/su11010270
18. van der Werf P, Seabrook JA, Gilliland JA (2019) Food for naught: Using the theory of planned behaviour to better understand household food wasting behaviour. Can Geogr 63:478-493. https://doi.org/10.1111/cag.12519
19. Fisher RJ (1993) Social desirability bias and the validity of indirect questioning. J Consum Res 20 (2):303-315. https://doi.org/10.1086/209351
20. van Herpen E, van der Lans IA, Holthuysen N, Nijenhuis-de Vries M, Quested TE (2019) Comparing wasted apples and oranges: An assessment of methods to measure household food waste. Waste Manag 88:71-84. https://doi.org/10.1016/j.wasman.2019.03.013
21. Møller H, Hanssen OJ, Svanes E, Hartikainen H, Silvennoinen K, Gustavsson J et al (2014) Standard approach on quantitative techniques to be used to estimate food waste levels. Ostfold Research Report 21.14. FUSIONS
22. Edjabou ME, Petersen C, Scheutz C, Astrup TF (2016) Food waste from Danish households: Generation and composition. Waste Manag 52:256-268. https://doi.org/10.1016/j.wasman.2016.03.032
23. Zapata IH (2017) Measuring household food waste the Spain experience: The household food waste panel. Ministry of Agriculture and Fisheries, Food and Environment (MAPAMA)
24. World Medical Association (2013) World Medical Association Declaration of Helsinki: Ethical Principles for Medical Research Involving Human Subjects. JAMA 310 (20):2191-2194. https://doi.org/10.1001/jama.2013.281053
25. Winkens LHH, van Strien T, Brouwer IA, Penninx BWJH, Visser M, Lähteenmäki L (2018) Associations of mindful eating domains with depressive symptoms and depression in three European countries. J Affect Disord 228:26-32. https://doi.org/10.1016/j.jad.2017.11.069
26. Lyndhurst B (2007) Food behaviour consumer research: Quantitative phase research. WRAP
27. Wahlen S, Winkel T (2017) Household food waste. In: Reference Module in Food Science. Elsevier. https://doi.org/10.1016/B978-0-08-100596-5.03368-0
28. Jörissen J, Priefer C, Bräutigam K-R (2015) Food waste generation at household level: Results of a survey among employees of two European research centers in Italy and Germany. Sustainability 7 (3):2695-2715. https://doi.org/10.3390/su7032695
29. Diaz-Ruiz R, Costa-Font M, Gil JM (2018) Moving ahead from food-related behaviours: an alternative approach to understand household food waste generation. J Clean Prod 172:1140-1151. https://doi.org/10.1016/j.jclepro.2017.10.148
30. Byrne BM (2016) Structural equation modeling with Amos: Basic concepts, applications, and programming. Third Edition edn. Routledge, New York, NY
31. Hu Lt, Bentler PM (1999) Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. Struct Equ Modeling 6 (1):1-55. https://doi.org/10.1080/10705519909540118
32. Hair JF, Black WC, Babin BJ, Anderson RE (2014) Confirmatory factor analysis. In: Limited PE (ed) Multivariate data analysis. pp 600-638
33. Fornell C, Larcker DF (1981) Evaluating structural equation models with unobservable variables and measurement error. J Mark Res 18 (1):39-50. https://doi.org/10.2307/3151312
34. Henseler J, Ringle CM, Sarstedt M (2015) A new criterion for assessing discriminant validity in variance-based structural equation modeling. J Acad Mark Sci 43 (1):115-135. https://doi.org/10.1007/s11747-014-0403-8
35. van de Schoot R, Lugtig P, Hox J (2012) A checklist for testing measurement invariance. Eur J Dev Psychol 9 (4):486-492. https://doi.org/10.1080/17405629.2012.686740

36. Byrne BM, Shavelson RJ, Muthén B (1989) Testing for the equivalence of factor covariance and mean structures: The issue of partial measurement invariance. Psychol Bull 105 (3):456-466. https://doi.org/10.1037/0033-2909.105.3.456
37. Seebauer S, Fleiß J, Schweighart M (2017) A household is not a person: Consistency of pro-environmental behavior in adult couples and the accuracy of proxy-reports. Environ Behav 49 (6):603-637. https://doi.org/10.1177/0013916516663796
38. Secondi L, Principato L, Laureti T (2015) Household food waste behaviour in EU-27 countries: A multilevel analysis. Food Policy 56:25-40. https://doi.org/10.1016/j.foodpol.2015.07.007
39. Quested TE, Marsh E, Stunell D, Parry AD (2013) Spaghetti soup: The complex world of food waste behaviours. Resour Conserv Recycl 79:43-51. https://doi.org/10.1016/j.resconrec.2013.04.011
40. Neff RA, Spiker ML, Truant PL (2015) Wasted food: U.S. consumers' reported awareness, attitudes, and behaviors. PLOS ONE 10 (6):e0127881. https://doi.org/10.1371/journal.pone.0127881
41. Cecere G, Mancinelli S, Mazzanti M (2014) Waste prevention and social preferences: the role of intrinsic and extrinsic motivations. Ecol Econ 107:163-176. https://doi.org/10.1016/j.ecolecon.2014.07.007
42. Graham-Rowe E, Jessop DC, Sparks P (2014) Identifying motivations and barriers to minimising household food waste. Resour Conserv Recycl 84:15-23. https://doi.org/10.1016/j.resconrec.2013.12.005
43. Canali M, Amani P, Aramyan L, Gheoldus M, Moates G, Östergren K et al (2017) Food waste drivers in Europe, from identification to possible interventions. Sustainability 9 (1). https://doi.org/10.3390/su9010037
44. Ministry of Agriculture and Fisheries Food and Environment (MAPAMA) (2016) Food waste from households in Spain Fall-Winter and Spring-Summer 2015 (presentation in Spanish). Kantar Worldpanel. https://www.mapa.gob.es/es/alimentacion/temas/estrategia-mas-alimento-menos-desperdicio/. Accessed 29 May 2019
45. Stancu V, Lähteenmäki L (2018) Consumer food waste in Denmark. DCA REPORT NO. 118. Danish Centre for Food and Agriculture (DCA)
46. Parizeau K, von Massow M, Martin R (2015) Household-level dynamics of food waste production and related beliefs, attitudes, and behaviours in Guelph, Ontario. Waste Manag 35:207-217. https://doi.org/10.1016/j.wasman.2014.09.019
47. Parfitt J, Barthel M, Macnaughton S (2010) Food waste within food supply chains: quantification and potential for change to 2050. Philos Trans R Soc Lond B Biol Sci 365 (1554):3065-3081. https://doi.org/10.1098/rstb.2010.0126

CHAPTER 3

Older consumers' readiness to accept alternative, more sustainable protein sources in the European Union

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Abstract

Protein-energy malnutrition (PEM) is a growing concern on account of an aging population and its negative health consequences. While dietary protein plays a key role in the prevention of PEM, it also plays a pivotal role in the environmental impact of the human diet. In search for sustainable dietary strategies to increase protein intake in older adults, this study investigated the readiness of older adults to accept the consumption of the following alternative, more sustainable protein sources: plant-based protein, insects, single-cell protein, and in vitro meat. Using ordinal logistic regression modeling, the associations of different food-related attitudes and behavior and socio-demographics with older adults' acceptance to consume such protein sources were assessed. Results were obtained through a consumer survey among 1825 community-dwelling older adults aged 65 years or above in five EU countries (United Kingdom, the Netherlands, Poland, Spain, and Finland). Dairy-based protein was generally the most accepted protein source in food products (75% of the respondents found its consumption acceptable or very acceptable). Plant-based protein was the most accepted alternative, more sustainable protein source (58%) followed by single-cell protein (20%), insect-based protein (9%), and in vitro meat-based protein (6%). We found that food fussiness is a barrier to acceptance, whereas green eating behavior and higher educational attainment are facilitators to older adults' acceptance to eat protein from alternative, more sustainable sources. Health, sensory appeal, and price as food choice motives, as well as gender and country of residence were found to influence acceptance, although not consistently across all the protein sources. Findings suggest that there is a window of opportunity to increase older adults' acceptance of alternative, more sustainable protein sources and in turn increase protein intake in an environmentally sustainable way in EU older adults.

1. Introduction

The world's population is estimated to reach 9.8 billion by 2050, and the number of persons aged 60 or above is expected to double compared to 2017 [1]. In the European Union (EU), one in five persons is already aged 65 or above, with the majority residing independently at home [2,3]. Protein-energy malnutrition (PEM) is a common and often underdiagnosed condition in this population and has serious consequences for health, functioning, and quality of life [4,5]. The risk of PEM in older adults is high because age-related changes in physiological, psychological, and environmental factors can disrupt the balance between dietary consumption and nutritional requirements [6]. The need for adequate consumption of protein, in particular, is increasingly recognized to prevent PEM and to enhance healthy aging [7,8]. It is argued that the recommended intake of protein inadequately meets the actual protein requirement of older adults and thus needs to increase to support good health and prevent decline in functional status in this population [6,9].

The challenge of meeting the higher protein requirement of an expanding population is compounded by environmental challenges, including climate change, biodiversity loss, land use change, and freshwater use [10]. Protein production, and food production in general, have a large impact on the environment, with animal-based protein production having a greater impact than plant-based protein production [11,12]. Relative to plant-based protein sources, animal-based protein sources are associated with more greenhouse gas emissions (GHGE) [13], greater requirements of land and nitrogen [14], and a greater impact on terrestrial and aquatic biodiversity [10]. Animal-based protein accounts for the majority (55% to 73%) of total protein consumed in the EU diet, with the contribution of protein derived from meat, dairy, eggs, and fish varying between countries [15]. A smaller percentage (24% to 39%) of total protein intake comes from plant origin, with the largest contribution of protein being derived from cereals [15]. The current ratio between animal and plant protein threatens the environment to the extent that business-as-usual for consumption and production is no longer an option [10,16].

In search of more sustainable protein sources, researchers are investigating the nutritional and environmental profiles of alternative protein sources that can act as meat substitutes, such as plant-based sources, insects, single-cell protein (e.g., mycoprotein such as Quorn™ or microalgae), and in vitro meat (also known as lab-grown, cultured or clean meat) [17]. Indeed, such alternative protein sources have been found to have environmental benefits and be comparable to animal-based protein sources in terms of protein content [18,19]. Some alternative sources even outperform animal-based protein sources with regard to nutritional content [18]. The protein quality of such alternative protein sources, however, is slightly lower than of animal-based sources, although when eaten in a diverse diet, the quality of the total daily protein intake remains high [20]. Until recently, foods containing plant-based protein were a niche market targeting vegetarian and vegan consumers, but now they are consumed by a wider range of consumers who for various reasons want to reduce their meat intake [21]. Other alternative protein sources remain a niche market but are expected to shift to a wider market in the next decade [17]. Single-cell proteins are well-established in the market, yet are limited to Quorn™ and algae-derived food supplements [22]. Edible insects are produced and sold in only a few EU countries, including the United Kingdom (UK), the Netherlands, and Finland, but are not yet widely available due to safety concerns [23]. In vitro meat has not yet penetrated the market but is expected to become commercially available in the coming years [24].

Considerable efforts have been made in recent years to determine opportunities and barriers for consumers to reduce their meat intake and to consume such alternative protein sources. Increasing evidence indicates that there is low consumer awareness of the environmental impact of meat production, as well as low willingness to change meat consumption behavior in terms of reducing or substituting meat in Europe [25]. Despite a seemingly close match between consumers' image of a sustainable, a healthy, and a plant-based diet [26], it appears that very few consumers are willing to change meat consumption behaviors for sustainability reasons [25]. Barriers to changing meat consumption behaviors include preconceptions towards vegetarian diets, habits and prices, lack of familiarity with meat substitutes, and lack of skills to prepare meals containing meat substitutes [27,28]. In addition, food neophobia—the aversion of unfamiliar foods—and the food choice motive sensory appeal have been identified as barriers to consumer acceptance of meat substitutes [29]. Food choice motives related to health and environmental impact, however, have been shown to play a facilitating role in changing meat consumption behaviors [30]. Moreover, carrying out sustainable food-related activities such as buying local or organic food, which has previously been defined by Weller et al. as green eating behavior, has been correlated with lower meat intake [31]. Other factors that have been found to influence meat consumption behavior and alternative protein uptake are socio-demographics such as gender, age, and education [23,32,33].

Previous studies in this field consist mainly of younger adults, as they are the consumers of the future. Very little is known of the attitudes towards alternative, more sustainable protein sources among community-dwelling older adults in Europe. To sustainably meet the increased protein need in general, and of older adults in particular, it is imperative that the growing population accepts plant-based and other alternative proteins in favor to animal-based protein. Food choices of older adults are therefore crucial in the transition towards more sustainable diets.

The objective of this study was to investigate consumer readiness to accept alternative, more sustainable protein sources among community-dwelling older adults (aged 65 years or above) in the EU. First, this study assessed the level of acceptance to consume the following alternative, potentially more sustainable protein sources: plant-based protein, insects, single-cell protein, and in vitro meat. Second, we investigated how different food-related attitudes and behavior (i.e., food fussiness, food choice motives, and green eating behavior) and socio-demographics (i.e., age, gender, country of residence, education) influence the acceptance to consume such protein sources. Insight into the readiness of older adults to accept alternative, more sustainable protein sources will help researchers and the food industry in particular to develop products that specifically target the preferences of older consumers with the overall aim to increase dietary protein intake within this population in an environmentally sustainable manner.

2. Materials and methods

2.1. Study design and sampling

The present study was conducted within the PROMISS (PRevention Of Malnutrition In Senior Subjects in the EU) project, a five-year multicountry project funded by the European Commission (EC) Horizon 2020 aiming to understand the relationship between food, physical activity and biological changes and to develop dietary and physical activity strategies for the prevention of PEM among older European adults. This study used cross-sectional quantitative survey data that were collected electronically in June 2017 in five EU countries, namely, the United Kingdom, the Netherlands, Poland, Spain, and Finland; n = ±365/country.

Participants (n = 1825) were recruited by a professional market research agency using probabilistic sampling from an online access proprietary panel. Recruitment criteria and quota were established for older adults (65 years or above) who live independently. A nationally representative sample was achieved with additional measures performed by the market research agency, in terms of gender and region in each of the study countries, following a standard procedure: 1. The selection of potential participants was based on the background information collected during the registration survey, profiling, and screening surveys as performed by the recruitment agency; 2. specified quotas were established for gender (an equal amount of female and male) and regions proportional to the distribution within the overall population; and 3. the panelists were invited at various and designated times with close monitoring of participation and eventual corrective action during the fieldwork to ensure that the quotas for gender and region were fulfilled correctly. The same market research agency was responsible for all recruitment and contact procedures and electronic questionnaire administration. Ethics approval for the study was granted by the Belgian Ethics Committee of Ghent University Hospital in March 2017 (Reference No. B670201422567).

2.2. Questionnaire and scales

The development of the questionnaire regarding translation and pretesting has been elaborated in Hung et al. [34]. The questionnaire started with a short description of the PROMISS project and an informed consent and was followed by a screening for sample selection based on gender, age, region, and current living condition. The questions consisted of various sections including dietary habits, food-related attitudes and behaviors, acceptance towards various protein sources, socio-demographics and personal information. Order bias was avoided by rotating items within a question.

2.2.1. Dietary habits

Regarding dietary habits, respondents were asked to indicate the frequency of consumption of various protein-rich food products, such as legumes, cooked meat, and cheese, while considering the last four weeks as the reference period. Furthermore, they were asked if they were currently following any dietary regime, such as a vegetarian diet that includes eggs and/or dairy products, a vegan diet, or any other diet regime, which they could specify. Respondents who reported following a vegetarian or vegan diet or reported having eaten meat (meat in a warm meal or cold-cuts) once a week or less in the past four weeks were considered to follow a meat-limiting diet.

2.2.2. Food fussiness

A food fussiness scale was adapted from den Uijl et al. [35] and Wardle et al. [36] to assess the degree to which one is selective about the range of foods that are accepted. The food fussiness scale consisted of seven items, e.g., 'I enjoy tasting new foods', in which respondents could indicate their level of agreement on a five-point scale from 'Strongly disagree' (=1) to 'Strongly agree' (=5).

2.2.3. Food choice motives

Food choice motives were assessed using a modified food choice questionnaire (FCQ) based on the scale developed by Steptoe and colleagues [37]. The modified FCQ consisted of 23 items and five factors: health, convenience, sensory appeal, price, and sustainability factors. The health, convenience, sensory appeal, and price factors have been validated and used previously [38]. Each item was answered on a five-point scale ranging from 'Not at all important' (=1) to 'Extremely important' (=5).

2.2.4. Green eating behavior

Green eating behavior was assessed using a modified scale based on Weller and colleagues [31], which provides insights related to environmentally-conscious eating. The scale consisted of five items in which respondents could indicate how often they consumed green food products on a five-point scale ranging from 'Never' (=1) to 'Always' (=5) or 'I don't know'. Green eating behavior included eating locally grown or produced foods, foods purchased directly from a farmer's market, organic foods, foods with an environmental sustainability label (e.g., Rainforest Alliance), and foods with an ethical sustainability label (e.g., Fair Trade).

2.2.5. Acceptance to consume various protein sources

Acceptance to consume food products containing various dietary protein sources was assessed. Participants were asked to indicate their acceptance to consume food products containing the following seven protein sources: (1) plant-based protein (derived from soy, pea, rice, canola, etc.), (2) meat-based protein (derived from cattle, pigs, poultry, etc.), (3) dairy-based protein (derived from milk, cheese, etc.), (4) seafood-based protein (derived from fish, shrimp, etc.), (5) insect-based protein (derived from mealworms, crickets, etc.), (6) single-cell protein (derived from microorganisms like algae, yeast, fungi, bacteria), and (7) in vitro meat-based protein (lab-made or cultured meat). Respondents could indicate their acceptance on a five-point scale ranging from 'Very unacceptable' (=1) to 'Very acceptable' (=5) or 'I don't know'. In this report, plant-, insect-, single-cell-, and in vitro meat-based protein sources are considered to be alternative, more sustainable protein sources as they in general are expected to have a lower environmental impact compared to animal-based protein sources [18].

2.2.6. Socio-demographics and personal information

The personal characteristics of respondents were assessed using a series of 17 questions. These included socio-demographics such as educational level, being the main household (HH) grocery shopper, HH income, food expenses, lifestyle such as smoking and alcohol use, and presence of various health problems. Monthly HH income was asked in euros (€) for the Netherlands, Finland, Spain, in pounds for the UK, and in złoty in Poland. For the purpose of this study, HH income categories (low, middle, high) were created based on country-specific distributions (converted to euros where applicable): for the UK, the Netherlands, and Spain, Low = less than €1499, Middle = €1500 to €2499, High = €2500 or more; for Finland, Low = less than €1999, Middle = €2000 to €2999, High = €3000 or more; and for Poland, Low = less than €500, Middle = €500 to €999, High = €1000 or more. The health status was assessed by asking respondents if they had any of the following 17 health problems: pain in mouth, teeth or gums; dry mouth; difficulty swallowing; difficulty chewing; overweight/obesity; underweight; cardiovascular/heart disease; hypertension (high blood pressure); irritable bowel syndrome; other digestive problems; diabetes or high blood sugar levels; high blood cholesterol levels; cancer; food allergy; food intolerance; chronic kidney disease; and other chronic diseases or pain in general.

2.3. Statistical analysis

Descriptive statistics were used to report frequency and percentages for categorical variables and means and standard deviations for continuous variables. Level of acceptance to eat alternative, more sustainable protein sources, as well as other dietary protein sources, was reported as percentages. Differences between background characteristics of those who answered 'I don't know' when asked to what extent they accept eating foods that contain an alternative, more sustainable protein source and those whose answer was within the range of the ordered scale for the alternative, more sustainable protein sources (very unacceptable (=1) to very acceptable (=5)) were tested using a Chi-square test or a t-test per protein source.

Exploratory factor analysis using principal axis factor analysis with varimax rotation, a type of orthogonal factor rotation, was conducted to check construct unidimensionality of food choice motives, food fussiness, and green eating behavior. Principal axis factoring finds the common variance among the items and identifies the factors or dimensions underlying the data [39]. Factors were considered reliable when Cronbach's alpha internal reliability coefficient was above the lower limit of 0.6 [39].

Ordinal logistic regression analyses were conducted to identify determinants influencing older adults' acceptance to eat sustainable protein sources, namely plant-, insect-, single-cell-, and in vitro meat-based protein. Those who responded 'I don't know' when asked to what extent they accept eating foods that contain an alternative, more sustainable protein source were excluded from the regression analyses because this response option does not fit in the ordered scale. In total, 7%–11% respondents were excluded. Furthermore, because of the very small proportion of respondents reporting finding the consumption of insect- (1.6%), single-cell- (3.5%), and in vitro meat-based (0.9%) protein sources to be ‘very acceptable’ and plant-based protein sources (4.4%) to be ‘very unacceptable’, the ordinal scale of the alternative sustainable protein sources was collapsed to an ordered scale of three levels: unacceptable, neutral, and acceptable. Separate ordered logit models were tested with each alternative sustainable protein source as a dependent variable (ordinal) and socio-demographics (i.e., gender (nominal), age group (nominal), country of residence (nominal), education (nominal)), food-related attitudes (i.e., food choice motives (interval), food fussiness (interval)), and green eating behavior (interval) as determinants.

Assumptions for ordinal logistic regression were tested and validated. Correlation matrices of all the potential explanatory variables were examined to check for multicollinearity prior to conducting the regression analyses. We considered multicollinearity if the correlation coefficient between two explanatory variables was larger than 0.8 [39]. There were no indications of multicollinearity (Appendix A Table A1). The parallel lines assumption for ordinal regression was met for all models (plant-based protein p-value = 0.079; insect-based protein p-value = 0.023; single-cell protein p-value = 0.023; in vitro meat-based protein p-value = 0.086).

Statistical significance was considered at the α level of 0.05. Data were analyzed using SPSS version 24.0 (IBM Corp. Released 2016. IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY, USA: IBM Corp.).

3. Results

3.1. Characteristics of the sample

Background characteristics of the respondents are shown in Table 1. The sample of older adults aged 65 years and older was equally represented by gender and country. It had a higher share of lower-educated respondents and respondents living at home with others and responsible for most of the food shopping. On average, the respondents reported having 2 out of 17 asked health problems, with the most reported health problems being hypertension (42%), overweight/obesity (37%), and high blood cholesterol levels (29%). By far the majority (86.8%) of the respondents did not follow a meat-limiting diet.

Table 1. Background characteristics of 1825 adults aged 65 years and older from five EU countries (n = 1825 unless indicated otherwise).

Characteristic	% of Sample
Gender	
Male	50.4
Female	49.6
Age group	
65–69	55.9
70–90	44.1
Country	
United Kingdom	20.0
The Netherlands	20.1
Poland	19.9
Spain	20.0
Finland	20.0
Educational attainment	
Below tertiary level	59.6
Tertiary level or above	40.4
Perceived financial situation (n = 1791)	
Have some or severe difficulties	16.4
Get by alright	38.3
Manage quite or very well	45.3
Living condition	
Lives alone	30.6
Lives with others	69.4
Responsibility for food purchases	
Does most of food shopping	70.3
Shared responsibility for food shopping	19.6
Does not shop for food	10.1
Number of health problems [1], mean ± sd (n = 1748)	2.3 ± 2.1
Dietary regime [2]	
Follows a meat-limiting diet	13.2
Does not follow a meat-limiting diet	86.8

[1] Sum of number of reported health problems out of 17 asked health problems. [2] Meat-limiting diet includes those who reported to follow a vegetarian or vegan diet or reported to eat meat (meat in a warm meal or cold-cuts) one time per week or less in the past four weeks.

3.2. Factor analysis

The principal axis factor analysis confirmed the unidimensionality of the constructs of health convenience, sensory, price and sustainability food choice motives, food fussiness, and green eating behavior (Appendix A Table A2). All factors had sufficient internal reliability (health food choice motive α = 0.90; convenience food choice motive α = 0.85; sensory food choice motive α = 0.86; price food choice motive α = 0.81; sustainability food choice motive α = 0.82; food fussiness α = 0.81; green eating behavior α = 0.81).

3.3. Acceptance towards different protein sources

Figure 1 illustrates the level of acceptance to eat protein from various sources among the 1825 adults aged 65 years and older from five EU countries. In general, dairy-, seafood-, and meat-based protein sources were the most accepted protein sources, followed by plant-, single-cell-, insect-, and in vitro meat-based protein sources. Plant-based protein was the most accepted alternative, more sustainable protein source, with

46% of the respondents finding its consumption acceptable and 12% very acceptable. Next was single-cell-based protein, with 17% of the respondents finding its consumption acceptable and 3% very acceptable. Insect- and in vitro meat-based protein were the least accepted, with only 9% of the respondents finding the consumption of insect-based protein acceptable or very acceptable and 6% for in vitro meat-based protein. The percentage of respondents who reported 'I don't know' was highest for single-cell- and in vitro meat-based protein (both 11%) compared to 7% for insect-based protein and 5% for plant-based protein. A greater proportion of respondents that responded 'I don't know' to plant- and single-cell-based protein had lower educational attainment compared to those who responded using the ordered scale (X^2 = 13.1, p <0.001 for plant-based protein and X^2 = 6.7, p =0.010 for single-cell-based protein) (see Appendix A Table A3).

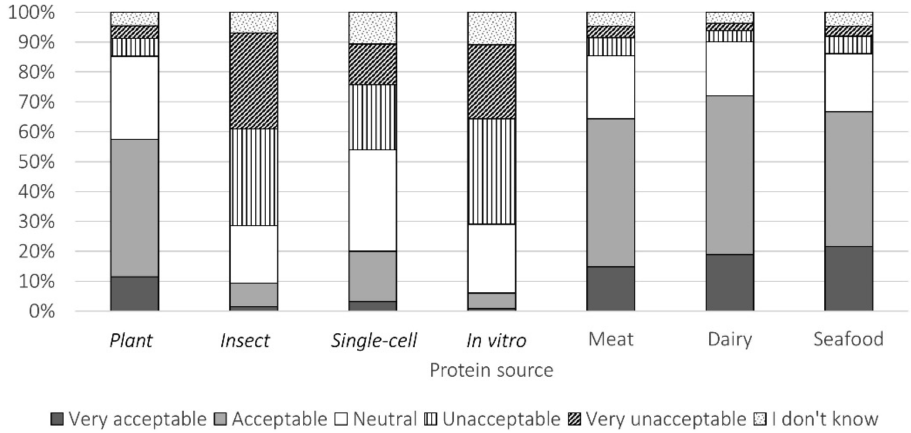

Figure 1. Level of acceptance to eat food products containing alternative, more sustainable protein sources (italicized and in bold) and other dietary protein sources in adults aged 65 years and older from five EU countries (%, n = 1825).

3.4. Determinants of older adults' acceptance to eat food products containing alternative, more sustainable protein sources

Table 2 shows that educational attainment, food fussiness, and green eating behavior are the most important factors influencing the acceptance to eat protein from alternative, more sustainable sources in adults 65 years and older from five EU countries. Higher-educated adults are 33%–41% more likely to accept eating food products containing alternative, more sustainable protein sources compared to those who did not complete higher education (p < 0.05). Similarly, a one-unit increase in green eating behavior is associated with an average 38% increase in the odds of being likely to accept alternative, more sustainable protein sources. Respondents who reported favoring more green eating behaviors are 29% more likely (95% CI 7%–57% more likely; p = 0.01) to accept in vitro meat-based protein sources, 36% more likely (95% CI 11%–66% more likely; p < 0.001) to accept single-cell-based protein sources, 44% more likely (95% CI 21%–72%

more likely; $p = 0.003$) to accept insect-based protein sources, and 45% more likely (95% CI 21%–73% more likely; $p < 0.001$) to accept plant-based protein sources.

By contrast, a one-unit increase in food fussiness score (i.e., those who are more selective about which foods they are willing to eat) is associated with an average 43% decrease in the odds of being likely to accept alternative, more sustainable protein sources. This ranges from a 27% decrease (95% CI 11%–40% decrease; $p = 0.002$) in the odds of being likely to accept in vitro meat-based protein to a 53% decrease (95% CI 44%–61% decrease; $p < 0.001$) in the odds of being likely to accept single-cell-based protein.

The other studied determinants resulted in less consistent associations across all alternative, more sustainable protein sources. Gender was found to influence older adults' acceptance towards the consumption of insect-, single-cell-, and in vitro meat-based protein sources, but not towards the consumption of plant-based protein sources. Female older adults are 57% less likely (95% CI: 45%–66% less likely; $p < 0.001$) to accept eating insect-based protein sources compared to male older adults. Furthermore, they were found to be 32% less likely (95% CI: 17%–45% less likely; $p < 0.001$) to accept eating single-cell based protein sources and 43% less likely (95% CI: 28%–55% less likely; $p < 0.001$) to accept eating in vitro meat-based protein sources. The country of residence also influenced older adults' acceptability to eat sustainable protein sources except for single-cell-based protein sources. Compared to those living in the UK, those living in Poland are 61% more likely (95% CI 9%–138% more likely; $p = 0.016$) to eat plant-based protein sources and 39% less likely (95% CI: 7%–60% less likely; $p = 0.022$) to eat in vitro meat-based protein sources. Those living in the Netherlands and Finland are more than twice as likely ($p < 0.001$) and in Spain 1.5 times as likely ($p = 0.042$) to eat insect-based protein sources compared to the UK. Being 70 years or older compared to 65 to 69 years did not influence older adults' acceptance to consume alternative, more sustainable protein sources.

Out of the five food choice motives, the sensory motive has a negative influence on acceptance of insect- and single-cell-based protein sources. Older adults who find sensory attributes (smell, texture, etc.) of food important when making food choices are 17% less likely (95% CI: 1%–30% less likely; $p = 0.040$) to accept eating single-cell-based protein sources and 30% less likely (95% CI: 15%–42% less likely; $p < 0.001$) to accept eating insect-based protein sources. Older adults are 47% more likely (95% CI 19%–82% more likely; $p < 0.001$) to accept eating plant-based protein sources if they value health when making food choices. Older adults who find price of food important when making food choices are 25% more likely (95% CI 6%–48% more likely; $p = 0.009$) to accept in vitro meat-based protein sources. Convenience and sustainability food choice motives were not found to be significant determinants.

The studied determinants of acceptance to eat food products containing alternative, more sustainable protein sources accounted for about 6.7%–15.2% of the variance, as shown by the Nagelkerke pseudo R^2 (Table 2).

Table 2 Determinants of acceptance to eat food products containing protein from alternative, more sustainable sources in adults aged 65 years and older from five EU countries—results from ordinal regression analyses [1].

	Plant (n = 1518)			Insect (n = 1483)			Single Cell (n = 1426)			In Vitro (n = 1435)		
	OR	(95% CI)	*p*-value	OR	(95% CI)	*p*-value	OR	(95% CI)	*p*-value	OR	(95% CI)	*p*-value
Gender												
Male (Ref)	-			-			-			-		
Female	0.96	(0.78–1.19)	0.719	**0.43**	(0.34–0.55)	< 0.001	**0.68**	(0.55–0.83)	<0.001	**0.57**	(0.45–0.72)	<0.001
Age (y)												
65–69 (Ref)	-			-			-			-		
70–90	1.08	(0.87–1.33)	0.499	1.06	(0.84–1.34)	0.605	0.93	(0.76–1.14)	0.501	1.06	(0.85–1.33)	0.587
Country												
United Kingdom (Ref)	-			-			-			-		
The Netherlands	1.02	(0.73–1.43)	0.907	**2.16**	(1.48–3.15)	< 0.001	0.89	(0.64–1.23)	0.477	1.23	(0.86–1.76)	0.249
Poland	**1.61**	(1.09–2.38)	0.016	0.87	(0.55–1.37)	0.554	0.83	(0.58–1.18)	0.299	**0.61**	(0.40–0.93)	0.022
Spain	1.11	(0.79–1.56)	0.553	**1.5**	(1.01–2.21)	0.042	1.32	(0.96–1.84)	0.092	0.95	(0.66–1.36)	0.771
Finland	0.98	(0.71–1.36)	0.894	**2.23**	(1.56–3.17)	< 0.001	0.73	(0.54–1.01)	0.054	1.14	(0.81–1.61)	0.446
Educational attainment [2]												
No higher education (Ref)	-			-			-			-		
Higher education	**1.33**	(1.06–1.66)	0.013	**1.4**	(1.11–1.78)	0.005	**1.41**	(1.14–1.73)	0.001	1.34	(1.06–1.70)	0.013
Food choice motives [3]								(0.88–1.33)				
Health	**1.47**	(1.19–1.82)	<0.001	0.8	(0.64–1.02)	0.071	1.08	(0.82–1.12)	0.442	0.88	(0.70–1.11)	0.293
Convenience	0.88	(0.75–1.03)	0.118	0.96	(0.81–1.15)	0.675	0.96	(0.70–0.99)	0.592	1.05	(0.88–1.24)	0.593
Sensory	1.01	(0.84–1.20)	0.953	**0.7**	(0.58–0.85)	< 0.001	**0.83**	(0.96–1.29)	0.04	0.83	(0.68–1.00)	0.05
Price	1.1	(0.94–1.28)	0.254	1.13	(0.95–1.35)	0.159	1.11	(0.92–1.31)	0.159	**1.25**	(1.06–1.48)	0.009
Sustainability	1.04	(0.86–1.25)	0.691	1.22	(0.99–1.50)	0.059	1.1		0.302	0.98	(0.81–1.20)	0.881
Food fussiness [4]	**0.55**	(0.45–0.66)	<0.001	**0.51**	(0.41–0.63)	< 0.001	**0.47**	(0.39–0.56)	<0.001	**0.73**	(0.60–0.89)	<0.001
Green eating behavior [5]	**1.45**	(1.21–1.73)	<0.001	**1.36**	(1.11–1.66)	0.003	**1.44**	(1.21–1.72)	<0.001	**1.29**	(1.07–1.57)	<0.001
Nagelkerke R square (%)	12.1			15.2			12.5			6.7		

[1] Odds ratio (OR) is bold if statistically significant, *p*-value < 0.05. [2] No higher education includes no education up to higher secondary education; Higher education includes bachelor, master or doctoral education. [3] Each food choice motive is a continuous score from one to five, with a greater score indicating more importance is placed on the respective motive (e.g., health) when making food choices. [4] Food fussiness is a continuous score from one to five, with a greater score indicating a greater tendency to be a fussy or picky eater. [5] Green eating behavior is a continuous score from one to five, with a greater score indicating a greater tendency to practice sustainable food-related behaviors such as buying local or organic food.

4. Discussion

This study examined the level of acceptance to eat protein from alternative, more sustainable sources and the potential determinants of acceptance in a sample of 1825 community-dwelling adults aged 65 years and older from five EU countries. While the willingness to consume sustainable protein sources has been explored in younger adults [25], research in older adults is lacking, yet highly relevant due to the challenge of fulfilling the high protein requirement of the expanding older population in an environmentally sustainable fashion [9,40]. As dietary strategies to increase protein intake among older adults are sought [7], it is important and relevant that older adults' attitudes towards sustainable food choices be further investigated.

4.1. Older adults' acceptance to eat food products containing alternative, more sustainable protein sources

In agreement with previous research in younger populations, this study showed that there is low acceptance to eat food products containing alternative, more sustainable protein sources (i.e., insect-, single-cell, in vitro meat-based) among older adults in Europe [41-43]. The acceptance to eat food containing plant-based protein sources was higher compared to the innovative and more technology-driven alternative protein sources, but slightly lower compared to the acceptance to eat meat-, dairy-, and seafood-based protein sources in our sample. Similarly, a study conducted primarily among middle-aged adults found that there was more willingness to consume plant-based meat substitutes compared to protein from insects, yet people were even more willing to consume hybrid meat, meat with lower environmental impact, organic meat, and sustainably farmed fish [28]. The high acceptance to eat meat, dairy, and seafood among our sample of older adults underscores the important status of animal-based protein in the habitual Western diet [44,45].

It is possible that in our study respondents may have answered the question "to what extent do you accept eating food products that contain [alternative protein source]" without having adequate knowledge of the environmental and health benefits of the protein source, or even of the protein source itself [33]. A Belgium study found that only 13% of their study participants made up of mainly students knew the concept of in vitro meat without being given prior information [46]. In this study, only 11% of the participants reported 'I don't know' when asked to what extent they accept eating single-cell- and in vitro meat-based protein. Furthermore, although all protein sources were presented in a consistent manner in the questionnaire, we speculate that compared to the familiar meat-, dairy-, and seafood-based protein sources, respondents may have not easily grasped the concept of eating unfamiliar protein sources such as insect-, single-cell-, and in vitro meat-based protein sources. Experimental research has shown that presenting such protein alternatives in the context of a meal or as an ingredient positively influences consumers' acceptance of various meat substitutes and insects [27,47]. For instance, a study conducted in the Netherlands found that pizza with processed insect protein was more acceptable than a salad with visible insects [27]. Presenting various protein sources as abstract concepts (e.g., to what extent do you accept eating food products that contain insect-based protein, e.g., derived from mealworms or crickets) rather than in context of a meal may have negatively influenced consumers' acceptance of protein alternatives [25].

4.2. Factors influencing acceptance

4.2.1. Food-related attitudes and green eating behavior

Food fussiness emerged as an important determinant of acceptance in our sample. Respondents with a higher degree of food fussiness were less likely to accept eating sustainable protein sources. Previous research has focused more on the concept of food neophobia, a construct that overlaps with food fussiness but refers specifically to the aversion of unfamiliar foods [48], as a barrier to the acceptance of novel foods [49,50], including meat substitutes [43], insects [41,51] and in vitro meat [46]. As plant-, insect- and single-cell-derived meat substitutes are relatively new products on the market, and in vitro meat-based food products have not yet penetrated the market [17], it is logical that fussy eaters would be less likely to accept these protein sources compared to less fussy eaters.

There was no food choice motive that had a consistent, significant association with the acceptability to eat all four alternative, more sustainable protein sources, suggesting that expectations towards alternative, more sustainable proteins vary per protein source. In agreement with past research, we found that health motives contributed to the acceptability of consuming plant-based protein, and sensory appeal was a barrier to the acceptability of consuming insect- and single-cell-based protein [43,52]. These findings suggest that there are expectations of health-promoting properties with plant-based protein and taste deficiencies with insect- and single-cell-based protein. Surprisingly, price food choice motive had a positive influence on acceptance to eat food products containing in vitro-based protein. We expected that price consciousness would have a negative influence, as it has been previously found as a barrier to sustainable food choices [53] and to the acceptance of in vitro meat among a Belgium sample [46]. Further, in vitro meat is expensive (about $25 per kilo), although innovations are advancing to soon bring it into the market at a competitive price [17,54]. One way to explain our finding is the high level of unfamiliarity with in vitro meat in our sample. Although only 11% of the respondents reported 'I don't know', it can be that the majority did not know the cost of in vitro meat-based protein. Eventually, participants may have assumed a low price for this product owing to the opportunity of industry-scale low-cost mass production without the need to raise, transport, and slaughter animals.

Another striking result is that the sustainability food choice motive did not play an integral, consistent role in shaping the acceptability to eat sustainable protein sources. Sustainability food choice motive was expected be associated with a higher odds of accepting alternative, more sustainable protein sources because it was found to positively influence sustainable food consumption in previous studies [33,55]. However, our finding is in accordance with earlier studies that indicated that environmental concern does not directly translate into sustainable food choices, as many people may be either unaware of the environmental impacts of meat and other food products [28,56], or unable/unwilling to act in line with their pro-environmental attitudes [57]. Yet, it is possible that the potential impact of sustainability food choice motive has been covered in this analysis because is it significantly associated with other determinants, notably the health motive. The correlation between health food choice motive and sustainability food choice motive was statistically significant (although below the cutoff for multicollinearity), which is in line with the perceived match between health and sustainability in food as reported in the study by Van Loo and colleagues [26]. While convenience has been found to be an important motive for food choices made by older adults [58], it was not found to influence the acceptance to eat various sustainable protein sources in our sample.

Consistent with expectations, those who reported practicing more green eating behaviors were more accepting of eating sustainable protein sources. Niva and colleagues [59] found that older adults (aged 65–80 years) were more active in sustainable food consumption practices, such as buying local or organic food, compared to younger adults in Scandinavia, suggesting that there is willingness among this population to make food consumption more sustainable.

4.2.2. Role of socio-demographics

In line with previous studies, we found that higher-educated consumers are more likely to accept eating alternative, more sustainable protein sources [60]. Earlier studies have also shown that education level is inversely related to meat consumption [61]. One can speculate that higher-educated adults are more aware of the health and/or environmental benefits of eating a primarily plant-based diet. This is corroborated by Van Loo and colleagues, who found that individuals involved in health and/or sustainable eating are more likely to be higher educated than those not involved [26]. Gender and country of residence influenced acceptance of only certain alternative, more sustainable protein sources. Females were less likely compared to males to accept eating alternative, more sustainable protein sources, although there is evidence that females are more willing than males to reduce meat consumption [33,56]. Females have also been previously found to be less likely to accept insects [41], but more likely to accept of meat substitutes compared to males [32]. The identified country differences are empirical findings that may eventually be due to the different food cultures and penetration of alternative, sustainable protein sources in the market [62].

4.3. Strengths and limitations of the study

The major strengths of this study include the use of a cross-European large-scale survey and the investigation of various determinants of acceptance to eat sustainable protein sources in older adults. Our study has a few limitations, which were also previously described in Hung et al. [34]. In short, these include potential selection bias and limited generalizability, as the sample was restricted to older adults with online access and a certain level of skills to access and complete the online survey and potential social desirability bias of the self-reported measures. Furthermore, although all protein sources were presented in a consistent manner, the question assessing the level of acceptance towards various protein sources may be susceptible to bias. Compared to animal-based protein sources, the alternative, more sustainable protein sources are less familiar, and thus, respondents may have not been able to conjure up ways in which such protein sources can fit into their accustomed meal formats and food combinations. Previous research suggests that presenting such protein sources out of context may result in an inaccurate portrayal of the consumers' actual attitude towards sustainable food choices [25]. However, even when placed in context, the acceptance of insect-, single-cell-, and in vitro meat-based protein sources is expected to remain lower compared to plant- and animal-based protein sources due to factors such as sensory appeal and perceived naturalness [25].

4.4. Implications of findings and future research

The low acceptance of alternative, more sustainable protein sources could be a barrier to the transition to environmentally-friendly diets adequate in protein in older adults. However, the relatively high acceptance to eat more familiar plant-based protein sources may provide a window of opportunity to increase protein intake in an environmentally sustainable way. Recommendations to increase consumption of plant-based protein sources will be widely accepted by older adults, although other barriers to increasing food consumption in general, such as poor appetite, may arise [34]. The negative relationship between food fussiness and acceptability to consume sustainable protein sources also provides an opportunity. High food fussiness scores associate with more aversion to unfamiliar food as four of the seven factors are related to novel foods [48]. Previous studies found that the acceptance of alternative, more sustainable protein sources such as cultured meat increased after informing health and/or environmental benefits of the protein source [46]. Therefore, targeted information provision to increase awareness and familiarity of alternative, more sustainable protein sources might have a positive impact on the readiness to accept consuming these products. Furthermore, repeated exposure to the food has been shown to increase acceptability of Quorn and tofu in a Dutch sample [63].

While significant determinants of acceptance to eat sustainable protein sources were found in this study, the results show that much of the variance of acceptance is left unexplained. Other possible determinants of acceptance to eat sustainable protein sources may include familiarity [63], social norms, awareness, perceived consumer effectiveness, and perceived availability of the product [57]. Future research investigating additional determinants of attitudes towards sustainable food choices in older adults can consider placing the sustainable food choice in context by providing pictures of meals or products with, or real products of, for example, insects or insect-based protein as an added ingredient. Furthermore, acceptance and positive attitude does not necessarily translate into favorable intentions and behavioral change [57], and thus, further investigation into the intention or willingness to consume sustainable protein sources among older adults is warranted.

5. Conclusions

This study provides insight into the readiness of older adults to accept alternative, more sustainable protein sources in the EU. To the best of our knowledge, this report is the first to focus on older adults' attitudes towards sustainable food choices. Findings suggest that there is a window of opportunity to increase older adults' acceptance of alternative, more sustainable protein sources and, in turn, increase protein intake in an environmentally sustainable way in EU older adults. Based on the results of this study, protein recommendations should focus on increasing consumption of plant-based protein sources as an alternative, more sustainable protein source, as these products will be the most accepted by older adults. Furthermore, our results indicate that older adults' acceptability to consume alternative, more sustainable protein sources is influenced by food fussiness, green eating behavior, educational attainment, different food motives, gender, and country of residence. To increase older adults' acceptance towards more innovative and more technology-driven alternative protein sources, evidence points to the need of greater awareness and familiarity of these products among this population. More studies are needed to investigate older adults' acceptance of alternative, more sustainable protein sources after being provided information and/or being exposed to the protein source in a meal context, as well as their intention or willingness to consume sustainable protein sources.

References

1. United Nations, Department of Economic and Social Affairs, Population Division (2017) World population prospects: The 2017 revision, Key findings and advance tables. Working Paper No. ESA/P/WP/248. Working Paper No. ESA/P/WP/248, New York, U.S.A.
2. Stula S (2012) Living in old age in Europe. Current developments and challenges. Working Paper No. 7 of the Observatory for Socio-political Developments in Europe. Working Paper No. 7 of the Observatory for Sociopolitical Developments in Europe, Berlin, Germany.
3. Eurostat (2017) Population structure and ageing. https://ec.europa.eu/eurostat/statistics-explained/index.php/Population_structure_and_ageing#Past_and_future_population_ageing_trends_in_the_EU. Accessed 15 March 2019
4. Morley JE (2012) Undernutrition in older adults. Fam Prac 29 (suppl_1):i89-i93. https://doi.org/10.1093/fampra/cmr054
5. Keller HH, Ostbye T, Goy R (2004) Nutritional risk predicts quality of life in elderly community-living Canadians. J Gerontol A Biol Sci Med Sci 59 (1):68-74. https://doi.org/10.1093/gerona/59.1.M68
6. de Morais C, Oliveira B, Afonso C, Lumbers M, Raats M, de Almeida MD (2013) Nutritional risk of European elderly. Eur J Clin Nutr 67 (11):1215-1219. https://doi.org/10.1038/ejcn.2013.175
7. Lonnie M, Hooker E, Brunstrom JM, Corfe BM, Green MA, Watson AW et al (2018) Protein for life: Review of optimal protein intake, sustainable dietary sources and the effect on appetite in ageing adults. Nutrients 10 (3). https://doi.org/10.3390/nu10030360
8. Hengeveld LM, Wijnhoven HAH, Olthof MR, Brouwer IA, Harris TB, Kritchevsky SB et al (2018) Prospective associations of poor diet quality with long-term incidence of protein-energy malnutrition in community-dwelling older adults: the Health, Aging, and Body Composition (Health ABC) Study. Am J Clin Nutr 107 (2):155-164. https://doi.org/10.1093/ajcn/nqx020
9. Bauer J, Biolo G, Cederholm T, Cesari M, Cruz-Jentoft AJ, Morley JE et al (2013) Evidence-based recommendations for optimal dietary protein intake in older people: A position paper from the PROT-AGE study group. J Am Med Dir Assoc 14 (8):542-559. https://doi.org/10.1016/j.jamda.2013.05.021
10. Willett W, Rockstrom J, Loken B, Springmann M, Lang T, Vermeulen S et al (2019) Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems. Lancet 393 (10170):447-492. https://doi.org/10.1016/s0140-6736(18)31788-4
11. Aiking H, de Boer J (2018) The next protein transition. Trends Food Sci Tech. https://doi.org/10.1016/j.tifs.2018.07.008
12. Tilman D, Clark M (2014) Global diets link environmental sustainability and human health. Nature 515:518. https://doi.org/10.1038/nature13959
13. Clune S, Crossin E, Verghese K (2017) Systematic review of greenhouse gas emissions for different fresh food categories. J Clean Prod 140:766-783. https://doi.org/10.1016/j.jclepro.2016.04.082
14. Davis KF, Gephart JA, Emery KA, Leach AM, Galloway JN, D'Odorico P (2016) Meeting future food demand with current agricultural resources. Global Environ Chang 39:125-132. https://doi.org/10.1016/j.gloenvcha.2016.05.004
15. Halkjær J, Olsen A, Bjerregaard LJ, Deharveng G, Tjønneland A, Welch AA et al (2009) Intake of total, animal and plant proteins, and their food sources in 10 countries in the European Prospective Investigation into Cancer and Nutrition. Eur J Clin Nutr 63:S16. https://doi.org/10.1038/ejcn.2009.73

16. Harwatt H (2019) Including animal to plant protein shifts in climate change mitigation policy: a proposed three-step strategy. Clim Policy 19 (5):533-541. https://doi.org/10.1080/14693062.2018.1528965
17. World Economic Forum (WEF) (2019) Meat: the future series: Alternative proteins. Prepared by the Oxford Martin School, Oxford University for the World Economic Forum's Meat: the Future dialogue series, Cologny/Geneva, Switzerland.
18. Parodi A, Leip A, De Boer IJM, Slegers PM, Ziegler F, Temme EHM et al (2018) The potential of future foods for sustainable and healthy diets. Nat Sustain 1 (12):782-789. https://doi.org/10.1038/s41893-018-0189-7
19. Kumar P, Chatli MK, Mehta N, Singh P, Malav OP, Verma AK (2017) Meat analogues: Health promising sustainable meat substitutes. Crit Rev Food Sci Nutr 57 (5):923-932. https://doi.org/10.1080/10408398.2014.939739
20. Seves M, Verkaik-Kloosterman J, Temme L, Van Raaij J (2015) Protein quality and food safety aspects of new protein source and of their product applications (report in Dutch). Rijksinstituut voor Volksgezondheid en Milieu (RIVM), Bilthoven, The Netherlands.
21. Clément T, Joya R, Bresson C, Clément C (2018) Market developments and policy evaluation aspects of the plant protein sector in the EU. Agrosynergie EEIG for the European Commission,, Brussels, Belgium.
22. Ritala A, Häkkinen ST, Toivari M, Wiebe MG (2017) Single Cell Protein-State-of-the-Art, Industrial Landscape and Patents 2001-2016. Front Microbiol 8:2009-2009. https://doi.org/10.3389/fmicb.2017.02009
23. Mancini S, Moruzzo R, Riccioli F, Paci G (2019) European consumers' readiness to adopt insects as food. A review. Food Res Int 122:661-678. https://doi.org/10.1016/j.foodres.2019.01.041
24. Stephens N, Di Silvio L, Dunsford I, Ellis M, Glencross A, Sexton A (2018) Bringing cultured meat to market: Technical, socio-political, and regulatory challenges in cellular agriculture. Trends Food Sci Tech 78:155-166. https://doi.org/10.1016/j.tifs.2018.04.010
25. Hartmann C, Siegrist M (2017) Consumer perception and behaviour regarding sustainable protein consumption: A systematic review. Trends Food Sci Tech 61:11-25. https://doi.org/10.1016/j.tifs.2016.12.006
26. Van Loo EJ, Hoefkens C, Verbeke W (2017) Healthy, sustainable and plant-based eating: Perceived (mis)match and involvement-based consumer segments as targets for future policy. Food Policy 69:46-57. https://doi.org/10.1016/j.foodpol.2017.03.001
27. Schösler H, de Boer J, Boersema JJ (2012) Can we cut out the meat of the dish? Constructing consumer-oriented pathways towards meat substitution. Appetite 58 (1):39-47. https://doi.org/10.1016/j.appet.2011.09.009
28. Vanhonacker F, Van Loo EJ, Gellynck X, Verbeke W (2013) Flemish consumer attitudes towards more sustainable food choices. Appetite 62:7-16. https://doi.org/10.1016/j.appet.2012.11.003
29. Hoefkens C, Verbeke W, Van Camp J (2011) European consumers' perceived importance of qualifying and disqualifying nutrients in food choices. Food Qual Prefer 22 (6):550-558. https://doi.org/10.1016/j.foodqual.2011.03.002
30. Latvala T, Niva M, Mäkelä J, Pouta E, Heikkilä J, Kotro J et al (2012) Diversifying meat consumption patterns: Consumers' self-reported past behaviour and intentions for change. Meat Sci 92 (1):71-77. https://doi.org/10.1016/j.meatsci.2012.04.014
31. Weller KE, Greene GW, Redding CA, Paiva AL, Lofgren I, Nash JT et al (2014) Development and validation of green eating behaviors, stage of change, decisional balance, and self-efficacy scales in college students. J Nutr Educ Behav 46 (5):324-333. https://doi.org/10.1016/j.jneb.2014.01.002

32. de Boer J, Schösler H, Aiking H (2014) “Meatless days” or “less but better”? Exploring strategies to adapt Western meat consumption to health and sustainability challenges. Appetite 76:120-128. https://doi.org/10.1016/j.appet.2014.02.002
33. Verain MCD, Dagevos H, Antonides G (2015) Sustainable food consumption. Product choice or curtailment? Appetite 91:375-384. https://doi.org/10.1016/j.appet.2015.04.055
34. Hung Y, Wijnhoven HAH, Visser M, Verbeke W (2019) Appetite and protein intake strata of older adults in the European Union: Socio-demographic and health characteristics, diet-related and physical activity behaviours. Nutrients 11 (4). https://doi.org/10.3390/nu11040777
35. den Uijl LC, Jager G, de Graaf C, Waddell J, Kremer S (2014) It is not just a meal, it is an emotional experience - a segmentation of older persons based on the emotions that they associate with mealtimes. Appetite 83:287-296. https://doi.org/10.1016/j.appet.2014.09.002
36. Wardle J, Guthrie CA, Sanderson S, Rapoport L (2001) Development of the children's eating behaviour questionnaire. J Child Psychol Psychiatry 42 (7):963-970. https://doi.org/10.1111/1469-7610.00792
37. Steptoe A, Pollard TM, Wardle J (1995) Development of a measure of the motives underlying the selection of food: the food choice questionnaire. Appetite 25 (3):267-284. https://doi.org/10.1006/appe.1995.0061
38. Januszewska R, Pieniak Z, Verbeke W (2011) Food choice questionnaire revisited in four countries. Does it still measure the same? Appetite 57 (1):94-98. https://doi.org/10.1016/j.appet.2011.03.014
39. Hair JF, Black B, Babin B, Anderson RE (2014) Multivariate data analysis: Pearson new international edition. vol 8, 7th edn. Pearson Education Limited, Essex
40. Rockström J, Steffen W, Noone K, Persson Å, Chapin Iii FS, Lambin EF et al (2009) A safe operating space for humanity. Nature 461:472. https://doi.org/10.1038/461472a
41. Verbeke W (2015) Profiling consumers who are ready to adopt insects as a meat substitute in a Western society. Food Qual Prefer 39:147-155. https://doi.org/10.1016/j.foodqual.2014.07.008
42. Verbeke W, Marcu A, Rutsaert P, Gaspar R, Seibt B, Fletcher D et al (2015) 'Would you eat cultured meat?': Consumers' reactions and attitude formation in Belgium, Portugal and the United Kingdom. Meat Sci 102:49-58. https://doi.org/10.1016/j.meatsci.2014.11.013
43. Hoek AC, Luning PA, Weijzen P, Engels W, Kok FJ, de Graaf C (2011) Replacement of meat by meat substitutes. A survey on person- and product-related factors in consumer acceptance. Appetite 56 (3):662-673. https://doi.org/10.1016/j.appet.2011.02.001
44. Holm L, Mohl M (2000) The role of meat in everyday food culture: an analysis of an interview study in Copenhagen. Appetite 34 (3):277-283. https://doi.org/10.1006/appe.2000.0324
45. Macdiarmid JI, Douglas F, Campbell J (2016) Eating like there's no tomorrow: Public awareness of the environmental impact of food and reluctance to eat less meat as part of a sustainable diet. Appetite 96:487-493. https://doi.org/10.1016/j.appet.2015.10.011
46. Verbeke W, Sans P, Van Loo EJ (2015) Challenges and prospects for consumer acceptance of cultured meat. J Integr Agric 14 (2):285-294. https://doi.org/10.1016/S2095-3119(14)60884-4
47. Elzerman JE, Hoek AC, van Boekel MAJS, Luning PA (2011) Consumer acceptance and appropriateness of meat substitutes in a meal context. Food Qual Prefer 22 (3):233-240. https://doi.org/10.1016/j.foodqual.2010.10.006

48. Smith AD, Herle M, Fildes A, Cooke L, Steinsbekk S, Llewellyn CH (2017) Food fussiness and food neophobia share a common etiology in early childhood. J Child Psychol Psychiatry 58 (2):189-196. https://doi.org/10.1111/jcpp.12647
49. Siegrist M, Hartmann C, Keller C (2013) Antecedents of food neophobia and its association with eating behavior and food choices. Food Qual Prefer 30 (2):293-298. https://doi.org/10.1016/j.foodqual.2013.06.013
50. Soucier VD, Doma KM, Farrell EL, Leith-Bailey ER, Duncan AM (2019) An examination of food neophobia in older adults. Food Qual Prefer 72:143-146. https://doi.org/10.1016/j.foodqual.2018.10.010
51. Hartmann C, Shi J, Giusto A, Siegrist M (2015) The psychology of eating insects: A cross-cultural comparison between Germany and China. Food Qual Prefer 44:148-156. https://doi.org/10.1016/j.foodqual.2015.04.013
52. Hoek AC, Luning PA, Stafleu A, de Graaf C (2004) Food-related lifestyle and health attitudes of Dutch vegetarians, non-vegetarian consumers of meat substitutes, and meat consumers. Appetite 42 (3):265-272. https://doi.org/10.1016/j.appet.2003.12.003
53. Mäkiniemi J-P, Vainio A (2014) Barriers to climate-friendly food choices among young adults in Finland. Appetite 74:12-19. https://doi.org/10.1016/j.appet.2013.11.016
54. Bhat ZF, Kumar S, Fayaz H (2015) In vitro meat production: Challenges and benefits over conventional meat production. J Integr Agric 14 (2):241-248. https://doi.org/10.1016/S2095-3119(14)60887-X
55. de Boer J, Schösler H, Aiking H (2017) Towards a reduced meat diet: Mindset and motivation of young vegetarians, low, medium and high meat-eaters. Appetite 113:387-397. https://doi.org/10.1016/j.appet.2017.03.007
56. Tobler C, Visschers VHM, Siegrist M (2011) Eating green. Consumers' willingness to adopt ecological food consumption behaviors. Appetite 57 (3):674-682. https://doi.org/10.1016/j.appet.2011.08.010
57. Vermeir I, Verbeke W (2006) Sustainable food consumption: Exploring the consumer "attitude – behavioral intention" gap. J Agric Environ Ethics 19 (2):169-194. https://doi.org/10.1007/s10806-005-5485-3
58. Kamphuis CB, de Bekker-Grob EW, van Lenthe FJ (2015) Factors affecting food choices of older adults from high and low socioeconomic groups: a discrete choice experiment. Am J Clin Nutr 101 (4):768-774. https://doi.org/10.3945/ajcn.114.096776
59. Niva M, Mäkelä J, Kahma N, Kjærnes U (2014) Eating sustainably? Practices and background factors of ecological food consumption in four Nordic countries. J Consum Policy 37 (4):465-484. https://doi.org/10.1007/s10603-014-9270-4
60. de Boer J, Aiking H (2011) On the merits of plant-based proteins for global food security: Marrying macro and micro perspectives. Ecol Econ 70 (7):1259-1265. https://doi.org/10.1016/j.ecolecon.2011.03.001
61. Ruby MB (2012) Vegetarianism. A blossoming field of study. Appetite 58 (1):141-150. https://doi.org/10.1016/j.appet.2011.09.019
62. Rayner G, Barling D, Lang T (2008) Sustainable food systems in Europe: Policies, realities and futures. J Hunger Environ Nutr 3 (2-3):145-168. https://doi.org/10.1080/19320240802243209
63. Hoek AC, Elzerman JE, Hageman R, Kok FJ, Luning PA, Graaf Cd (2013) Are meat substitutes liked better over time? A repeated in-home use test with meat substitutes or meat in meals. Food Qual Prefer 28 (1):253-263. https://doi.org/10.1016/j.foodqual.2012.07.002

Appendix A

Table A1. Correlation matrix of determinants in ordinal regression analyses for acceptance to consume sustainable protein sources in older adults in five EU countries [1].

Independent Variables	×1	×2	×3	×4	×5	×6	×7	×8	×9	×10
×1: Gender [2]	–									
x2: Age [3]	−0.043	–								
×3: Education [4]	−0.079 **	0.03	–							
×4: Health [5]	0.158 **	−0.053 *	0.047 *	–						
×5: Convenience [5]	0.109 **	−0.031	0.008	0.338 **	–					
×6: Sensory [5]	0.185 **	−0.073 **	−0.036	0.462 **	0.295 **	–				
×7: Price [5]	0.057 *	−0.078 **	−0.105 **	0.361 **	0.446 **	0.289 **	–			
×8: Sustainability [5]	0.202 **	−0.081 **	0.051 *	0.655 **	0.374 **	0.423 **	0.279 **	–		
×9: Food fussiness	−0.059 *	0.005	−0.066 **	−0.118 **	0.199 **	−0.088 **	0.104 **	−0.019	–	
×10: Green eating behavior	0.130 **	−0.058 *	0.134 **	0.247 **	−0.028	0.141 **	−0.070 **	0.429 **	−0.177 **	–

[1] Items with asterisk are statistically significant, * p-value < 0.05, ** p-value < 0.01. [2] Gender was coded 0 = male, 1 = female. [3] Age was coded 0 = below 70 years, 1 = 70 years and older. [4] Education was coded 0 = No higher education, 1 = Higher education. [5] Food choice motive.

Table A2. Factor loadings from principal axis factor analysis in of 1825 adults aged 65 years and older from five EU countries.

Factor	Health [1]	Convenience [1]	Sensory [1]	Price [1]	Sustainability [1]	Food Fussiness	Green Eating Behavior
It is important to me that the food I eat on a typical day…							
… contains a lot of vitamins	0.74						
… keeps me healthy	0.79						
… is nutritious	0.76						
… is high in protein	0.68						
… is good for my skin, teeth, hair, nails, etc.	0.73						
… is high in fiber and roughage	0.70						
… is easy to prepare		0.82					
… can be cooked very simply		0.91					
… takes no time to prepare		0.77					
… can be bought in shops close to where I live		0.53					
… is easily available in shops and supermarkets		0.43					
… smells nice			0.72				
… looks nice			0.82				
… has a pleasant texture			0.79				
… has no small pieces that go between my teeth [2]			–				
… is easy to chew and swallow [2]			–				
… tastes good			0.59				
… is not expensive				0.80			
… is cheap				0.78			
… is good value for money				0.56			
… is sustainable					0.35		
… is environmentally-friendly					0.71		
… is organic					0.70		
To what extent do you agree or disagree with the statement…							
I enjoy tasting new foods						0.73	
I enjoy a wide variety of foods						0.63	
I am interested in tasting food that I have not tasted before						0.76	
I refuse new foods at first						0.65	
I decide that I don't like food, even without tasting it						0.61	
I am difficult to please with meals						0.46	
I refuse changing my daily dietary pattern						0.48	
How often do you consume…							
Locally grown or produced foods							0.681
Foods purchased directly from farmer's markets							0.636
Organic foods							0.756
Foods with environmental sustainability label							0.836
Foods with ethical sustainability label							0.827
N	1825	1825	1825	1825	1825	1825	1808
Mean of construct	3.6	3.1	3.6	3.2	3.1	2.3	2.8
Standard deviation of construct	0.7	0.8	0.7	0.8	0.9	0.6	0.8
Cronbach's α	0.90	0.85	0.86	0.81	0.82	0.81	0.81

[1]Food choice motive; [2] Items were removed as they did not have a significant loading on any factor.

Table A3. Sociodemographic characteristics of the sample who responded 'I don't know' (DK) versus the sample who responded in the ordered scale (R) (very unacceptable (=1) to very acceptable (=5)) when asked to what extent they eat foods containing a sustainable protein source [1].

Sociodemographic Characteristic	Plant (n = 1518)			Insect (n = 1483)			Single Cell (n = 1426)			In Vitro (n = 1435)		
	DK	R	*p*-value	DK	R	*p*-value	DK	R	*p*-value	DK	R	*p*-value
n =	84	1741		126	1699		195	1630		199	1626	
Gender			0.455			0.779			0.208			0.962
Male	46.4	50.6	0.177	49.2	50.2	0.051	46.2	50.9	0.065	50.3	50.4	
Female	53.6	49.4	0.009	50.8	49.5	0.052	53.8	49.1	0.013	49.7	49.6	
Age (y)			<0.001			0.063			0.01			0.42
Below 70	48.8	56.3	0.32	47.6	56.6	0.059	49.7	56.7	0.818	53.3	56.3	
70+	51.2	43.7	0.508	52.4	43.4	0.905	50.3	43.3	0.346	46.7	43.7	
Country			0.74			0.729			0.477			0.192
United Kingdom	27.4	19.6	0.585	23	19.8	0.575	19.5	20.1	0.452	19.6	20	
The Netherlands	13.1	20.4	0.518	11.1	20.7	0.876	16.4	20.5	0.061	17.1	20.4	
Poland	8.3	20.5		19.8	20		14.9	20.6		16.1	20.4	
Spain	23.8	19.8	0.455	19	20.1	0.779	20.5	19.9	0.208	22.1	19.7	
Finland	27.4	19.6	0.177	27	19.5	0.051	28.7	19	0.065	25.1	19.4	
Educational attainment			0.009			0.052			0.013			0.082
Below tertiary level	78.6	58.7	<0.001	67.5	59	0.063	68.2	41.4	0.01	65.3	58.9	
Tertiary level or above	21.4	41.3	0.32	32.5	41	0.059	31.8	58.6	0.818	34.7	41.1	
Perceived financial situation	(n = 78)	(n = 1713)	0.508	(n = 122)	(n = 1669)	0.905	(n = 190)	(n = 1601)	0.346	(n = 191)	(n = 1600)	0.595
Have some or severe difficulties	12.8	16.6	0.74	13.1	16.7	0.729	17.9	16.2	0.477	14.1	16.7	
Get by alright	46.2	37.9	0.585	48.4	37.6	0.575	36.8	38.5	0.452	40.8	38	
Manage quite or very well	41	45.5	0.518	38.5	45.8	0.876	45.3	45.3	0.061	45	45.3	
Living condition												0.295
Lives alone	27.4	30.8	0.455	30.2	30.7	0.779	27.8	31	0.208	26.6	31.1	
Lives with others	72.6	69.2	0.177	69.8	69.3	0.051	72.3	69	0.065	73.4	68.9	
Responsibility for food purchases			0.009			0.052			0.013			0.983
Does most of food shopping	66.7	70.5	<0.001	67.5	70.5	0.063	66.7	70.7	0.01	69.8	70.4	
Shared responsibility	21.4	19.5	0.32	22.2	19.4	0.059	22.6	19.3	0.818	20.1	19.6	
Does not shop for food	11.9	10	0.508	10.3	10.1	0.905	10.8	10	0.346	10.1	10.1	
Number of health Problems [3],	(n = 76)	(n = 1672)	0.74	(n = 116)	(n = 1632)	0.729	(n = 183)	(n = 1565)	0.477	(n =1 88)	(n = 1560)	0.632
Dietary regime [4]	2.4 ± 2.2	2.5 ± 2.1	0.585	2.4 ± 2.1	2.5 ± 2.1	0.575	2.4 ± 2.1	2.5 ± 2.1	0.452	2.5 ± 2.1	2.5 ± 2.1	
Follows meat-limiting diet			0.518			0.876			0.061			0.195
Does not Follow Meat-Limiting	15.5	13		12.7	13.2		17.4	12.6		16.1	12.8	

[1] Presented as percent of total unless otherwise indicated. [2] Result from a test for significant difference between the two groups, using chi-square test or Fisher's exact test for categorical variables or a t-test for continuous variables. [3] Sum of number of reported health problems out of 17 asked health problems. [4] Meat-limiting diet includes those who reported to follow a vegetarian or vegan diet or reported to eat meat one time per week or less in the past four weeks.

CHAPTER 4

Understanding meat consumption in later life: A segmentation of older consumers in the EU

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Abstract

Protein intake is important for the maintenance of health, independence, and quality of life especially for older adults, yet the expanding older population is at risk of not consuming adequate levels. Notwithstanding its importance in terms of health, dietary protein choice has major ramifications for the state of the environment and for climate change, with meat holding the most weight in the environmental impact of diets. To support older consumers in making environmentally sustainable dietary protein choices, this study aims to gain deeper understanding of older consumers' meat consumption behavior by profiling older consumer segments on the basis of their meat consumption and liking. Results were obtained through a 2019-survey among 2,500 community-dwelling older adults aged 65+ years in Finland, Poland, Spain, the Netherlands, and the United Kingdom. Three segments of older consumers were identified by means of a two-step cluster analysis: heavy meat consumers, medium meat consumers, and light meat consumers. The segments differed significantly in several socio-demographics and background characteristics, appetite, protein intake, attitudes towards meat and plant-based 'meat' substitutes, and liking of protein sources other than meat. Health and sustainability food choice motives were important determinants for being classified as a medium or light meat consumer compared to a heavy meat consumer whereas food fussiness, sensory appeal, and familiarity were important determinants for being classified as a heavy meat consumer compared to a light meat consumer. Understanding older consumers' meat consumption behavior has important implications for designing dietary strategies to meet older consumers' protein needs in an environmentally sustainable way.

1. Introduction

It is estimated that between 2020 and 2050 the older adult population (aged 65+ y) will increase by 42.3% while the working-age population (aged 15-64 y) will decrease by 9.5% in the European Union (EU) [1]. While this demographic shift is expected to lead to new challenges with regard to health care, long-term care, and social expenditures, the challenges can be partly moderated by maintaining health and well-being in the growing older population [2]. Currently, protein intake of at least 0.8 g/kg body weight/day is recommended for adults, including adults aged 65 years and older [3]. Yet, short-term metabolic studies show that older adults require a higher protein intake compared to young adults to maximally stimulate muscle protein synthesis [4-6]. Further, observational studies show that higher protein intake is associated with less decline in muscle or lean mass and in performance-based physical function in older adults [7-9], providing benefits for overall health, independence, and quality of life in old age [10,11]. Consequently, expert groups suggest increasing protein intake recommendations to 1.0 to 1.2 g/kg body weight/day for older adults aged 65+ years [12,13] and several nutrition societies have already revised their recommendations accordingly [14]. However, a substantial number of older adults have a difficult time meeting the currently recommended daily protein intake [15,16], warranting more research into effective strategies to increase protein intake in this growing older population.

Notwithstanding its importance in terms of health, dietary protein choice has major implications for environmental sustainability. Increasing protein intake is likely to result in net increases in the environmental impact of the diet, especially if consumption of meat is favored [17,18]. Animal protein accounts for approximately 60% of total protein consumed in the EU, with the largest contribution of protein being derived from meat [19]. Meat production, and animal protein production in general, is resource intensive and on average produces more greenhouse gas emissions and has a larger impact on land use, water use, and biodiversity loss compared to plant protein production [20,21]. It has been previously shown that in addition to total energy intake, total meat and the proportion of ruminant meat (e.g. beef, veal, lamb) hold the most weight in the environmental impact of EU diets [22]. While meat and other animal protein sources such as dairy, fish, and eggs are important sources of high quality protein and essential nutrients [23], the high levels of meat and animal protein consumed in the EU are considered not only unsustainable but also unhealthy [24]. On average Europeans eat 36% more meat compared to the amount recommended in their respective food-based dietary guidelines, and 49% more than the amount recommended by the EAT-Lancet Commission's planetary health diet [25]. Therefore, to minimize the environmental costs of fulfilling the high protein requirement of the expanding older population, it is imperative to design dietary strategies that consider the environmental impacts of protein choices and promote pro-environmental protein consumption among older consumers.

According to de Boer, Aiking [26], two interrelated types of pro-environmental behavior that are relevant for protein consumption are 1) "using fewer natural resources" and 2) "doing things in a different way and with a reduced environmental impact". Examples include reducing the portion size of meat (type 1) and replacing meat with a plant-based protein sources like legumes and nuts (type 2). Given the unique nutritional requirements of older adults, 'doing things differently' may be more appropriate than 'using less' to achieve adequate protein intake within environmental limits. There is a broad variety of alternative, more sustainable protein sources that can replace meat, including traditional plant-based sources (e.g. legumes, nuts, seeds, whole grains), processed plant-based 'meat' substitutes which are designed to imitate meat, and novel protein sources such as insects and cultured meat. Moreover, a large majority of the general population perceive a match between a healthy and a sustainable diet and associated this more with a plant-based rather than a meat-based diet [27]. Yet, a study in the Netherlands found that older adults were more likely to prefer a smaller meat portion size rather than replacing meat by something else [28]. Another study in five EU countries found that there is low readiness among older consumers to eat novel protein sources such as insects, although their acceptance to eat plant-based sources (e.g. derived from soy or pea protein) was comparable to that of meat [29]. While past meat consumption behavior is a significant predictor of pro-environmental protein consumption [30], unraveling the intricacies of older consumers' meat consumption behavior provides important information for the promotion of alternative, more sustainable protein sources.

Food consumption behavior is a complex issue influenced by many factors ranging from biological and psychological to environmental and lifestyle factors [31,32]. Multiple aspects may influence meat consumption behavior, including attitudes, values, subjective norms, culinary skills, habit, and tradition [30,33,34]. Consumers' positive perception of meat (e.g. taste, pleasure, nutritious, familiarity) and disbelief of meat's impact on the environment have been found to hinder attitudinal change [33]. In addition, tradition, social norms, and lack of culinary skills have been found to impede willingness to change meat consumption behaviors [35]. However, important individual differences exist in terms of habitual meat consumption and willingness to reduce meat consumption. Dagevos, Voordouw [36] reported that different modes of "flexitarianism", or meat reduction, exist, from "light flexitarians" who abstain from eating meat once or twice per week to "heavy flexitarians" who eat meat only once or twice per week. Ethical concerns, health motives, and personal norms were important drivers to being committed to change meat consumption behavior [36]. Similarly, Vainio, Niva, Jallinoja, Latvala [37] found that food choice motives play an important role in explaining differences in meat consumption behavior, with health being a facilitating motive to replace meat with plant-based protein sources and convenience and price being inhibitory factors.

Considering the heterogeneity of older food consumers, a targeted approach to increase protein intake in an environmental-friendly manner would be more effective than a "one-size-fits-all" approach [38,39]. Identifying and comparing different groups or segments of consumers wherein individuals with a similar profile are clustered can help tailor dietary strategies to older consumer segments with specific needs and preferences [40]. This current study aims to analyze meat consumption decision-making and behavior in community-dwelling older adults in the EU by conducting a segmentation analysis. To gain an understanding of the consumers in each segment, the segments are profiled in terms of socio-demographics and background characteristics, appetite, protein intake, attitudes towards meat and plant-based 'meat' substitutes, and liking of protein sources other than meat. Further, this study explores whether psychographic characteristics including food choice motives, food fussiness, and food sustainability knowledge can explain the differences in segment membership.

1. Material and methods

1.1. Data collection

This study makes use of cross-sectional data from 2,500 community-dwelling adults aged 65 years and older from an online pan-EU survey conducted in October 2019. The survey was administered in Finland, Poland, Spain, the Netherlands, and the United Kingdom (UK) by a professional market research agency. It was developed in English and translated into the respective national languages. Respondents meeting the criteria of being 65 years or older and living independently were recruited by the agency using probabilistic sampling from an online access proprietary panel. Sampling quotas were applied on and regions proportional to the distribution within the national population. The target for gender (i.e. 50% women and 50% men) was not fully met but the distribution was close to evenly distributed (Table 1). All participants were asked to provide written informed consent before taking part in the study. Ethical approval for the study was granted by the Belgian Ethics Committee of Ghent University Hospital in August 2019 (Reference No. 2019/0933).

1.2. Questionnaire and scales

The survey was conducted within the PROMISS (PRevention Of Malnutrition In Senior Subjects in the EU) project, a five-year Horizon 2020 project funded by the European Commission focused on advancing healthy aging among seniors in the EU. It began with a brief overview of the PROMISS project and an informed consent, which was followed by a screening for gender, age, region, and current living situation. The questionnaire focused on dietary and physical activity habits, attitudes and preferences, and knowledge related to protein consumption. Individual items were rotated within questions to avoid order and response bias. Questions and scales used in this study are described below.

1.3. Dietary habits

Consumption frequency of ten protein-rich food groups, including cooked meat, was assessed with a short, modified version of a validated food frequency questionnaire [41]. The measurement included questions asking the number of days one consumed the ten different food groups with a reference period of four weeks. Examples of cooked meat were provided and adapted to the context of each country (e.g. beef steak, pork chop, hamburger meat, sausages, and chicken for the UK). In addition to consumption frequency, the average amount of meat consumed with a warm meal on a meat-eating day was assessed with five photos of a plate with different portion sizes of cooked meat.

Cooked meat consumption was calculated by multiplying the frequency of consumption per day with the average portion size consumed.

The probability of low protein intake was assessed with the Protein Screener 55+ [42]. Low protein intake was defined as having a 0.3 or higher probability of protein intake less than 1.0 g protein per kilogram of adjusted body weight per day (g/kg adjusted BW/d) based on recalibrated models [15,42].

Further, respondents were asked to report whether or not they were following any dietary regime, with the following options and definitions provided: flexitarian diet (tries to limit meat intake), pesco-vegetarian diet (does not eat meat but eats fish and/or seafood), ovo- and/or lacto-vegetarian diet (does not eat meat but eats eggs and/or dairy products), vegan diet (does not eat meat, fish, and any other animal products, only eats plant-based foods), and other diet (not defined further). Respondents who chose 'other diet' were able to report the other diet they were following. Open responses were translated to English and then recoded, so that answers that are equivalent to a meat-limiting diet were recoded to one of the response options (e.g. flexitarian).

1.3.1. Appetite

Appetite was assessed using the validated simplified nutritional appetite questionnaire (SNAQ) consisting of four items [43-45]. The total SNAQ score is the sum across the four items, ranging from 4 to 20, and was dichotomized such that a respondent with SNAQ$\leq$14 was classified as having a 'poor appetite' and SNAQ>14 as having a 'good appetite' [45].

1.3.2. Liking of protein sources

Respondents were asked to what extent they like four different meat types (i.e. beef or veal, lamb, pork, poultry), other animal protein sources, and various plant protein sources. Respondents rated these items on a 5-point Likert scale ranging from 1=Dislike extremely to 5=Like extremely, with a sixth option 6=I never tried this food. To gauge how much respondents like meat, liking scores for the four meat products were averaged to obtain a mean meat liking score, ranging from 1=Extremely dislikes meat to 5=Extremely likes meat. A meat liking score was calculated for respondents who answered on the Likert scale for at least one meat product, while no meat liking score was calculated for respondents who reported to have never tried any of the four meat products (n=22).

Next, to get more insight into attitudes towards meat and plant-based 'meat' substitutes, reasons for liking or disliking meat and plant-based 'meat' substitutes were assessed. If respondents indicated that they like at least one of the meat products and/or plant-based 'meat' substitutes, or if they were neutral (neither like/dislike), respondents were then prompted to report their level of agreement towards statements about different reasons why one may like meat and/or plant-based 'meat' substitutes. Similarly, if respondents indicated that they dislike at least one of the meat products and/or plant-based 'meat' substitutes, respondents were then prompted to report their level of agreement towards statements about different reasons why one may dislike meat and/or plant-based 'meat' substitutes. Respondents answered on a five-point scale, ranging from 1=Strongly disagree to 5=Strongly agree.

1.3.3. Food choice motives

A single-item scale for six factors of the original food choice questionnaire developed by Steptoe, Pollard, Wardle [46] was used [47]. The six food choice motives assessed include health, sustainability, price, sensory appeal, convenience, and familiarity. Respondents indicated the extent to which these motives are important when choosing a food eaten on a typical day on a five-point scale, ranging from 1=Not at all important to 5=Very important.

1.3.4. Food fussiness

A food fussiness scale was adapted from den Uijl, Jager, de Graaf, Waddell, Kremer [39] and Wardle, Guthrie, Sanderson, Rapoport [48] to assess the degree to which one is selective about consuming both known and unknown foods. The food fussiness scale consisted of seven items, e.g. "I decide that I don't like food, even without tasting it", for which respondents could indicate their level of agreement on a five-point scale ranging from 1=Strongly disagree to 5=Strongly agree. An exploratory factor analysis using principal components with varimax rotation confirmed that the items could be explained by a single factor with a reliability of α=0.795. The final food fussiness score is an average of the seven items, ranging from 1=Not a fussy eater to 5=A very fussy eater.

1.3.5. Food sustainability knowledge

Food sustainability knowledge was assessed by three true or false questions developed by the researchers: 1) A diet high in animal-based foods contributes more to global warming than a diet high in plant-based foods (true); 2) Eating foods with a high carbon footprint is bad for the environment (true); and 3) Eating beef is better for the environment than eating chicken (false). Respondents reported either 'true', 'false', or 'I don't know'. The correct answer was coded as 1, the incorrect answer and 'I don't know' were coded as 0, and a composite score was created, ranging from 0=Not-informed, no answers correct to 3=Well-informed, all answers correct.

1.3.6. Socio-demographic and background characteristics

Gender, age, education level, living situation, household (HH) financial situation, being the main HH grocery shopper, making own decisions of what to eat, ability to prepare own warm meal, and health status were assessed. Education level was defined by two categories based on respondents' highest level of education obtained: below Bachelor level (no education, primary education, lower secondary education or higher secondary education), and Bachelor level and above (bachelor level, master level or PhD). Living situation of older adults was defined by whether one lives alone or not, which was ascertained by the number of persons living in the HH. Respondents were asked to describe their HH financial situation by selecting one of the following: manages very well, manages quite well, gets by alright, has some financial difficulties, or has severe financial difficulties. Health status was assessed by asking respondents if they experienced some out of a list of 17 different possible health problems. Of the 17 health problems asked, four were used to assess oral health status, namely self-reported pain in the mouth, teeth, or gums, dry mouth, difficulty swallowing, and difficulty chewing. Oral health problems was dichotomized to 0=no oral health problems, 1=presence of one or more oral health problems.

1.4. Data analysis

All analyses were performed with SPSS version 26.0 (IBM Corp. Released 2019. IBM SPSS Statistics for Windows, Version 26.0, Armonk, NY: IBM Corp.). Given the large sample size, statistical significance was considered at the α level of 0.01.

1.4.1. Segmentation

Cooked meat consumption and meat liking score were used to classify 2,478 older adults into consumer segments. The analytical sample excluded 22 respondents from the total sample of 2,500 respondents because “I never try this food” was indicated for each of the meat products. Segments of older adults based on cooked meat consumption and meat liking were identified using a Two-Step cluster analysis. This approach combines an agglomerative hierarchical clustering procedure and a non-hierarchal (k-means) approach. The hierarchical procedure is used as a basis for determining the appropriate number of clusters, and the non-hierarchical procedure “fine-tunes” the results and validates the final cluster solution [49]. As the final solution may depend on the order of cases (i.e. respondents) [50], the cases were randomly ordered 10 times and a cluster analysis was run on each of the resulting datasets. The final solution was chosen based on a combination of the lowest Bayesian Information Criterion (BIC) in the 10 cluster analyses and interpretability. There was no issue of dependence between the variables in the cluster model (r=0.249), but both variables deviated from a normal distribution (Shapiro-Wilk p-value<0.001). Despite this violation, no transformation was applied to the variables as the Two-Step procedure has been shown to be fairly robust to violations of the major assumptions [51].

1.4.2. Profiling the segments

The segments were profiled based on socio-demographic and background characteristics, appetite, protein intake, liking of protein sources, and attitudes towards meat and plant-based ‘meat’ substitutes.

The role of the different variables in identifying the clusters was investigated with the use of Chi-square tests for categorical profiling variables and Kruskal-Wallis one-way analyses of variance for continuous profiling variables. To prevent making a Type I error in the null hypothesis testing due to the large sample size, the level of 0.01 is used as the threshold for statistical significance, and the effect size, i.e. Cramer’s *V* (*V*) for Chi-square and partial eta-squared (η_p^2) for Kruskal-Wallis one-way test, is reported. Effect sizes measure the proportion of the variability in the older consumer segments that is accounted for by variation in the profiling variable, reflecting the strength of association between the variables [52]. Effect size was considered small when $0.1 \leq V < 0.3$ and $0.01 \leq \eta_p^2 < 0.06$, medium when $0.3 \leq V < 0.5$ and $0.06 \leq \eta_p^2 < 0.13$, and large when $V \geq 0.5$ and $\eta_p^2 \geq 0.14$ [53-55].

1.4.3. Multivariate analysis

In a final step, we analyzed psychographic characteristics that can explain the differences between the segments. To substantiate differences between the segments we considered conducting discriminant analysis, however assumptions of multivariate normal distributions and homogeneity of covariance matrices were not satisfied. Multinomial logistic regression was therefore the chosen method. One of the resulting segments (the so-called "heavy meat consumer" segment, see results) was assigned as the reference group relative to which the other segments were compared. The explanatory variables included the following continuous variables: food choice motives (i.e. health, sustainability, price, sensory appeal, convenience, and familiarity), food fussiness, and food sustainability knowledge. Multicollinearity was checked and found not to be an issue (Appendix Table A.1).

2. Results

2.1. Identification of segments based on meat consumption and liking

Three segments based on meat consumption and liking were established as the optimal solution from the cluster analysis. The cluster centroids of the segmentation variables are shown in Table 1. The first segment represents 27% of the sample and is characterized by a relatively high consumption of cooked meat and a moderate to high meat liking score. Therefore this segment was labeled as "heavy meat consumers". The second segment is the largest, representing about half of the sample (52%). Respondents in this segment have the highest meat liking score. By contrast, they reported a lower cooked meat consumption relative to that of heavy meat consumers. Therefore this segment was labeled as "medium meat consumers". The third segment is the smallest, containing 21% of the sample. Respondents in this segment reported a significantly lower relative consumption of cooked meat and a lower meat liking score. Therefore this segment was labeled as "light meat consumers".

Table 1 Segmentation variables and socio-demographic and background characteristics in total sample of adults aged 65 years and older from five EU countries, and differences between the older consumer segments

	Total sample	Older consumer segments			
		Heavy meat consumer	Medium meat consumer	Light meat consumer	*p*-value (V or η_p^2)
n (%)	**2,478 (100)**	**663 (26.8)**	**1,290 (52.0)**	**525 (21.2)**	
Segmentation variables [1]					
Cooked meat consumption (g/d) [2]	33.1 ± 27.9	71.9 ± 28.1 [a]	21.0 ± 12.5 [b]	13.6 ± 12.3 [c]	<0.001 (0.63)
Meat liking [3]	3.9 ± 0.8	4.1 ± 0.6 [b]	4.3 ± 0.4 [a]	2.9 ± 0.7 [c]	<0.001 (0.52)
Socio-demographic & background characteristics [4]					
Gender (Male)	52.2	57.2 [a]	54.8 [a]	39.6 [b]	<0.001 (0.13)
Age (<75 y)	85.4	86.3	84.3	86.9	0.292 (0.03)
Country					<0.001 (0.14)
Finland	19.9	20.5	20.2	18.1	
Poland	20.1	13.7 [b]	24.4 [a]	17.5 [b]	
Spain	20.2	20.4	20.8	18.5	
The Netherlands	20.1	26.1 [a]	13.5 [b]	29.0 [a]	
United Kingdom	19.7	19.3	21.1	17.0	
Education level					0.893 (0.01)
Below Bachelor level	62.2	62.3	61.9	63.0	
Bachelor level or higher	37.8	37.7	38.1	37.0	
Lives alone	28.5	24.7 [b]	27.2 [b]	36.4 [a]	<0.001 (0.09)
HH financial situation (n=2,435)					0.008 (0.05)
Manages well or very well	40.1	45.7 [a]	38.3 [b]	40.8 [a,b]	
Gets by alright	38.0	36.2	39.0	41.0	
Has some or severe difficulties	20.1	18.0	22.7	18.2	
Main HH grocery shopper					0.001 (0.06)
Yes	65.9	64.3 [b]	64.0 [b]	72.8 [a]	
No	7.1	6.3	7.2	7.8	
Shared responsibility	27.0	29.4 [a]	28.8 [a]	19.4 [b]	
Own food decision maker					0.003 (0.06)
Yes, always	62.5	61.4 [b]	60.0 [b]	69.9 [a]	
Yes, sometimes	31.6	32.9	33.7	25.0	
No, someone else decides	5.9	5.7	6.3	5.1	
Ability to prepare own warm meals (n=2419)					0.201 (0.04)
Yes without difficulties	88.3	88.3	89.2	86.1	
Yes with difficulties or no unless with help	11.7	11.7	10.8	13.9	
BMI (kg/m^2; mean ± sd)	27.0 + 4.3	27.1 ± 4.4	27.1 ± 4.2	26.6 ± 4.6	0.014 (<0.01)
Oral health problems (n=2,462)	26.2	27.1	25.8	26.8	0.822 (0.01)

[1] Cluster centroids for a three-cluster solution presented as mean ± standard deviation. [2] Cooked meat consumption frequency (d/wk) and average amount of meat consumed with warm meal (g/d) are provided in Appendix Figure 1 for each consumer segment. [3] Meat liking is a mean liking score of four meat sources, namely beef or veal, lamb, pork and poultry, and is measured on a 5-point scale, ranging from 1 (dislike extremely) to 5 (like extremely). [4] Presented as percent (%) unless noted otherwise. [a-c] Different superscripts indicate significantly different standardized means in each row following ANOVA post hoc Tukey test or Chi-square test at $p < 0.01$. Cramer's V (V) and partial eta-squared (η_p^2) indicates the effect size. HH: household. BMI: body mass index.

2.1.1. Socio-demographic and background characteristics

The light meat consumer segment is dominated by female gender and has a greater proportion of older adults living alone, who do most of the grocery shopping themselves, and decide what to eat for themselves compared to the other two segments (Table 1). Compared to the heavy and light meat consumers, the medium meat consumer segment contains more older adults who live in Poland and fewer older adults who live in the Netherlands, and also fewer older adults who reported that their household financial situation is managed well or very well. The segments do not differ on body mass index and presence of oral health problems.

2.1.2. Appetite and protein intake, liking and attitudes

The light meat consumer segment is accounted by more older adults with a low appetite compared to the other two segments, although the difference is trivial ($V<0.1$) (Table 2). All three segments differ significantly in the proportion of older adults with a high probability of protein intake below 1.0 g/kg adjusted BW/d (Table 2). The light meat consumer segment has the largest proportion of older adults with a high probability of low protein intake (62%) while the heavy meat consumer segment has the smallest proportion of older adults with a high probability of low protein intake (35%). The segments also differ significantly in terms of proportion of older adults following a meat-limiting diet, with the light meat consumer segment having the largest share of older adults who reported to follow a meat-limiting diet on the one end and the heavy meat consumer segment having smallest share on the other end (Table 2). In total 14% of our respondents reported to follow a flexitarian diet while 17% reported to eat cooked meat five days or more per week and 5% to eat cooked meat every day of the week. Further examination of meat consumption tendencies reveal a negative correlation between meat consumption frequency and average portion size of meat consumed (Appendix Fig. A.1).

Table 2 Appetite, protein intake, and liking of protein sources by older consumer segments

	Older consumer segments			
	Heavy meat consumer (N=663)	**Medium meat consumer (N=1,290)**	**Light meat consumer (N=525)**	***p*-value (V or η_p^2)**
Poor appetite (SNAQ≤14) [1]	27.5 [b]	32.3 [b]	39.0 [a]	<0.001 (0.09)
High probability of low protein intake [2]	34.5 [c]	53.5 [b]	61.7 [a]	<0.001 (0.20)
Dietary regime [3]				<0.001 (0.20)
Follows meat-limiting diet	8.1 [c]	15.5 [b]	29.3 [a]	
Does not follow meat-limiting diet	91.9	84.5	70.7	
Consumption [4]				
Fish (d/wk)	1.5 ± 1.4	1.4 ± 1.4	1.3 ± 1.3	0.023 (<0.01)
Dairy products excl. cheese (d/wk)	3.5 ± 2.8 [a]	2.8 ± 2.7 [b]	3.3 ± 2.8 [a]	<0.001 (0.01)
Eggs (d/wk)	2.2 ± 1.9 [a]	1.9 ± 1.7 [b]	1.9 ± 1.9 [b]	<0.001 (0.01)
Legumes (d/wk)	1.5 ± 1.8 [a]	1.1 ± 1.4 [b]	1.4 ± 1.7 [a]	0.001 (0.01)
Nuts or peanuts (d/wk)	1.7 ± 2.1	1.5 ± 2.2	1.8 ± 2.3	0.116 (<0.01)
Pasta or noodles (d/wk)	1.4 ± 1.5	1.2 ± 1.2	1.2 ± 1.3	0.019 (0.01)
Processed meat (d/wk)	3.5 ± 2.3 [a]	2.7 ± 2.1 [b]	1.8 ± 2.0 [c]	<0.001 (0.02)
Cheese (d/wk)	3.7 ± 2.5 [a]	2.0 ± 2.5 [b]	3.2 ± 2.6 [b]	<0.001 (0.01)
Plant-based 'meat' (d/wk)	0.3 ± 1.0 [c]	0.2 ± 0.6 [b]	0.5 ± 1.1 [a]	<0.001 (0.07)
Liking [5]				
Beef or veal (n=2,444)	4.3 ± 0.8 [a]	4.2 ± 0.7 [a]	3.0 ± 1.0 [b]	<0.001 (0.34)
Lamb (n=2,403)	3.8 ± 1.1 [b]	4.1 ± 0.9 [a]	2.2 ± 1.0 [c]	<0.001 (0.34)
Pork (n=2,449)	4.1 ± 0.8 [a]	4.2 ± 0.7 [a]	2.8 ± 1.1 [b]	<0.001 (0.31)
Poultry (n=2,456)	4.3 ± 0.7 [b]	4.4 ± 0.6 [a]	3.4 ± 1.2 [c]	<0.001 (0.20)
Fish or seafood (n=2,449)	4.3 ± 0.9 [b]	4.5 ± 0.8 [a]	3.9 ± 1.2 [c]	<0.001 (0.05)
Hybrid meat (n=1,990)	2.4 ± 1.1 [b]	2.6 ± 1.0 [a]	2.5 ± 1.0 [a,b]	0.008 (<0.01)
Dairy (n=2,456)	4.4 ± 0.7 [a]	4.4 ± 0.7 [a]	4.1 ± 0.9 [b]	<0.001 (0.03)
Egg (n=2,458)	4.3 ± 0.7 [a]	4.4 ± 0.6 [a]	4.1 ± 0.9 [b]	<0.001 (0.03)
Plant-based 'meat' (n=2,101)	2.3 ± 1.1 [c]	2.4 ± 1.1 [b]	2.8 ± 1.2 [a]	<0.001 (0.02)
Legumes (n=2,429)	4.1 ± 0.9	4.2 ± 0.9	4.1 ± 1.0	0.025 (0.03)
Nuts or seeds (n=2453)	4.1 ± 0.9 [b]	4.2 ± 0.9 [a]	4.1 ± 1.0 [b]	0.009 (0.01)
Grain-based products excl. bread (n=2,453)	3.8 ± 0.9 [b]	4.0 ± 0.8 [a]	3.8 ± 0.9 [a,b]	<0.001 (0.02)
Bread (n=2,464)	4.3 ± 0.8 [a]	4.3 ± 0.7 [a]	4.0 ± 0.9 [b]	<0.001 (0.03)

[1] Presented as percent. [2] Presented as percent. High probability of low protein intake was defined as having a 0.3 or higher probability of protein intake lower than 1.0 g protein per kilogram of adjusted body weight per day. [3] Respondents who reported to follow either a flexitarian diet, a pesco-vegetarian diet, an ovo- and/or lacto-vegetarian diet or a vegan diet were grouped into one group 1=Follows meat-limiting diet, while those who reported to not follow one of these diets were grouped into another group 0=Does not follow meat-limiting diet. [4] Frequency of consumption in day per week (d/w) or consumption in grams per day (g/d) presented as mean ± sd. [5] Liking score is a continuous score from one to five, with a greater score indicating greater liking towards food item. Respondents were recoded as missing if they reported to have never tried the food. [a-c] Different superscripts indicate significantly different standardized means in each row following ANOVA post hoc Tukey test or Chi-square test at $p < 0.01$. Cramer's V (V) and partial eta-squared (η_p^2) indicates the effect size.

When it comes to consumption of protein-rich foods other than cooked meat, the heavy meat consumer segment reported greater consumption of eggs, processed meat, and cheese compared to the medium and light meat consumer segments. Medium meat consumers reported a lower consumption of dairy products and legumes compared to the heavy and light meat consumers and a higher consumption of processed meat compared to the light meat consumers. The light meat consumer segment reported a higher consumption of plant-based 'meat' substitutes compared to the heavy and medium meat consumers. These differences, however, resulted in small effects only.

The extent to which the older consumer segments like various protein sources differed across all protein sources except legumes (Table 2). The largest differences were found in the liking towards different types of meat, with light meat consumers having a lower liking across all meat types compared to heavy and medium meat consumers. Compared to heavy and medium meat consumers, light meat consumers had a higher liking score for plant-based 'meat' substitutes.

The level of agreement towards different reasons for liking and disliking meat and plant-based 'meat' substitutes differed between the segments (Figure 1). Compared to light meat consumers, heavy and medium meat consumers agreed more strongly that meat is important for health, tastes good, is good value for money, that they grew up eating meat, and because the people they live with want to eat meat. Compared to heavy and medium meat consumers, light meat consumers agreed more strongly that plant-based 'meat' substitutes taste good and are good for health and better for animal welfare.

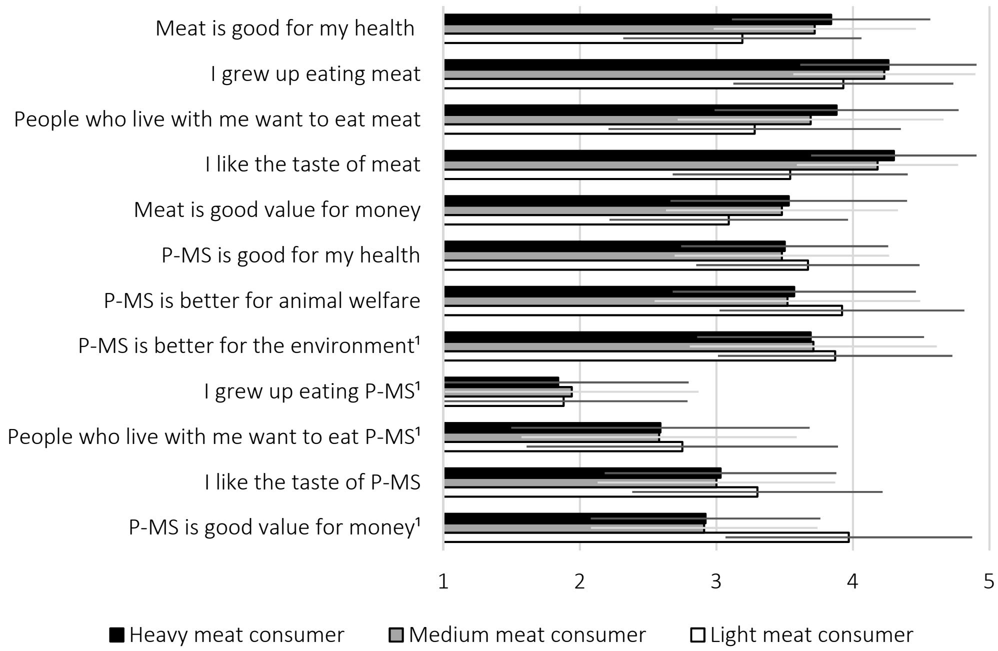


Fig. 1 Differences in agreement towards reasons of liking meat (n=2,432) and plant-based 'meat' substitutes (P-MS) (n=954) between the three older consumer segments. Bars represent means and lines represent standard deviations. Likert scale ranges from 1=Strongly disagree to 5=Strongly agree. [1] Differences between the segments not significant at p<0.01 from Kruskal-Wallis one-way t-test. Otherwise, differences between segments significant at p<0.01 from Kruskal-Wallis one-way t-test.

With regards to reasons for disliking meat, light meat consumers agreed more strongly that meat is not good for health nor the environment, that they do not like the taste of meat and did not grow up with it, and that they value animal welfare, although the level of agreement did not statistically differ with the other two segments with one exception (Appendix Fig A.2). Compared to light and medium meat consumers, heavy meat consumers agreed more strongly that they did not grow up with plant-based 'meat' substitutes and that they live with people who do not want to eat it as reasons for disliking plant-based 'meat' substitute.

2.2. Psychographic characteristics associated with segment classification

Table 3 shows the odds of being classified as a medium and light meat consumer as compared to being classified as a heavy meat consumer based on food choice motives, food fussiness, and food sustainability knowledge. A one-unit increase in the importance attached to health and sustainability when making food choices is associated with an average 12-14% increase in the odds of being classified as a medium meat consumer and 20-35% increase in the odds of being classified as a light meat consumer compared to a heavy meat consumer. A one-unit increase in the importance attached to sensory appeal and familiarity when making food choices is associated with a 13-23% decrease in the odds of being classified as a light meat consumer compared to a heavy meat consumer. Further, a one-unit increase in the food fussiness score (i.e. more likely to be a fussy eater) was associated with an average 42% higher likelihood of being classified as a light meat consumer than a heavy meat consumer. Food sustainability knowledge was not a significant determinant of the segment classification. Overall, these psychographic characteristics combined have low power to explain the variability in older consumer segments (Nagelkerke pseudo R-square=4.5%).

Table 3 Psychographic variables associated with being classified as a medium meat consumer or light meat consumer as compared to a heavy meat consumer– results from multinomial logistic regression analysis

	Medium meat consumer (n=1,290)			Light meat consumer (n=525)		
	OR	95% CI		OR	95% CI	
		Lower	Upper		Lower	Upper
Food choice motive [1]						
Health	**1.14**	1.02	1.27	**1.20***	1.04	1.38
Sustainability	**1.12**	1.02	1.23	**1.35****	1.19	1.52
Price	1.04	0.94	1.14	0.92	0.81	1.03
Sensory appeal	0.92	0.82	1.03	**0.77****	0.67	0.88
Convenience	0.95	0.87	1.04	1.04	0.93	1.17
Familiarity	1.09	0.99	1.20	**0.87**	0.78	0.98
Food fussiness [2]	0.97	0.83	1.13	**1.42****	1.17	1.72
Food sustainability knowledge [3]	0.99	0.90	1.08	1.03	0.92	1.16

Note: R^2=0.045 (Nagelkerke). Reference category for the multinomial regression was the heavy meat consumer segment (n=663). Significant odds ratio (OR) shown in bold based on $p<0.05$. * $p<0.01$. ** $p<0.001$. [1] Food choice motives are a continuous score ranging from one to five, with a greater score indicating more importance is placed on the respective motive when making food choices. [2] Food fussiness is a continuous score from one to five, with a greater score indicating a greater tendency to be a fussy or picky eater. [3] Food sustainability knowledge is a continuous score from one to three with a greater score indicating greater knowledge related to the environmental impact of food.

3. Discussion

The present study identified three older consumer segments according to their cooked meat consumption and liking and explored differences in individual factors to better understand meat consumption behavior among community-dwelling older adults in the EU. Our findings confirm that the overwhelming majority of older adults is a meat-eater, with only 1.1% of the study sample being a self-declared pesco-vegetarian, 0.5% ovo-and/or lacto-vegetarian, and 0.1% vegan. Yet, the results show that there are diverse patterns of meat consumption analogous to the various levels of flexitarianism reported by Dagevos, Voordouw [36]. Opportunities and barriers to meeting the high protein needs in an environmentally sustainable way and implications for designing dietary strategies to address the unique health and sustainability challenges among older consumers in the EU are discussed below.

3.1. Socio-demographic and background characteristics

As observed in this study and supported by previous research [28,36,56-61], there were differences in gender between the different meat consumer segments, with females being more likely to be classified as a light meat consumer compared to males. Slightly more males than females were classified as heavy or medium meat consumers, which is consistent with studies observing the maleness of meat [56,62,63]. However, our results showed a rather small effect in gender, suggesting that cultural norms related to meat and masculinity may alter in later life, or that other factors may trump cultural norms in influencing meat consumption in older adults, such as changing appetite and reduced access to food due to mobility difficulties [64].

In line with previous studies, meat consumption and liking were also found to be closely linked to country of residence and household financial status [26,65]. A study conducted across several EU countries found regional differences in terms of pro-environmental protein consumption and attitudes, which could be explained by cultural, culinary, and economic factors [26]. For instance, a decrease in availability of animal protein and gross domestic product per capita going from west to east in the EU might explain why heavy meat consumers are largely made up of older adults living in the Netherlands and why medium meat consumers are largely made up of older adults living in Poland, and who have a less comfortable household financial situation compared to the other two segments [66]. Paradoxically, we found that the light meat consumer segment is also largely made up of older consumers living in the Netherlands. This might be due to heightened interest in the societal impacts of meat consumption and improvements in product development and marketing of commercial meat substitutes in the Netherlands [67]. Further innovations and marketing in commercial meat substitutes may aid meat replacement in countries with similar food cultures where meal patterns and dishes are traditionally more centered on meat, such as the UK and Finland [33,68,69].

In terms of involvement with food, it appears that light meat consumers were more likely to live alone and be the main household grocery shopper and food decision maker than the other two segments. In an earlier study in older adults in the UK, living alone was linked with a lack of motivation to cook and preparing simpler meals, which was further associated with a higher risk of low appetite and malnutrition [64]. In the current study this connection between living alone and risk of low appetite and low protein intake was observed among light meat consumers. While Whitelock, Ensaff [64] found that reduced meat consumption was also attributed to a deterioration in oral health, our study found no relationship between oral health and segment membership.

3.2. Appetite, protein intake and liking and attitudes towards protein sources

A positive relationship between meat consumption and protein intake status was observed in this study, which supports associations that have been previously reported in observational studies among community-dwelling older adults [70,71]. Light meat consumers are the most vulnerable segment according to their high probability of low protein intake and poor appetite. Although they reported a low consumption of meat, light meat consumers reported a higher frequency of consumption of plant-based ‘meat’ substitutes and a comparable frequency of consumption of non-meat protein-rich food groups to that of one or both segments. Further, light meat consumers tended to have a lower liking towards all meat types, fish or seafood, dairy, eggs, and bread, but reported to like and have more positive attitudes towards plant-based ‘meat’ substitutes compared to the other two segments. This presents an opportunity to focus on health, animal welfare, and taste of plant-based ‘meat’ substitutes to facilitate greater consumption of these protein sources among light meat consumers.

Contrastingly, heavy and medium meat consumers’ positive attitudes towards meat with regards to health, taste, value for money, and their conditioning to eating meat, i.e. having grown up eating meat and being surrounded by others who like to eat meat, have been previously documented as key barriers to replacing meat with alternative, more sustainable plant-based protein sources [33,34]. Notably, medium meat consumers had a slightly more positive attitude towards animal welfare compared to heavy meat consumers, suggesting that valuing animal welfare may caution medium meat consumers away from heavy meat consumption [72,73].

3.3. Psychographic determinants of meat consumption behavior

Beyond investigating differences between the older consumer segments, we also identified potential determinants associated with the classification of older adults into one of the three consumer segments. The findings of this study reinforce the importance of health and sustainability food choice motives as facilitators and sensory appeal and familiarity as barriers for altering meat consumption behavior [74,75]. Convenience and price were not significant determinants in our study, although these motives have been found previously to be significant inhibitory motives for meat replacement and key motivations for food choice among older consumers [37,76,77]. In this study, convenience was defined as the ease of food preparation (e.g. importance that the food can be cooked very simply, takes no time to prepare, is easy to prepare) whereas in other studies among older adults convenience also included the component of accessibility (e.g. importance that the food is easily available in shops or supermarkets) [76,77]. Kamphuis, de Bekker-Grob, van Lenthe [76] found that the accessibility component of convenience (i.e. travel time) was a significant determinant for older adults’ preferences in meal planning and food purchasing decisions while ease of food preparation (i.e. preparation time) was not. Further, we found that light meat consumers were more likely to be a fussy eater compared to heavy meat consumers, which contrasts expectations, as a previous study among adults found that food neophobia, an overlapping construct of food fussiness, was more common among those who eat meat more frequently [59]. However, as food fussiness has been previously linked to low appetite in older adults [15], it is likely that low meat consumers’ poorer appetite partly explains this finding. Although several studies have found knowledge of the environmental impact of food to affect environmental sustainable food choices [78,79], our findings are in line with other studies that found knowledge not to influence environmental sustainable food choices [80]. This supports previous deductions that knowledge alone may be insufficient to directly change one's meat consumption towards more pro-environmental protein consumption [80,81].

3.4. Health and sustainability implications of meat consumption in older adults

Moderate consumption of meat is important for achieving high-quality protein and essential nutrients [23,82] and can be part of an environmentally sustainable diet [83]. However, cohort studies reporting the habitual meat intake of older adults indicate that their average meat consumption may be above the amount recommended for a healthy diet [18,84]. The findings discussed above underscore the heterogeneity of meat consumption behavior in this sub-population and the importance of tailoring strategies for pro-environmental protein consumption among older consumers. Further, they support the hypothesis that older adults need to 'do things differently', e.g. choose alternative protein sources instead of meat, rather than only 'use less', e.g. meat reduction only, to achieve adequate protein intake within environmental limits. The actual pro-environmental protein consumption strategy, however, will vary depending on alternative proteins being readily available in the market [69] and the country in which the strategy is implemented given the different food cultures, preferences, and habits across the EU countries (see Appendix A.2).

A diet optimization study in older adults shows that meat reduction paired with increases in diverse plant-based protein sources is a potential strategy to increase protein intake in older adults that can have dual benefits in terms of human and planet health [18]. The current study shows that older adults on average like legumes, nuts or seeds, and bread and grain products, all of which could be options for sustainable protein sources. Emphasizing the healthiness and sustainability of these alternatives and other plant-based protein sources could be used as a focus in targeted strategies relating to meat replacement among medium meat consumers [74]. By contrast, addressing sensory appeal and familiarity of alternative protein sources in communication strategies and product development is needed for meat replacement particularly among heavy meat consumers. Consumer-oriented product development and improvements in the resemblance and sensory attributes of commercial meat substitutes may be important incentives for heavy meat consumers in the transition towards pro-environmental protein consumption [34].

While a reduction in meat consumption and increase in plant-based protein sources would provide the greatest health and environmental benefits [85], it may not be suitable for vulnerable older adults with a high risk of low protein intake. A strategy to lower the diet's impact on the environment without changing the amount of meat consumed is substituting environmentally-intensive meat (e.g. beef) with less environmentally-intensive meat (e.g. chicken, pork) [18,24,86]. Further, encouraging increased consumption of other animal-based protein sources such as dairy, fish, and eggs may be beneficial for increasing the intake of high-quality protein and essential nutrients [83], yet would elicit more adverse effects for the environment compared to promoting intake of plant-based protein sources like legumes, nuts, and whole grains [87]. This is a trade-off that needs to be made especially for vulnerable older adults with poor appetite. As plant-based protein sources contain fewer and lower amounts of essential amino acids and are less well digested than animal-based protein sources, higher intakes of plant-based proteins per meal may be needed to achieve similar anabolic responses as compared to animal-based protein foods [88]. Further, older adults with poor appetite have a slightly higher risk of malnutrition than those with a good appetite [15] and hence promotion of animal-based protein sources may be a more efficient source of protein and other nutrients like vitamin B12, iron, and zinc [89,90].

3.5. Future prospects

More research is needed to understand the factors that influence meat consumption in later life. Food choice motives, food fussiness, and food sustainability knowledge were found to explain little of the variance in older consumer segment membership, making it clear that there are other important factors that influence meat consumption behavior. Food sustainability knowledge was assessed using an ad hoc scale and should be tested for validity and reliability and refined in future studies. Investigating other factors such as values, subjective norms, self-efficacy, and motivations may help further the understanding of pro-environmental protein consumption in community-dwelling older adults [30,59,91].

In addition, more exploratory research is needed to identify culturally acceptable sustainable protein sources that older adults are willing to either replace meat with or to consume in greater quantity to increase their protein intake. Increasing awareness and acceptance of hybrid meat, for instance, may be a viable solution especially for heavy meat consumers as it is most similar to conventional meat in terms of texture and taste [92]. It was previously found that older adults are not accepting of alternative protein sources like insects and cultured meat, but that they were relatively accepting of plant-based protein sources [29]. Further innovations in plant-based 'meat' substitutes could better appeal to those who enjoy eating meat. Protein enrichment in foods by the food industry or by adding protein powder to meals are other alternative approaches to increasing protein intake, yet the environmental impact of these approaches are under-researched.

Meat consumption in this study was measured by two questions on frequency of cooked meat consumption and average portion size of meat consumed with a warm meal. No distinction was made on the types of meat consumed. It is likely that intake of cooked meat was underestimated due to the measurements' reliance on memory and the global-way meat consumption was probed [93]. As different meat types are associated with different environmental impacts [21], future segmentation research among older adults should evaluate habitual consumption of various types of meat to get a more nuanced picture of meat consumption in this older population. For instance, heavy meat consumers may be fragmented into smaller groups depending on the type of meat eaten (e.g. heavy meat consumers primarily eating beef may have a different profile than heavy meat consumers primarily eating poultry). Furthermore, different meat types are associated with additional concerns outside the scope of this paper, e.g. antibiotic use in poultry production and animal welfare [94], warranting more differentiated (e.g. food safety-related) considerations in future research searching for more sustainable meat consumption strategies. Assessing attitudes towards other factors influencing the sustainability of meat, such as its production method (e.g. conventional versus organic meat) [95], could provide further insights into meat consumption behavior.

The use of the Protein Screener 55+ allowed us to gauge the risk of low protein intake using a short FFQ with relatively low burden on the participant. Consequently, this study did not conduct a full assessment of protein intake. A limitation of the Protein Screener 55+ is that it focuses on the most important protein sources for Dutch community-dwelling older adults, which may overestimate low risk of protein intake in countries that have different important sources of protein. Future studies should determine the habitual protein intake of the older consumer segments to determine whether intake is indeed above or below their protein requirement. Further, as the division of protein over meals may be relevant to maintain lean body mass and strength [96,97], more research into the timing of protein-rich food groups consumption would give more insights into a redistribution strategy.

The results of the current study apply primarily to community-dwelling older adults with access to and basic competencies for using a computer, and the implications should therefore focus on this target group. While the relevance of the implications drawn in this study may extend to other older populations, more research is needed to identify, quantify, and profile consumer segments within such populations.

4. Conclusions

In conclusion, community-dwelling older adults in the EU can be grouped into three segments based on meat consumption and liking. Relevant differences between the older consumer segments were found in socio-demographic and background characteristics, appetite, protein intake status, and liking and attitudes towards meat and plant-based ‘meat’ substitutes. Health, sustainability, sensory appeal, and familiarity food choice motives and food fussiness were the main drivers of the segmentation. These findings reinforce the importance and need for developing dietary strategies that consider the context of meat consumption, the environmental impact of protein sources, and the unique nutrition and health needs and preferences of different older consumer groups.

References

1. European Commission (2017) The 2018 Ageing Report: Underlying assumptions & projection methodologies. European Economy Institutional Papers. European Union, Luxembourg.
2. Cylus J, Figueras J, Normand C (2019) Will population ageing spell the end of the welfare state: A review of evidence and policy options. The economics of healthy and active ageing series. World Health Organization, Copenhagen, Denmark.
3. EFSA (2012) Scientific opinion on dietary reference values of protein European Food Safety Authority Panel on Dietetic Products, Nutrition and Allergies (NDA), Parma.
4. Wall BT, Gorissen SH, Pennings B, Koopman R, Groen BBL, Verdijk LB et al (2015) Aging is accompanied by a blunted muscle protein synthetic response to protein ingestion. PLOS ONE 10 (11):e0140903. https://doi.org/10.1371/journal.pone.0140903
5. Cuthbertson D, Smith K, Babraj J, Leese G, Waddell T, Atherton P et al (2005) Anabolic signaling deficits underlie amino acid resistance of wasting, aging muscle. FASEB J 19 (3):1-22. https://doi.org/10.1096/fj.04-2640fje
6. Moore DR, Churchward-Venne TA, Witard O, Breen L, Burd NA, Tipton KD et al (2015) Protein ingestion to stimulate myofibrillar protein synthesis requires greater relative protein intakes in healthy older versus younger men. J Gerontol A 70 (1):57-62. https://doi.org/10.1093/gerona/glu103
7. Isanejad M, Mursu J, Sirola J, Kröger H, Rikkonen T, Tuppurainen M et al (2016) Dietary protein intake is associated with better physical function and muscle strength among elderly women. Br J Nutr 115 (7):1281-1291. https://doi.org/10.1017/S000711451600012X
8. Houston DK, Nicklas BJ, Ding J, Harris TB, Tylavsky FA, Newman AB et al (2008) Dietary protein intake is associated with lean mass change in older, community-dwelling adults: the Health, Aging, and Body Composition (Health ABC) Study. Am J Clin Nutr 87 (1):150-155. https://doi.org/10.1093/ajcn/87.1.150
9. Scott D, Blizzard L, Fell J, Giles G, Jones G (2010) Associations between dietary nutrient intake and muscle mass and strength in community-dwelling older adults: The Tasmanian Older Adult Cohort Study. J Am Geriatr Soc 58 (11):2129-2134. https://doi.org/10.1111/j.1532-5415.2010.03147.x
10. Mendonça N, Granic A, Hill TR, Siervo M, Mathers JC, Kingston A et al (2019) Protein intake and disability trajectories in very old adults: The Newcastle 85+ study. J Am Geriatr Soc 67 (1):50-56. https://doi.org/10.1111/jgs.15592
11. Paddon-Jones D, Campbell WW, Jacques PF, Kritchevsky SB, Moore LL, Rodriguez NR et al (2015) Protein and healthy aging. Am J Clin Nutr 101 (6):1339S-1345S. https://doi.org/10.3945/ajcn.114.084061
12. Bauer J, Biolo G, Cederholm T, Cesari M, Cruz-Jentoft AJ, Morley JE et al (2013) Evidence-based recommendations for optimal dietary protein intake in older people: A position paper from the PROT-AGE study group. J Am Med Dir Assoc 14 (8):542-559. https://doi.org/10.1016/j.jamda.2013.05.021
13. Deutz NEP, Bauer JM, Barazzoni R, Biolo G, Boirie Y, Bosy-Westphal A et al (2014) Protein intake and exercise for optimal muscle function with aging: Recommendations from the ESPEN Expert Group. Clin Nutr 33 (6):929-936. https://doi.org/10.1016/j.clnu.2014.04.007
14. Richter M, Baerlocher K, Bauer JM, Elmadfa I, Heseker H, Leschik-Bonnet E et al (2019) Revised reference values for the intake of protein. Ann Nutr Metab 74 (3):242-250. https://doi.org/10.1159/000499374
15. Hung Y, Wijnhoven HAH, Visser M, Verbeke W (2019) Appetite and protein intake strata of older adults in the European Union: Socio-demographic and health characteristics, diet-related and physical activity behaviours. Nutrients 11 (4). https://doi.org/10.3390/nu11040777

16. Hengeveld LM, Boer JMA, Gaudreau P, Heymans MW, Jagger C, Mendonça N et al (2020) Prevalence of protein intake below recommended in community-dwelling older adults: a meta-analysis across cohorts from the PROMISS consortium. Journal of Cachexia, Sarcopenia and Muscle. https://doi.org/10.1002/jcsm.12580
17. Chen C, Chaudhary A, Mathys A (2019) Dietary change scenarios and implications for environmental, nutrition, human health and economic dimensions of food sustainability. Nutrients 11 (4):856. https://doi.org/10.3390/nu11040856
18. Grasso AC, Olthof MR, van Dooren C, Broekema R, Visser M, Brouwer IA (2020) Protein for a healthy future: How to increase protein intake in an environmentally sustainable way in older adults in the Netherlands. J Nutr 151 (1):109-119. https://doi.org/10.1093/jn/nxaa322
19. Halkjær J, Olsen A, Bjerregaard LJ, Deharveng G, Tjønneland A, Welch AA et al (2009) Intake of total, animal and plant proteins, and their food sources in 10 countries in the European Prospective Investigation into Cancer and Nutrition. Eur J Clin Nutr 63:S16. https://doi.org/10.1038/ejcn.2009.73
20. Godfray HCJ, Aveyard P, Garnett T, Hall JW, Key TJ, Lorimer J et al (2018) Meat consumption, health, and the environment. Science 361 (6399):eaam5324. https://doi.org/10.1126/science.aam5324
21. Poore J, Nemecek T (2018) Reducing food's environmental impacts through producers and consumers. Science 360 (6392):987-992. https://doi.org/10.1126/science.aaq0216
22. Mertens E, Kuijsten A, van Zanten HHE, Kaptijn G, Dofková M, Mistura L et al (2019) Dietary choices and environmental impact in four European countries. J Clean Prod 237:117827. https://doi.org/10.1016/j.jclepro.2019.117827
23. Phillips SM (2012) Nutrient-rich meat proteins in offsetting age-related muscle loss. Meat Sci 92 (3):174-178. https://doi.org/10.1016/j.meatsci.2012.04.027
24. Willett W, Rockstrom J, Loken B, Springmann M, Lang T, Vermeulen S et al (2019) Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems. Lancet 393 (10170):447-492. https://doi.org/10.1016/s0140-6736(18)31788-4
25. Springmann M, Spajic L, Clark MA, Poore J, Herforth A, Webb P et al (2020) The healthiness and sustainability of national and global food based dietary guidelines: modelling study. BMJ 370:m2322. https://doi.org/10.1136/bmj.m2322
26. de Boer J, Aiking H (2018) Prospects for pro-environmental protein consumption in Europe: Cultural, culinary, economic and psychological factors. Appetite 121:29-40. https://doi.org/10.1016/j.appet.2017.10.042
27. Van Loo EJ, Hoefkens C, Verbeke W (2017) Healthy, sustainable and plant-based eating: Perceived (mis)match and involvement-based consumer segments as targets for future policy. Food Policy 69:46-57. https://doi.org/10.1016/j.foodpol.2017.03.001
28. de Boer J, Schösler H, Aiking H (2014) "Meatless days" or "less but better"? Exploring strategies to adapt Western meat consumption to health and sustainability challenges. Appetite 76:120-128. https://doi.org/10.1016/j.appet.2014.02.002
29. Grasso AC, Hung Y, Olthof MR, Verbeke W, Brouwer IA (2019) Older consumers' readiness to accept alternative, more sustainable protein sources in the European Union. Nutrients 11 (8). https://doi.org/10.3390/nu11081904
30. Çoker EN, van der Linden S (2020) Fleshing out the theory of planned of behavior: Meat consumption as an environmentally significant behavior. Current Psychology. https://doi.org/10.1007/s12144-019-00593-3
31. Asp EH (1999) Factors affecting food decisions made by individual consumers. Food Policy 24 (2):287-294. https://doi.org/10.1016/S0306-9192(99)00024-X
32. Rozin P (2007) Understanding Consumers of Food Products. vol 1. Woodhead Publishing Limited, Cambridge. doi:https://doi.org/10.1533/9781845692506.1.3

33. Macdiarmid JI, Douglas F, Campbell J (2016) Eating like there's no tomorrow: Public awareness of the environmental impact of food and reluctance to eat less meat as part of a sustainable diet. Appetite 96:487-493. https://doi.org/10.1016/j.appet.2015.10.011
34. Stubbs RJ, Scott SE, Duarte C (2018) Responding to food, environment and health challenges by changing meat consumption behaviours in consumers. Nutr Bull 43 (2):125-134. https://doi.org/10.1111/nbu.12318
35. Sanchez-Sabate R, Badilla-Briones Y, Sabaté J (2019) Understanding attitudes towards reducing meat consumption for environmental reasons. A qualitative synthesis review. Sustainability 11 (22). https://doi.org/10.3390/su11226295
36. Dagevos H, Voordouw J (2013) Sustainability and meat consumption: is reduction realistic? Sustainability: Science, Practice and Policy 9 (2):60-69. https://doi.org/10.1080/15487733.2013.11908115
37. Vainio A, Niva M, Jallinoja P, Latvala T (2016) From beef to beans: Eating motives and the replacement of animal proteins with plant proteins among Finnish consumers. Appetite 106:92-100. https://doi.org/10.1016/j.appet.2016.03.002
38. van der Zanden LDT, van Kleef E, de Wijk RA, van Trijp HCM (2015) Examining heterogeneity in elderly consumers' acceptance of carriers for protein-enriched food: A segmentation study. Food Qual Prefer 42:130-138. https://doi.org/10.1016/j.foodqual.2015.01.016
39. den Uijl LC, Jager G, de Graaf C, Waddell J, Kremer S (2014) It is not just a meal, it is an emotional experience - a segmentation of older persons based on the emotions that they associate with mealtimes. Appetite 83:287-296. https://doi.org/10.1016/j.appet.2014.09.002
40. van der Zanden LDT, van Kleef E, de Wijk RA, van Trijp HCM (2014) Understanding heterogeneity among elderly consumers: an evaluation of segmentation approaches in the functional food market. Nutrition Research Reviews 27 (1):159-171. https://doi.org/10.1017/S0954422414000092
41. Beukers MH, Dekker LH, de Boer EJ, Perenboom CWM, Meijboom S, Nicolaou M et al (2014) Development of the HELIUS food frequency questionnaires: ethnic-specific questionnaires to assess the diet of a multiethnic population in The Netherlands. Eur J Clin Nutr 69:579. https://doi.org/10.1038/ejcn.2014.180
42. Wijnhoven HAH, Elstgeest LEM, de Vet HCW, Nicolaou M, Snijder MB, Visser M (2018) Development and validation of a short food questionnaire to screen for low protein intake in community-dwelling older adults: The Protein Screener 55+ (Pro55+). PLOS ONE 13 (5):e0196406. https://doi.org/10.1371/journal.pone.0196406
43. Wilson M-MG, Thomas DR, Rubenstein LZ, Chibnall JT, Anderson S, Baxi A et al (2005) Appetite assessment: Simple appetite questionnaire predicts weight loss in community-dwelling adults and nursing home residents. Am J Clin Nutr 82 (5):1074-1081. https://doi.org/10.1093/ajcn/82.5.1074
44. Young AM, Kidston S, Banks MD, Mudge AM, Isenring EA (2013) Malnutrition screening tools: Comparison against two validated nutrition assessment methods in older medical inpatients. Nutrition 29 (1):101-106. https://doi.org/10.1016/j.nut.2012.04.007
45. Hanisah R, Shahar S, Lee FS (2012) Validation of screening tools to assess appetite among geriatric patients. J Nutr Health Aging 16 (7):660-665. https://doi.org/10.1007/s12603-012-0056-6
46. Steptoe A, Pollard TM, Wardle J (1995) Development of a measure of the motives underlying the selection of food: the food choice questionnaire. Appetite 25 (3):267-284. https://doi.org/10.1006/appe.1995.0061
47. Onwezen MC, Reinders MJ, Verain MCD, Snoek HM (2019) The development of a single-item Food Choice Questionnaire. Food Qual Prefer 71:34-45. https://doi.org/10.1016/j.foodqual.2018.05.005

48. Wardle J, Guthrie CA, Sanderson S, Rapoport L (2001) Development of the children's eating behaviour questionnaire. J Child Psychol Psychiatry 42 (7):963-970. https://doi.org/10.1111/1469-7610.00792
49. Hair JF, Black B, Babin B, Anderson RE (2014) Multivariate data analysis: Pearson new international edition. vol 8, 7th edn. Pearson Education Limited, Essex
50. SPSS Inc. (2001) The SPSS TwoStep cluster component: A scalable component enabling more efficient customer segmentation. White paper - technical report. IBM, Armonk.
51. SPSS Inc. (2009) SPSS Statistics base 17.0 user's guide. IBM, Chicago.
52. Levine TR, Hullett CR (2006) Eta Squared, partial eta squared, and misreporting of effect size in communication research. Human Communication Research 28 (4):612-625. https://doi.org/10.1111/j.1468-2958.2002.tb00828.x
53. Olivier J, Bell ML (2013) Effect sizes for 2×2 contingency tables. PLOS ONE 8 (3):e58777-e58777. https://doi.org/10.1371/journal.pone.0058777
54. Cohen J (1995) Statistical power analysis for the behavioral sciences. vol 7, 2nd ed., 5th print. edn. Erlbaum, Hillsdale, N.J.
55. Lakens D (2013) Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. Frontiers in Psychology 4 (863). 10.3389/fpsyg.2013.00863
56. Schösler H, de Boer J, Boersema JJ, Aiking H (2015) Meat and masculinity among young Chinese, Turkish and Dutch adults in the Netherlands. Appetite 89:152-159. https://doi.org/10.1016/j.appet.2015.02.013
57. Tobler C, Visschers VHM, Siegrist M (2011) Eating green. Consumers' willingness to adopt ecological food consumption behaviors. Appetite 57 (3):674-682. https://doi.org/10.1016/j.appet.2011.08.010
58. Lacroix K, Gifford R (2020) Targeting interventions to distinct meat-eating groups reduces meat consumption. Food Qual Prefer 86:103997. https://doi.org/10.1016/j.foodqual.2020.103997
59. Lacroix K, Gifford R (2019) Reducing meat consumption: Identifying group-specific inhibitors using latent profile analysis. Appetite 138:233-241. https://doi.org/10.1016/j.appet.2019.04.002
60. Graça J, Calheiros MM, Oliveira A (2015) Attached to meat? (Un)Willingness and intentions to adopt a more plant-based diet. Appetite 95:113-125. https://doi.org/10.1016/j.appet.2015.06.024
61. Graça J, Oliveira A, Calheiros MM (2015) Meat, beyond the plate. Data-driven hypotheses for understanding consumer willingness to adopt a more plant-based diet. Appetite 90:80-90. https://doi.org/10.1016/j.appet.2015.02.037
62. Rozin P, Hormes JM, Faith MS, Wansink B (2012) Is meat male? A quantitative multimethod framework to establish metaphoric relationships. J Consum Res 39 (3):629-643. https://doi.org/10.1086/664970
63. De Backer C, Erreygers S, De Cort C, Vandermoere F, Dhoest A, Vrinten J et al (2020) Meat and masculinities. Can differences in masculinity predict meat consumption, intentions to reduce meat and attitudes towards vegetarians? Appetite 147:104559. https://doi.org/10.1016/j.appet.2019.104559
64. Whitelock E, Ensaff H (2018) On your own: Older adults' food choice and dietary habits. Nutrients 10 (4). https://doi.org/10.3390/nu10040413
65. Milford AB, Le Mouël C, Bodirsky BL, Rolinski S (2019) Drivers of meat consumption. Appetite 141:104313. https://doi.org/10.1016/j.appet.2019.06.005
66. de Boer J, Schösler H, Aiking H (2018) Exploring the relative importance of "Reward" and "Reflection" in food orientations: Relevance for healthier and more sustainable diets. Food Qual Prefer 64:126-130. https://doi.org/10.1016/j.foodqual.2017.10.001

67. Dagevos H, Verhoog D, Van Horne P, Hoste R (2018) Vleesconsumptie per hooft van de bevolking in Nederland, 2005-2017. Wageningen Economic Research, Wageningen.
68. Vinnari M, Mustonen P, Räsänen P (2010) Tracking down trends in non-meat consumption in Finnish households, 1966-2006. British Food Journal 112 (8):836-852. https://doi.org/10.1108/00070701011067451
69. Schösler H, de Boer J, Boersema JJ (2012) Can we cut out the meat of the dish? Constructing consumer-oriented pathways towards meat substitution. Appetite 58 (1):39-47. https://doi.org/10.1016/j.appet.2011.09.009
70. Hengeveld LM, Pelgröm ADA, Visser M, Boer JMA, Haveman-Nies A, Wijnhoven HAH (2019) Comparison of protein intake per eating occasion, food sources of protein and general characteristics between community-dwelling older adults with a low and high protein intake. Clin Nutr ESPEN 29:165-174. https://doi.org/10.1016/j.clnesp.2018.10.013
71. Berner LA, Becker G, Wise M, Doi J (2013) Characterization of dietary protein among older adults in the United States: Amount, animal sources, and meal patterns. J Acad Nutr Diet 113 (6):809-815. https://doi.org/10.1016/j.jand.2013.01.014
72. de Boer J, Schösler H, Aiking H (2017) Towards a reduced meat diet: Mindset and motivation of young vegetarians, low, medium and high meat-eaters. Appetite 113:387-397. https://doi.org/10.1016/j.appet.2017.03.007
73. Hartmann C, Siegrist M (2020) Our daily meat: Justification, moral evaluation and willingness to substitute. Food Qual Prefer 80:103799. https://doi.org/10.1016/j.foodqual.2019.103799
74. Graça J, Godinho CA, Truninger M (2019) Reducing meat consumption and following plant-based diets: Current evidence and future directions to inform integrated transitions. Trends Food Sci Tech 91:380-390. https://doi.org/10.1016/j.tifs.2019.07.046
75. Hoek AC, Luning PA, Weijzen P, Engels W, Kok FJ, de Graaf C (2011) Replacement of meat by meat substitutes. A survey on person- and product-related factors in consumer acceptance. Appetite 56 (3):662-673. https://doi.org/10.1016/j.appet.2011.02.001
76. Kamphuis CB, de Bekker-Grob EW, van Lenthe FJ (2015) Factors affecting food choices of older adults from high and low socioeconomic groups: a discrete choice experiment. Am J Clin Nutr 101 (4):768-774. https://doi.org/10.3945/ajcn.114.096776
77. Locher JL, Ritchie CS, Roth DL, Sen B, Vickers KS, Vailas LI (2009) Food choice among homebound older adults: Motivations and perceived barriers. J Nutr Health Aging 13 (8):659-664. https://doi.org/10.1007/s12603-009-0194-7
78. Peschel AO, Grebitus C, Steiner B, Veeman M (2016) How does consumer knowledge affect environmentally sustainable choices? Evidence from a cross-country latent class analysis of food labels. Appetite 106:78-91. https://doi.org/10.1016/j.appet.2016.02.162
79. Wunderlich S, Gatto K, Smoller M (2018) Consumer knowledge about food production systems and their purchasing behavior. Environment, Development and Sustainability 20 (6):2871-2881. https://doi.org/10.1007/s10668-017-0021-y
80. Asvatourian V, Craig T, Horgan GW, Kyle J, Macdiarmid JI (2018) Relationship between pro-environmental attitudes and behaviour and dietary intake patterns. Sustainable Production and Consumption 16:216-226. https://doi.org/10.1016/j.spc.2018.08.009
81. Hoek AC, Pearson D, James SW, Lawrence MA, Friel S (2017) Healthy and environmentally sustainable food choices: Consumer responses to point-of-purchase actions. Food Qual Prefer 58:94-106. https://doi.org/10.1016/j.foodqual.2016.12.008
82. Phillips SM, Fulgoni VL, III, Heaney RP, Nicklas TA, Slavin JL, Weaver CM (2015) Commonly consumed protein foods contribute to nutrient intake, diet quality, and nutrient adequacy. Am J Clin Nutr 101 (6):1346S-1352S. https://doi.org/10.3945/ajcn.114.084079
83. Vieux F, Privet L, Soler LG, Irz X, Ferrari M, Sette S et al (2020) More sustainable European diets based on self-selection do not require exclusion of entire categories of food. J Clean Prod 248:119298. https://doi.org/10.1016/j.jclepro.2019.119298

84. Struijk EA, Banegas JR, Rodríguez-Artalejo F, Lopez-Garcia E (2018) Consumption of meat in relation to physical functioning in the Seniors-ENRICA cohort. BMC Medicine 16 (1):50. https://doi.org/10.1186/s12916-018-1036-4
85. Springmann M, Wiebe K, Mason-D'Croz D, Sulser TB, Rayner M, Scarborough P (2018) Health and nutritional aspects of sustainable diet strategies and their association with environmental impacts: a global modelling analysis with country-level detail. Lancet Planet Health 2 (10):e451-e461. https://doi.org/10.1016/S2542-5196(18)30206-7
86. Berners-Lee M, Hoolohan C, Cammack H, Hewitt CN (2012) The relative greenhouse gas impacts of realistic dietary choices. Energy Policy 43:184-190. https://doi.org/10.1016/j.enpol.2011.12.054
87. de Gavelle E, Leroy P, Perrimon M, Huneau J-F, Sirot V, Orset C et al (2019) Modeled gradual changes in protein intake to increase nutrient adequacy lead to greater sustainability when systematically targeting an increase in the share of plant protein. Clim Change. https://doi.org/10.1007/s10584-019-02592-6
88. Berrazaga I, Micard V, Gueugneau M, Walrand S (2019) The role of the anabolic properties of plant- versus animal-based protein sources in supporting muscle mass maintenance: A critical review. Nutrients 11 (8):1825. https://doi.org/10.3390/nu11081825
89. Lonnie M, Hooker E, Brunstrom JM, Corfe BM, Green MA, Watson AW et al (2018) Protein for life: Review of optimal protein intake, sustainable dietary sources and the effect on appetite in ageing adults. Nutrients 10 (3). https://doi.org/10.3390/nu10030360
90. Tijhuis MJ, Ezendam J, Westenbrink S, van Rossum C, Temme L (2011) Replacement of meat and dairy by more sustainable protein sources in the Netherlands, Quality of the diet. RIVM Letter Report 350123001/2011. Dutch National Institute for Public Health and the Environment (RIVM), Bilthoven.
91. Hunter E, Röös E (2016) Fear of climate change consequences and predictors of intentions to alter meat consumption. Food Policy 62:151-160. https://doi.org/10.1016/j.foodpol.2016.06.004
92. Lang M (2020) Consumer acceptance of blending plant-based ingredients into traditional meat-based foods: Evidence from the meat-mushroom blend. Food Qual Prefer 79:103758. https://doi.org/10.1016/j.foodqual.2019.103758
93. Haftenberger M, Heuer T, Heidemann C, Kube F, Krems C, Mensink GBM (2010) Relative validation of a food frequency questionnaire for national health and nutrition monitoring. Nutrition Journal 9 (1):36. https://doi.org/10.1186/1475-2891-9-36
94. Mottet A, Tempio G (2017) Global poultry production: current state and future outlook and challenges. World's Poultry Science Journal 73 (2):245-256. https://doi.org/10.1017/S0043933917000071
95. Garnett T, Godde C, Muller A, Röös E, Smith P, de Boer I et al (2017) Grazed and confused? Ruminanting on cattle, grazing systems, methane, nitrous oxide, the soil carbon sequestration question - and what it all means for greenhouse gas emissions. Food Climate Research Network, Oxford Martin Programme on the Future of Food, Environmental Change Institute, University of Oxford, Oxford.
96. Loenneke JP, Loprinzi PD, Murphy CH, Phillips SM (2016) Per meal dose and frequency of protein consumption is associated with lean mass and muscle performance. Clin Nutr 35 (6):1506-1511. https://doi.org/10.1016/j.clnu.2016.04.002
97. Farsijani S, Morais JA, Payette H, Gaudreau P, Shatenstein B, Gray-Donald K et al (2016) Relation between mealtime distribution of protein intake and lean mass loss in free-living older adults of the NuAge study. Am J Clin Nutr 104 (3):694-703. https://doi.org/10.3945/ajcn.116.130716

Appendix

Table A.1 Correlation matrix of determinants in multinomial logistic regression [1]

	X1	X2	X3	X4	X5	X6	X7	X8
X1: Health [2]	-							
X2: Sustainability [2]	.500*	-						
X3: Price [2]	.214*	.154*	-					
X4: Sensory appeal [2]	.356*	.233*	.250*	-				
X5: Convenience [2]	.153*	.101*	.311*	.189*	-			
X6: Familiarity [2]	.146*	.105*	.220*	.171*	.328*	-		
X7: Food fussiness [3]	-.207*	-.125*	-.027	-.199*	.119*	.254*	-	
X8: Food-related sustainability knowledge [4]	.144*	.119*	.044	.134*	-.013	-0.92*	-.232*	-

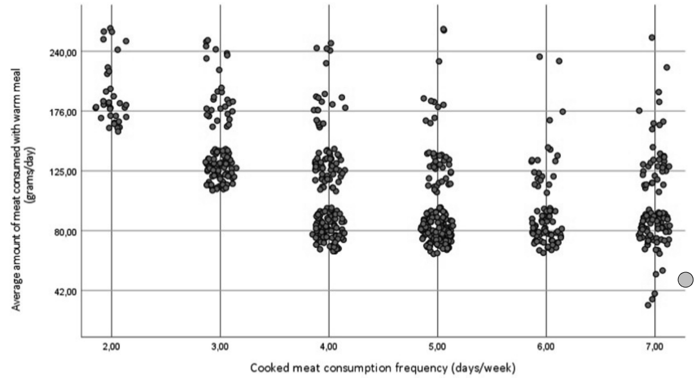
[1] Items with asterisk have a statistically significant Pearson correlation, *p<0.01. [2] Food choice motives are a continuous score ranging from one to five, with a greater score indicating more importance is placed on the respective motive when making food choices. [3] Food fussiness is a continuous score from one to five, with a greater score indicating a greater tendency to be a fussy or picky eater. [4] Food sustainability knowledge is a continuous score from one to three with a greater score indicating greater knowledge related to the environmental impact of food.

Table A.2 Consumption and liking of meat and other protein-rich food groups in older adults by country

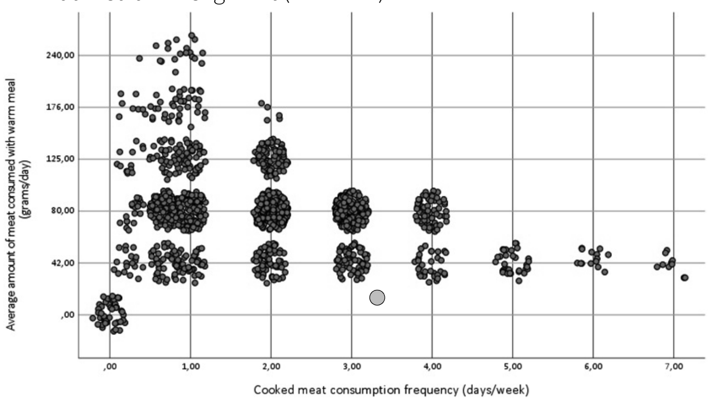
	Finland (n=500)	Poland (n=500)	Spain (n=500)	Netherlands (n=500)	UK (n=500)	*p*-value (η_p^2)
Consumption						
Cooked meat (g/d)	35.0 ± 33.4 [a]	25.6 ± 27.8 [b]	33.7 ± 29.6 [a]	37.6 ± 28.1 [a]	32.1 ± 28.2 [a]	<0.001 (0.09)
Frequency (d/wk)	2.7 ± 2.0 [b]	2.1 ± 1.6 [c,d]	2.1 ± 1.5 [d]	3.6 ± 2.0 [a]	2.5 ± 1.9 [b,c]	<0.001 (0.09)
Fish (d/wk)	1.8 ± 1.7 [a]	1.0 ± 1.1 [b]	2.0 ± 1.6 [a]	1.1 ± 1.1 [b]	1.1 ± 1.0 [b]	<0.001 (0.09)
Dairy products excl. cheese (d/wk)	3.7 ± 2.9 [a,b]	2.1 ± 2.2 [c]	3.4 ± 2.7 [b]	4.1 ± 2.7 [a]	2.2 ± 2.6 [c]	<0.001 (0.09)
Eggs (d/wk)	2.3 ± 2.3 [a]	1.8 ± 1.6 [b]	2.3 ± 1.7 [a]	2.0 ± 1.8 [a,b]	1.6 ± 1.5 [b]	<0.001 (0.02)
Legumes (d/wk)	0.6 ± 1.2 [c]	1.3 ± 1.4 [b]	1.9 ± 1.4 [a]	1.6 ± 2.0 [a]	1.0 ± 1.4 [b]	<0.001 (0.07)
Nuts or peanuts (d/wk)	1.4 ± 2.2 [c]	1.4 ± 2.0 [c]	2.4 ± 2.4 [a]	1.9 ± 2.1 [a]	1.1 ± 1.9 [c]	<0.001 (0.05)
Pasta or noodles (d/wk)	1.1 ± 1.6 [b]	1.4 ± 1.3 [a]	1.4 ± 1.3 [a]	1.2 ± 1.2 [a,b]	1.0 ± 1.0 [b]	<0.001 (0.02)
Processed meat (d/wk)	3.5 ± 2.6 [a]	3.3 ± 2.0 [a]	2.1 ± 1.8 [c]	2.8 ± 2.3 [b]	1.6 ± 1.5 [d]	<0.001 (0.11)
Cheese (d/wk)	4.9 ± 2.4 [a]	2.8 ± 2.4 [c]	2.0 ± 2.1 [d]	4.1 ± 2.4 [b]	2.4 ± 2.0 [c,d]	<0.001 (0.19)
Plant-based 'meat' (d/wk)	0.2 ± 0.7 [c]	0.3 ± 0.9 [b,c]	0.2 ± 0.8 [c]	0.4 ± 1.0 [a]	0.3 ± 0.9 [a,b]	<0.001 (0.01)
Liking						
Beef or veal (n=2444)	4.0 ± 0.9	4.0 ± 0.9	4.0 ± 0.9	4.0 ± 1.0	4.0 ± 1.0	0.394 (<0.01)
Lamb (n=2403)	3.4 ± 1.1 [b]	3.6 ± 1.2 [b]	3.9 ± 1.0 [a]	3.1 ± 4.1 [c]	3.9 ± 1.3 [a]	<0.001 (0.06)
Pork (n=2449)	3.9 ± 0.9 [a]	4.0 ± 0.9 [a]	3.9 ± 0.9 [a]	3.6 ± 1.2 [b]	3.9 ± 1.1 [a]	<0.001 (0.03)
Poultry (n=2456)	4.4 ± 0.7 [a]	4.2 ± 0.8 [b,c]	4.1 ± 0.8 [c]	4.0 ± 1.1 [c]	4.3 ± 0.9 [a,b]	<0.001 (0.03)
Fish or seafood (n=2449)	4.4 ± 0.8 [a]	4.3 ± 1.0 [a,b]	4.4 ± 0.7 [a]	4.1 ± 2.1 [b]	4.3 ± 1.0 [a,b]	<0.001 (0.02)
Hybrid meat (n=1990)	2.6 ± 0.9 [a,b]	2.5 ± 0.9 [b,c]	2.8 ± 1.1 [a]	2.3 ± 1.1 [c]	2.4 ± 1.0 [c]	<0.001 (0.04)
Dairy (n=2456)	4.3 ± 0.8	4.3 ± 0.8	4.3 ± 0.7	4.4 ± 0.7	4.4 ± 0.7	0.441 (<0.01)
Egg (n=2458)	4.4 ± 0.6	4.4 ± 0.8	4.3 ± 0.7	4.3 ± 0.7	4.3 ± 0.8	0.059 (<0.01)
Plant-based 'meat' (n=2101)	2.7 ± 1.0 [a]	2.5 ± 1.0 [a,b]	2.3 ± 1.1 [b]	2.5 ± 1.3 [a,b]	2.4 ± 1.2 [a,b]	<0.001 (0.01)
Legumes (n=2429)	3.8 ± 0.9 [b]	4.4 ± 0.8 [a]	4.4 ± 0.7 [a]	4.5 ± 0.6 [a]	3.6 ± 1.1 [c]	<0.001 (0.16)
Nuts or seeds (n=2453)	4.1 ± 1.0 [a,b]	4.3 ± 0.9 [a]	4.3 ± 0.8 [a]	4.2 ± 0.9 [a]	3.9 ± 1.0 [b]	<0.001 (0.02)
Grain-based products excl. bread (n=2453)	3.8 ± 0.8 [c]	4.1 ± 0.8 [a]	3.9 ± 0.9 [b,c]	3.9 ± 1.0 [b,c]	4.0 ± 0.8 [a,b]	<0.001 (0.02)
Bread (n=2464)	4.5 ± 0.7 [a]	4.2 ± 0.8 [b]	4.2 ± 0.7 [b]	4.2 ± 0.8 [b]	4.1 ± 0.7 [b]	<0.001 (0.03)

[a-d] Different superscripts indicate significantly different standardized means in each row following ANOVA post hoc Tukey test at $p < 0.01$. Partial eta-squared (η_p^2) indicates the effect size.

A. Meat lover segment (N=663)



B. Meat restrainer segment (N=1290)



C. Meat avoider segment (N=525)

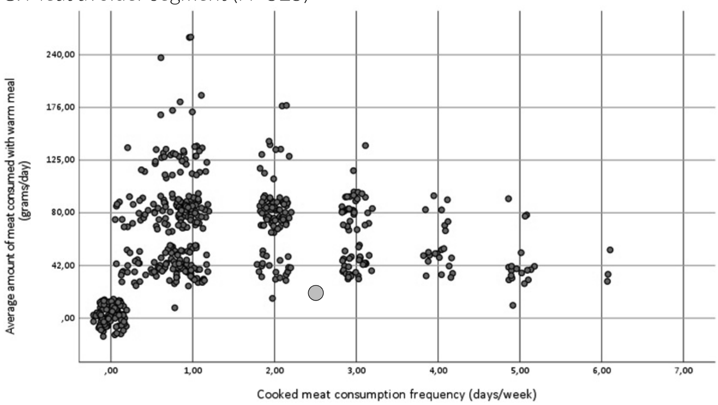


Fig. A.1 Jittered scatterplots of cooked meat consumption frequency and average amount of meat consumed with warm meal by older consumer segments. Pearson correlations between cooked meat consumption frequency and average amount of meat consumed with warm meal are r = -0.458, p<0.001 for meat lovers, r = -0.216, p<0.001 for meat restrainers, and r = 0.177, p<0.001 for meat avoiders. Light grey circle represents average value.

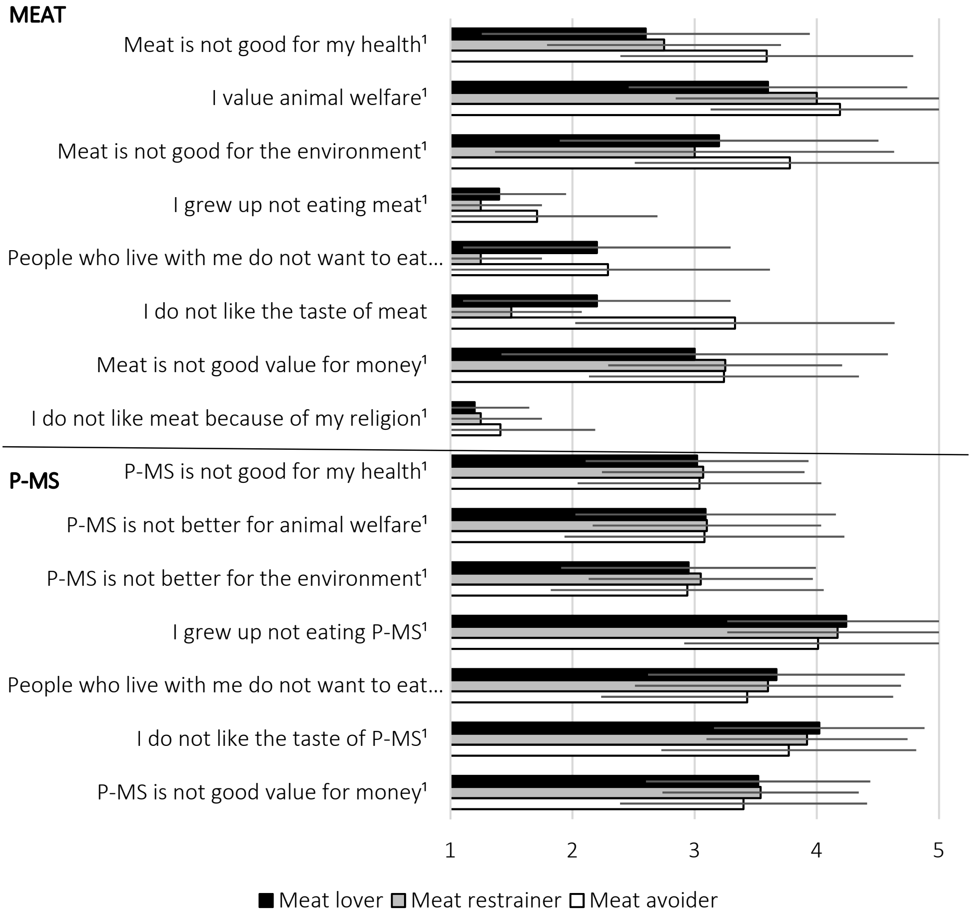


Fig. A.2 Differences in agreement towards reasons of disliking meat (n=99) and plant-based 'meat' substitutes (P-MS) (n=1147) between the older consumer segments. Bars represent means and lines represent standard deviations. Likert scale ranges from 1=Strongly disagree to 5=Strongly agree. [1] Differences between the segments not significant at p<0.01 from Kruskal-Wallis one-way t-test. Otherwise, differences between segments significant at p<0.01 from Kruskal-Wallis one-way t-test.

PART II

Environmental impact of dietary change due to health-oriented dietary guidance

CHAPTER 5

Protein for a healthy future: how to increase protein intake in an environmentally sustainable way in older adults in the Netherlands

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Abstract

Background Protein intake greater than the currently recommended amount is suggested to improve physical functioning and well-being in older adults, yet it is likely to increase diet-associated greenhouse gas emissions (GHGE) if environmental sustainability is not considered. Objective: We aimed to identify dietary changes needed to increase protein intake while improving diet environmental sustainability in older adults.

Methods Starting from the habitual diet of 1,354 Dutch older adults (56-101 y) from the Longitudinal Aging Study Amsterdam cohort, mathematical diet optimization was used to model high-protein diets with minimized departure from habitual intake in cumulative steps. First, a high-protein diet defined as one providing $\geq$ 1.2 g protein $\cdot$ kg body weight^{-1} $\cdot$ day^{-1} was developed isocalorically while maintaining or improving nutritional adequacy of the diet. Second, adherence to the Dutch food-based dietary guidelines (FBDG) was imposed. Third, a stepwise 10% GHGE reduction was applied.

Results Achieving a high-protein diet aligned with the FBDG without considering GHGE required an increase in vegetables, legumes, nuts, whole grains, meat/dairy alternatives, dairy, and eggs and a reduction in total meat (for men only) and discretionary products, but resulted in 5% increase in GHGE in men and 9% increase in women. When a stepwise GHGE reduction was additionally applied, increases in poultry and pork (mainly for women) and decreases in beef/lamb and processed meat were accrued, with total meat staying constant until a 50-60% GHGE reduction. Increases in whole grains, nuts, and meat/dairy alternatives and decreases in discretionary products were needed to lower GHGE.

Conclusions A high-protein diet aligned with FBDG can be achieved in concert with reductions in GHGE in Dutch older adults by consuming no more than the recommended 500 g meat per week while replacing beef and lamb and processed meat with poultry and pork and increasing intake of diverse plant-protein sources.

1. Introduction

Adequate protein intake is a fundamental prerequisite for muscle protein synthesis and maintenance of skeletal muscle mass and physical function [1,2], and has been shown to be especially important for healthy aging [3]. Several metabolic and observational studies indicate that older adults require a greater protein intake than younger adults for adequate muscle synthesis and for maintaining physical function [4-7]. Age-related changes in physiological, psychological, and social factors may upset the balance between dietary consumption and nutritional requirements, making older adults aged 65 years in particular vulnerable to inadequate protein intake [8]. Inadequate protein intake is one of several determinants of malnutrition and frailty in older adults, increasing the risk of mortality and comorbidities [8,9]. Currently, the recommended dietary allowance (RDA) for protein established by the Health Council of the Netherlands (HCN), the European Food Safety Authority (EFSA), and the World Health Organization (WHO) is 0.8 g protein · kg body weight $(BW)^{-1}$ · day $(d)^{-1}$ for adults, including older adults [10-12]. However, as protein intake above this amount is suggested to better maintain physical functioning and well-being in older adults aged 65 years and older, a higher RDA of 1.0 to 1.2 g protein · kg BW^{-1} · d^{-1} has been proposed by expert groups [2,5,13].

While an increase in protein intake could potentially support better health in older adults [14], it presents an environmental concern. The current protein demand and supply places a substantial burden on the environment, playing a paramount role in anthropogenic climate change and biodiversity loss, among other negative environmental effects [15-17]. Animal-based protein in particular plays a pivotal role in the diet's overall environmental impact [18]. In Europe approximately 25% of all greenhouse gas emissions (GHGE) is due to food consumption, with animal-based food consumption contributing to more than half of the diet's overall impact [19]. In the Netherlands, 60% of total protein consumed by community-dwelling older adults is derived from animal-based sources, of which approximately 50% comes from meat and dairy [20,21]. In addition to having a large environmental impact, red and processed meat has been associated with chronic diseases and overall mortality when consumed in high quantities [22-24]. Shifting towards a more plant-based diet (i.e. shifting the direction of the animal- to plant-protein ratio from 60:40 towards 50:50 or 40:60) has thus been recommended by the HCN in their 2015 guidelines for a healthy diet [22,25] and by the Agriculture and Land Use sector table in the 2019 [26,27]. The need for a more plant-based diet is also addressed in the Farm to Fork Strategy of the European Green Deal, which aims to achieve a 50% GHGE reduction by 2030 compared to 1990 levels and climate neutrality by 2050 [28,29]. Not meeting this target risks increasing global warming to 1.5^{o}C above pre-industrial levels sometime between 2030 and 2052, which is predicted to have significant impacts on ecosystems, oceans, biodiversity, and human health [30].

To meet the suggested higher protein requirement of the aging population and at the same time improve the environmental sustainability of the diet, it is essential to customize protein advice for this population [31]. The present modeling study aimed to identify dietary changes that deviate least from habitual intake and increase protein intake in the context of the 2015 Dutch food-based dietary guidelines (FBDG) while reducing diet-associated GHGE in Dutch community-dwelling older adults.

2. Materials and methods

2.1. Study population and sample

The 2014/2015 Nutrition and Food-Related Behavior ancillary study from the Longitudinal Aging Study Amsterdam (LASA) provided the study population for this analysis. LASA is an ongoing cohort study in a representative sample of Dutch community-dwelling older adults aged 55 years and over living in three geographical regions in the Netherlands [32,33]. The sample and data collection procedures for the LASA cohort [34,35] and the Nutrition and Food-Related Behavior ancillary study [36,37] have been described in detail and are summarized as follows. Dietary intake data were collected during the Nutrition and Food-Related Behavior ancillary study from 1,439 participants (684 men and 755 women) by means of a food frequency questionnaire (FFQ) [36-38]. Of the 1,439 participants, 85 participants in total were excluded in this study due to not fully completing the FFQ (n=19), over-reporting energy intake according to Willett's cut off values (>4000 kcal/d for men and >3500 kcal/d for women) (n=23), and not having a valid measured body weight (n=43) [37,38]. Body weight was measured during the LASA medical interviews in 2011/2012, 2012/2013, and 2015/2016 and was averaged across the different measurement periods for each participant [37]. Data on comorbidity, measured as self-reports of the number of chronic diseases from a list of seven health conditions [35], and physical activity, measured using the validated LASA Physical Activity Questionnaire [34], were obtained during the main interview of the regular LASA waves.

The analytical sample of 1,354 participants (644 men and 710 women) had a mean age of 69 years, a mean body mass index of 27 kg/m^2, and a mean physical activity level of 62 MET h/wk. Comorbidities present in the sample include osteoarthritis (48.3%), hypertension (39.4%), incontinence (25.4%), cardiac disease (21.3%), cancer (15.1%), chronic non-specific lung disease (12.8%), diabetes mellitus (11.8%), rheumatoid arthritis (9.9%), peripheral arterial disease (6.3%), and cerebrovascular accident or stroke (5.7%). Ethical approval for the LASA study and ancillary study was given by the Medical Ethics Committee of the VU University Medical Center, and all participants provided written informed consent.

2.2. Dietary data

Dietary intake data were collected by means of an adapted validated semi-quantitative FFQ which asked participants how often they consumed various food items in the past four weeks, as well as how much of the food they normally consumed per occasion [38,39]. In total 254 food items were included in this analysis, and each food item was linked to the Dutch Food Composition Table 2011 to calculate nutrient intakes [40]. Furthermore, estimates of nine essential amino acids (EAA), i.e. lysine, methionine, leucine, isoleucine, threonine, valine, histidine, tryptophan, and phenylalanine, were obtained for each food item from the U.S. Department of Agriculture's (USDA) food composition database [41], which is to our knowledge the most comprehensive EAA database available. When estimates were not available in the USDA database they were retrieved from the Danish Frida Food Data database [42]. The food items were aggregated into 25 food groups adapted from the food group classification used for the Dutch Food Consumption Surveys originally based on EPIC-Soft classification [43]. Food items comprising of two or more ingredients were classified into respective food groups based on the recipe calculations used in the FFQ (Supplementary Table 1) [39].

2.3. Environmental data

The environmental impact of the diet is measured using life cycle assessments (LCA) of three environmental impact indicators, namely GHGE, land use (LU) and fossil energy use (FEU). LCAs were performed over the entire life cycle of the product, from cultivation and processing to packing, consumption and final disposal using ReCiPe 2016 Midpoint v1.00 method by Blonk Consultants [44,45]. Environmental impact estimates were largely obtained from two life cycle inventory databases from Blonk Consultants. The FFQ food items were first linked with environmental data from the Optimeal® database, which contains environmental data of 208 commonly eaten food products in The Netherlands [46]. Food items were matched based on similarities of foods in their nutritional composition and function as well as production methods as determined by an LCA expert. Food items that did not have a match in the Optimeal® database were then matched to food products in a life cycle inventory database developed by Blonk Consultants in the context of the EU-funded project PROMISS ("PRevention Of Malnutrition In Senior Subjects in the EU"), which contains environmental data of 94 commonly eaten food products by European older adults. Further, environmental data for three food items were obtained from the life cycle inventory database from the Netherlands National Institute for Public Health and Environment [47]. GHGE expressed in kilograms of carbon dioxide equivalents (kg CO_2-eq), LU in square meter per year (m^2*y) and FEU in mega joules (MJ) were calculated per 100g food.

2.4. Diet optimization with quadratic programming

To investigate possible directions for change on the food group level to achieve a high-protein in the context of the Dutch FBDG while improving the environmental impact of the diet in older adults, quadratic programming (QP) was conducted. QP is a mathematical optimization technique that finds an unique combination of variables (e.g. quantities of food in a diet) to optimize a quadratic objective function, while subject to a number of linear constraints (e.g. protein requirement) [48]. Whereas most previous research has approached the challenge of simultaneously meeting nutritional and environmental goals by using linear programming, which produces large changes in a limited number of food products, we chose QP because it leads to a wider range of small changes, making it a more favorable approach to identify realistic changes on the population level, especially for a vulnerable population like older adults. The modeling exercise was carried out in several cumulative steps involving the application of nutritional, acceptability, and progressively stringent environmental constraints. The steps and constraints are described below and shown in Table 1. Optimizations were performed using diet optimization software Optimeal® 3.0 (Blonk Consultants, Gouda, the Netherlands) [49] and were done for men and women separately as men and women have been found to have different eating patterns [50,51], which may lead to different dietary changes to reach the modeling objectives described below.

Table 1 Nutritional, environmental and acceptability constraints applied during diet optimizations for Dutch older adults [1]

	Lower constraint	Upper constraint	Reference
Step 1: High-protein diet (PROT)			
Nutritional constraints [2]			
Energy (kcal/d)	mean HAB	mean HAB	
Protein (g·kg body weight^{-1}·d^{-1})	1.2	-	[2,52]
SFA (g/d)	-	mean HAB	[54]
MUFA (g/d)	mean HAB	-	[54]
PUFA (g/d)	mean HAB	-	[54]
Fiber (g/d)	mean HAB or 25	-	[54]
DHA+EPA (mg)	mean HAB or 250	-	[54]
Folate equivalents (μg/d)	mean HAB or 300	1000	[53]
Vitamin C (mg/d)	mean HAB or 75	-	[53]
Calcium (mg/d)	mean HAB or 1200	2500	[53]
Iron (mg/d)	mean HAB or 11	25	[53]
Acceptability constraint			
Food items (g/d)	-	95th percentile [3]	[58]
Step 2: Step 1 + Dutch FBDG (+PROT)			
Food groups			
Vegetables (g/d)	200	-	[22]
Fruit (g/d)	200	-	[22]
Whole grains (g/d)	90	-	[22]
Nuts (g/d)	14.3	-	[22]
Fish (g/d)	-	14.3 [4]	[22]
Meat (g/d)	-	71.4 [5]	[55]
Red meat (g/d)	-	42.9 [6]	[55]
Processed meat (g/d)	-	mean HAB	[22]
Warm savory snacks (g/d)	-	mean HAB	
Sweets (g/d)	-	mean HAB	[22]
Sugar-sweetened beverages (g/d)	-	mean HAB	[22]
Step 3: Step 2 + reduction on GHGE (+PROT-GHGE)			
Environmental constraint			
GHGE (kgCO_2-eq/d)	Stepwise 10% reduction from level in mean habitual diet	-	

[1] Mean habitual intakes of the respective nutrients, food items, and food groups are calculated for men and women separately. The constraints applied in each step are in addition to the constraints applied in the prior step(s). [2] When the mean habitual intake of a nutrient was above the dietary reference intake (DRI) of that nutrient, the DRI defined by the Health Council of the Netherlands (HCN) [53] or the European Food Safety Authority [54] (if not defined by the HCN) was used. [3] Non-consumers excluded. [4] Equivalent to about 1 serving (100g) of fish a week. [5] Equivalent to the recommended maximum 500g meat per week. [6] Equivalent to the recommended maximum 300g red meat per week. Abbreviations: DHA+EPA docosahexaenoic acid and eicosapentaenoic acid; FBDG food-based dietary guidelines; GHGE greenhouse gas emissions; kg CO_2-eq/d kilograms of carbon dioxide equivalents per day; HAB habitual intake; MUFA monounsaturated fatty acids; PROT high-protein diet; +PROT high-protein diet aligned with the Dutch food-based dietary guidelines; +PROT-GHGE high-protein diets aligned with the Dutch food-based dietary guidelines accounting for greenhouse gas emissions; PUFA polyunsaturated fatty acids; SFA saturated fatty acids.

2.4.1. Nutritional constraints

Starting from the mean habitual diet (HAB) of older men and women, high-protein diets (PROT), defined as one providing $\geq$ 1.2 g protein · kg BW^{-1} · d^{-1} [2,52], were modeled isocalorically to identify compositional changes in the diet needed to achieve a higher protein intake. To ensure that the nutritional adequacy of the diet did not worsen and had room to improve, micronutrients, fiber and fatty acids were minimally constrained and saturated fatty acid was maximally constrained to the mean habitual sub-population intake. When the mean habitual intake of a nutrient was above the dietary reference intake (DRI) of that nutrient, the recommended intake defined by the HCN [53] or EFSA [54] (if not defined by the HCN) was used as the lower constraint.

Building on the high-protein diets (PROT) of men and women separately, high-protein diets aligned with the 2015 Dutch FBDG (+PROT) were modeled [22,55]. A lower constraint was set for vegetables, fruit, whole grains, and nuts equal to the recommended daily intake while an upper constraint was set for meat and red meat equal to the respective recommended weekly intake. While the Dutch FBDG advises to limit consumption of processed meat, sweets, savory snacks, and sugar-sweetened beverages, there is no maximum consumption boundary suggested for these food groups [22] and therefore an upper constraint equal to the respective mean habitual sub-population intake was established to prevent increases in these food groups.

When it comes to fish, the Dutch FBDG recommends eating one serving of fish, preferably oily, per week [22]. While consuming more than one weekly serving of fish may provide additional health benefits, it poses a threat to fish stocks and marine biodiversity [56]. Therefore we set an upper constraint to one serving of fish per week. As other diet optimization studies often conclude that higher fish intake is needed to meet nutritional requirements as well as lower diet-associated GHGE [51], we conducted a sensitivity analysis with a lower constraint applied to fish intake to at least one serving per week (results presented in Supplementary Fig. 1).

2.4.2. Environmental constraints (+PROT-GHGE)

Building on the high-protein diets aligned with the Dutch FBDG (+PROT), the diets were further modeled for increasingly stringent reductions on GHGE (see Table 1). The +PROT diet was first constrained to have the same GHGE value as the habitual diet (+PROT-GHGE-0%), then was subjected to a 10%-stepwise decrease in GHGE (i.e. +PROT-GHGE-10%, +PROT-GHGE-20%, +PROT-GHGE-30%, etc.) [51,57]. The maximum number of 10%-reduction steps was reached when no diet solution could be achieved with a further 10% GHGE reduction. In other words, a maximum GHGE reduction was reached when an additional 10% GHGE reduction was not feasible given the model parameters (i.e. food items, constraints, and objective function).

2.4.3. Acceptability constraints

To attain realistic dietary changes, food item quantities were constrained to an upper limit equal to the 95th percentile of the habitual intakes of consumers, calculated for men and women separately [58]. An upper limit for organ meat was set to the mean habitual intake per sex because only a small percentage of the sample consumed organ meat (23% male and 17% female older adults). Additionally, a lower limit for the food group fats/oils was set to the 5th percentile of the habitual intakes of consumers. In preliminary analyses fats/oils were removed from the diet with GHGE reductions $\geq$ 50%, which we deemed culturally unacceptable.

2.4.4. Objective function

The objective function of the model ensured that the modeled diet stayed closest to the habitual diet when subjected to the aforementioned nutritional, environmental and acceptability constraints. The objective function $\boldsymbol{f}$ was minimized:

$$f = \sum_{i=1}^{n} (x_i^* - x_i)^2 , \qquad \textit{Equation 1}$$

where $\boldsymbol{i}$ is a food item, $\boldsymbol{n}$ is number of available food items, $\boldsymbol{x_i}$ is the value in grams of food item $\boldsymbol{i}$ in the reference diet of the sub-populations and $\boldsymbol{x_i^*}$ is the value in grams of the same food item in the modeled diet.

2.5. Data analysis

Descriptive statistics were conducted to describe the content of nutrients, environmental impact, and quantities of food groups of the mean habitual diet (HAB) and modeled diets (PROT, +PROT, and +PROT-GHGE diets) for older men and women separately. To assess the acceptability of the modeled diets, departure from the mean habitual diet in terms of absolute change in mean intake of food groups ($\boldsymbol{abs\Delta_{food\ groups}}$; $\boldsymbol{n}$ = 25) and food items ($\boldsymbol{abs\Delta_{food\ items}}$; $\boldsymbol{n}$ = 254) (in %) was calculated. Diets similar to the mean habitual diet in terms of diet composition, i.e. diets with minimal departure were considered culturally acceptable and feasible, while diets with larger departure from the mean habitual diet were considered to have greater risk of lower acceptability [57]. Based on the formula used by Perignon et al. [57], we calculated the absolute departure from mean habitual intake by:

$$abs\Delta_{food\ groups} = \frac{1}{25}\sum_{j=1}^{25} ABS\left(\frac{x_j^* - x_j}{x_j^*}\right), \qquad \textit{Equation 2}$$

$$abs\Delta_{food\ items} = \frac{1}{254}\sum_{i=1}^{254} ABS\left(\frac{x_i^* - x_i}{x_i^*}\right), \qquad \textit{Equation 3}$$

where $\boldsymbol{j}$ is the 25 food groups and $\boldsymbol{i}$ is the 254 food items, $\boldsymbol{ABS}$ refers to the absolute value, $\boldsymbol{x}$ is the observed quantity in the reference diet and $\boldsymbol{x^*}$ is the quantity in the modeled diet. Taking into account the Dutch and European climate goals [26,27], we describe the dietary changes needed to achieve a 50% GHGE reduction. We then assessed whether these changes would be acceptable by discerning the diets' departure from the mean habitual diet as established by Equation 2 and Equation 3 [57].

3. Results

3.1. Total protein content and GHGE of habitual and modeled diets

The habitual diet provided 1.02 g protein · kg $BW^{-1} \cdot d^{-1}$ for men and 1.00 g protein · kg $BW^{-1} \cdot d^{-1}$ for women. Protein content of the diet needed to increase by 16% for men and 20% for women to reach the 1.20 g protein · kg $BW^{-1} \cdot d^{-1}$ goal. The GHGE of the habitual diet was 6.81 kg CO_2-eq/d for men and 5.68 kg CO_2-eq/d for women. Achieving a high-protein diet, whether aligned with the food-based dietary guidelines (+PROT) or not (PROT), implied higher diet-associated GHGE. A change from the habitual diet to the high-protein diet resulted in a 12% increase in GHGE for men and 14% for women, while a change from the habitual diet to the high-protein diet aligned with the food-based dietary guidelines resulted in a 5% and 9% GHGE increase. For the +PROT-GHGE diets, the maximum attainable GHGE reduction in the diet modeling exercise was 80% GHGE reduction for both men and women.

3.2. Changes in food group quantities from the habitual diet to modeled diets

The changes in food group quantities from habitual diet to the high-protein diet, the high-protein diet aligned to the food-based dietary guidelines, and the high-protein diet aligned to the food-based dietary guidelines with a 50% GHGE reduction are shown in Figure 1. The stepwise changes in food group quantities from habitual diet to modeled diets is similar for men and women (Supplementary Fig. 2). For both sexes, achieving a high-protein diet without taking the guidelines or environmental impact into account (PROT) implied an increase in all meat products (besides organ meat), fish, cheese, eggs, legumes, nuts, meat/dairy alternatives, and savory snacks, and a decrease in fats/oils and discretionary products including dressing/sauces and sweets. Taking the food-based dietary guidelines into account (+PROT) resulted in increases from the habitual diet in vegetables and fruit (men only) and stronger increases in cheese, eggs, nuts, and meat/dairy alternatives than from the habitual diet to PROT. As men had a habitually higher meat intake than what is recommended in the guidelines, total meat needed to decrease by 29% from the habitual diet to +PROT. The habitual intake of meat among women, on the other hand, was already aligned with the food-based dietary guidelines. Fish was reduced from the habitual diet to +PROT by 36% for men and 33% for women to the established upper constraint of one serving per week.

Achieving a high-protein diet aligned with the food-based dietary guidelines while meeting the Dutch and European GHGE reduction goal of 50% did not induce substantial changes in total meat from the recommended limit of 500 g/d (it reduced to 482 g/d for women) but required the removal of beef and lamb from the diet as well as a reduction of processed meat and pork and an increase in poultry for both sexes. Although total meat quantity remained relatively constant, the GHGE impact of meat reduced due to the partial substitution of beef and lamb and processed meat with poultry and pork

(Supplementary Fig. 3). While the quantity of cheese hardly changed for men (4% above habitual intake), it needed to be reduced by 36% below habitual intake for women. For both sexes, moderate increases in whole grains (20-30%) and legumes (14%) and substantial increases in nuts (250-310%), and meat/dairy alternatives (190-250%) were needed, as well as substantial reductions in fats/oils (70-80%), dressings/sauces (30-40%), and sweets (60-70%) for both sexes.

3.3. Diet properties and protein type and quality

The habitual intakes of dietary fiber, omega-3 fatty acids (DHA+EPA), folate, and calcium were below the DRI but the habitual intake of vitamin C exceeded the DRI in both men and women (Supplementary Table 2). While the habitual intake of iron was above the DRI for men, it was below for women. For both sexes, achieving a high-protein diet with or without taking the food-based dietary guidelines into account resulted in increases in quantities of several nutrients. Although intake levels of DHA+EPA increased above the DRI from HAB to PROT, it remained at habitual intake levels for +PROT and subsequent +PROT-GHGE diets with an exceptional spike at 50% and 60% GHGE reduction levels due to high increases in poultry. Applying a progressive GHGE reduction led to nutrients fluctuating above and below the DRI, with fiber and calcium remaining below the DRI for women in most modeled diets. The diet weights in terms of dry matter in the modelled diets were higher relative to the habitual diet except for PROT, and subtly increased with greater GHGE reductions.

When increasing protein intake is the main goal and neither the food-based dietary guidelines nor GHGE are considered, the ratio of animal- to plant-based protein increased from 60:40 (HAB) to 65:35 (PROT) in men and 61:39 (HAB) to 66:34 (PROT) in women (Figure 2). Taking the food-based dietary guidelines into account produced a trifling decrease in the animal- to plant-protein ratio from the habitual diet. A progressive reduction in GHGE resulted in small but cumulative reductions in the animal- to plant-based protein ratio. It was only with a ≥50% GHGE reduction when plant-protein contributed to more than 50% of total protein intake for both sexes. The animal- to plant-protein ratio of +PROT-GHGE-50% was 49:51 for both sexes, which is close to the 50:50 ratio recommended by the Netherlands Nutrition Center [25]. The +PROT-GHGE-50% required an increase in the contribution to total protein from poultry, vegetables (only for men), whole grains, nuts, and meat/dairy alternatives and a decreased from beef and lamb, pork, processed meat, fish, milk and milk products, cheese (only for women), potatoes (only for men), and sweets (Supplementary Fig. 3).

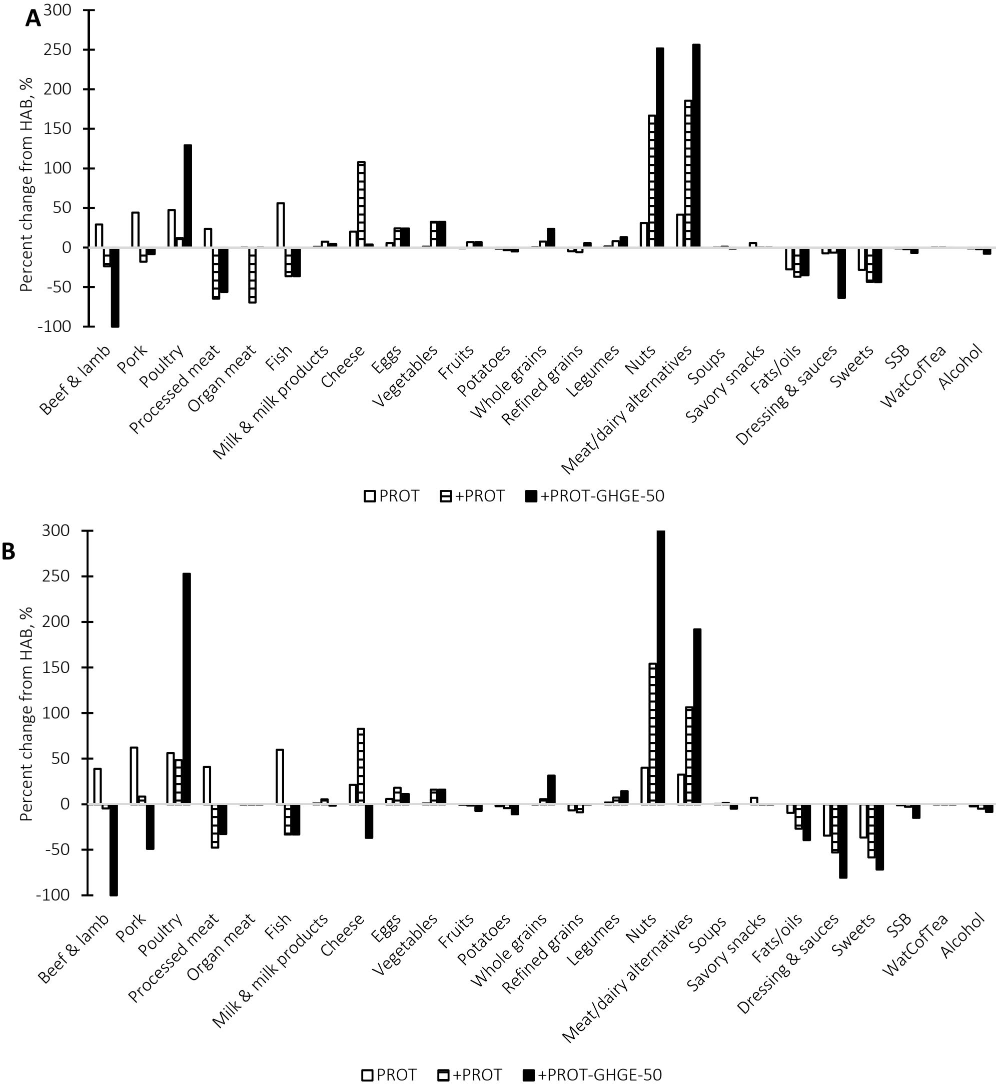


Figure 1 Percent change in food group quantities from habitual diet to high-protein diet, high-protein diet aligned with the Dutch food-based dietary guidelines, and high-protein diets aligned with the Dutch food-based dietary guidelines accounting for a 50% greenhouse gas emission reduction in older Dutch men (A, n=644) women (B, n=710) aged 56-101y. Abbreviations: GHGE greenhouse gas emissions; HAB habitual diet; PROT high-protein diet; +PROT high-protein diet aligned with the Dutch food-based dietary guidelines; +PROT-GHGE-50 high-protein diet aligned with the Dutch food-based dietary guidelines with 50% GHGE reduction; SSB sugar-sweetened beverages; WatCofTea Water coffee tea.

Using the quantity of nine EAA as a proxy for protein quality, the modeled diets generally led to improvements in protein quality relative to the habitual diet (Figure 3). At a 50% GHGE reduction, only lysine slightly fell below habitual levels. Protein quality became compromised with a >50% GHGE reduction, when quantities of lysine, methionine, threonine, isoleucine, leucine, valine, and histidine fell below habitual intakes for both sexes. The reduction in quantities of seven EAA coincides with the dominance of plant-based protein sources in the diet, as illustrated in Figure 2.

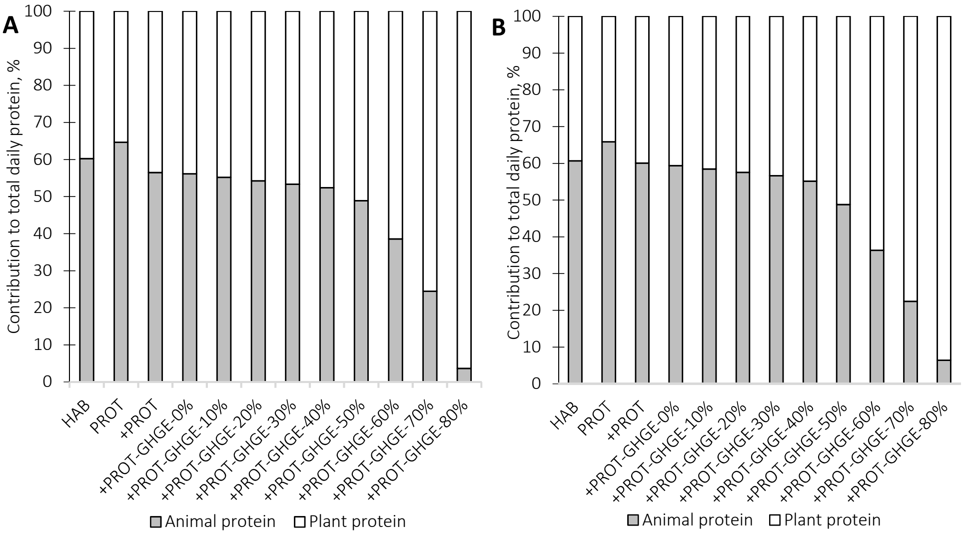


Figure 2. Contribution of animal protein and plant protein to total daily protein intake in the habitual diet, high-protein diet, high-protein diet aligned with the Dutch food-based dietary guidelines, and high-protein diets aligned with the Dutch food-based dietary guidelines accounting for greenhouse gas emissions in older Dutch men (A, n=644) and women (B, n=710) aged 56-101y. The percentage on the +PROT-GHGE diets is the percent reduction in GHGE applied to the diet. Abbreviations GHGE greenhouse gas emissions, HAB habitual diet, PROT high-prtoein diet, +PROT high-protein diet aligned with the Dutch food-based dietary guidelines, +PROT-GHGE high-protein diets aligned with the Dutch food-based dietary guidelines accounting for greenhouse gas emissions. Abbreviations: GHGE greenhouse gas emissions; HAB habitual diet; PROT high-protein diet; +PROT high-protein diet aligned with the Dutch food-based dietary guidelines; +PROT-GHGE high-protein diets aligned with the Dutch food-based dietary guidelines accounting for greenhouse gas emissions.

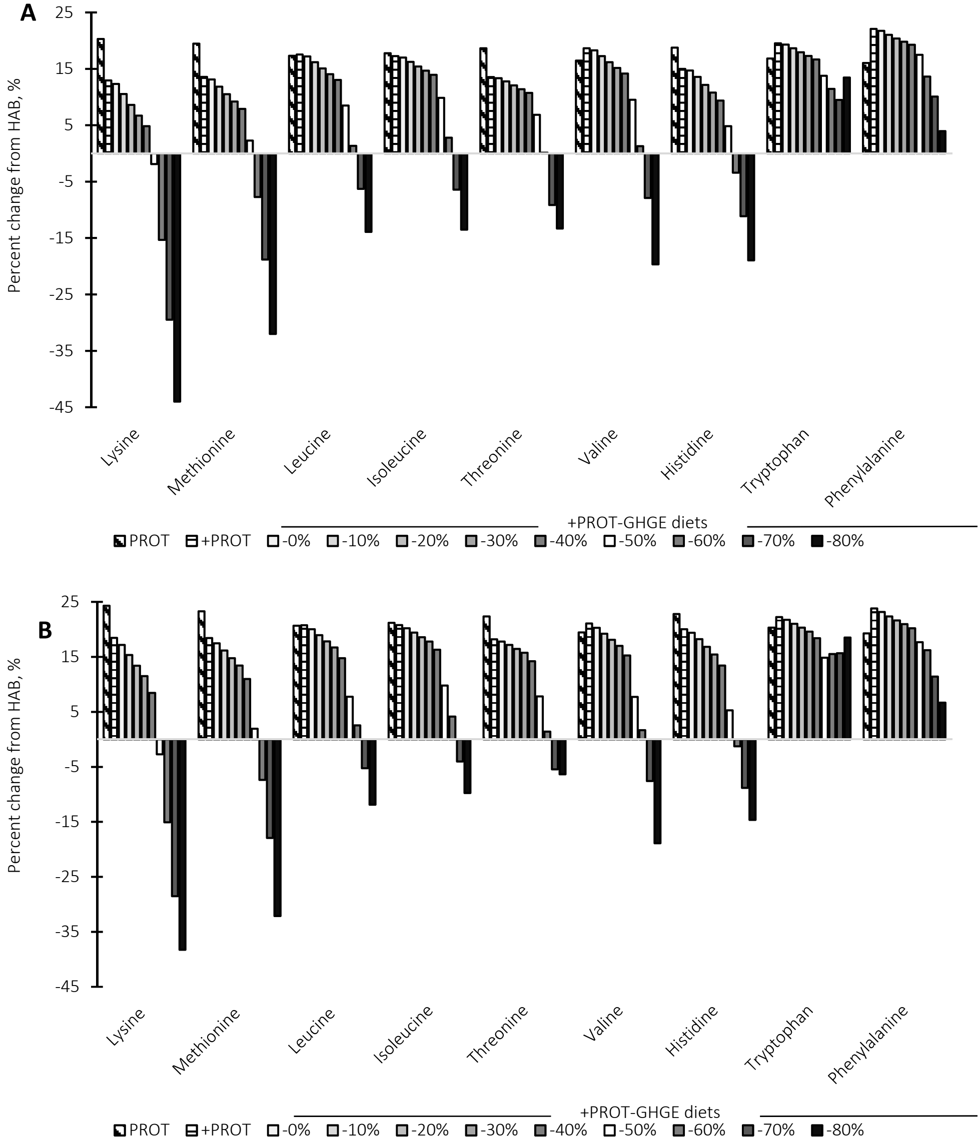


Figure 3. Percent change in essential amino acids from habitual diet to high-protein diet, high-protein diet aligned with the Dutch food-based dietary guidelines, and high-protein diets aligned with the Dutch food-based dietary guidelines accounting for greenhouse gas emissions in older Dutch men (A, n=644) and women (B, n=710) aged 56-101y. The percentage on the +PROT-GHGE diets is the percent reduction in GHGE applied to the diet. Abbreviations: GHGE greenhouse gas emissions; HAB habitual diet; PROT high-protein diet; +PROT high-protein diet aligned with the Dutch food-based dietary guidelines; +PROT-GHGE high-protein diets aligned with the Dutch food-based dietary guidelines accounting for greenhouse gas emissions.

3.4. Environmental impact of the habitual and modeled diets

PROT led to higher diet-associated LU and FEU compared to HAB diet, much alike to GHGE (Figure 4). Taking the FBDG into account resulted in LU and FEU levels similar to those in the habitual diet for men and slightly higher levels than those in the habitual diet for women. A progressive reduction in GHGE resulted in a corresponding progressive reduction in LU and FEU of the diet. While LU decreased in a linear-like fashion similar to GHGE, FEU decreased in a more geometric-like fashion. The FEU remained close to habitual levels up to and including a 40% GHGE reduction, and substantially reduced with ≥50% GHGE reduction.

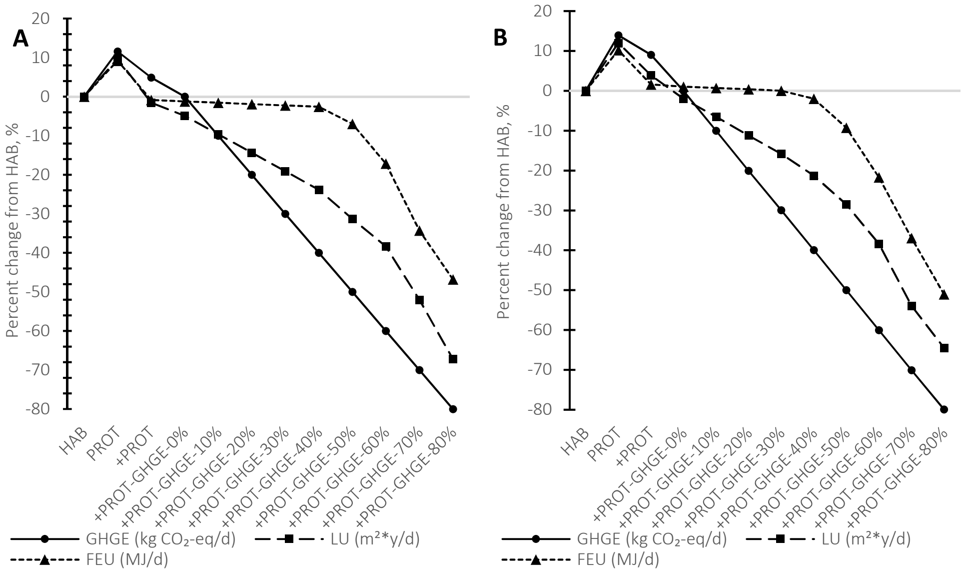


Figure 4. Percent change in greenhouse gas emissions, land use and fossil energy use from the habitual diet to high-protein diet, high-protein diet aligned with the Dutch food-based dietary guidelines, and high-protein diets aligned with the Dutch food-based dietary guidelines accounting for greenhouse gas emissions in older Dutch men (A, n=644) and women (B, n=710) aged 56-101y. The percentage on the +PROT-GHGE diets is the percent reduction in GHGE applied to the diet. Abbreviations HAB habitual diet, PROT high-prtoein diet, +PROT high-protein diet aligned with the Dutch food-based dietary guidelines, +PROT-GHGE high-protein diets aligned with the Dutch food-based dietary guidelines accounting for greenhouse gas emissions. Abbreviations: FEU fossil energy use; GHGE greenhouse gas emissions; HAB habitual diet; kg CO2-eq/d kilograms of carbon dioxide equivalents per day; LU land use; m^2*y/d square meter per year per day; MJ/d mega joules per day; PROT high-protein diet; +PROT high-protein diet aligned with the Dutch food-based dietary guidelines; +PROT-GHGE high-protein diets aligned with the Dutch food-based dietary guidelines accounting for greenhouse gas emissions.

3.5. Acceptability of the modeled diets

PROT was most similar to the habitual diet in terms of diet composition, i.e. it resulted in the smallest departure from HAB on the food group and food item levels (Figure 5).

+PROT resulted in a greater departure from the habitual diet, approximately two times greater than that of PROT. Imposing an additional constraint for GHGE did not induce substantial changes in absolute departure compared to that of +PROT until >50% GHGE reduction. A GHGE reduction higher than 50% resulted in a considerably larger departure from HAB in food quantities on both the food group and food item levels, having a higher risk of lower cultural acceptability.

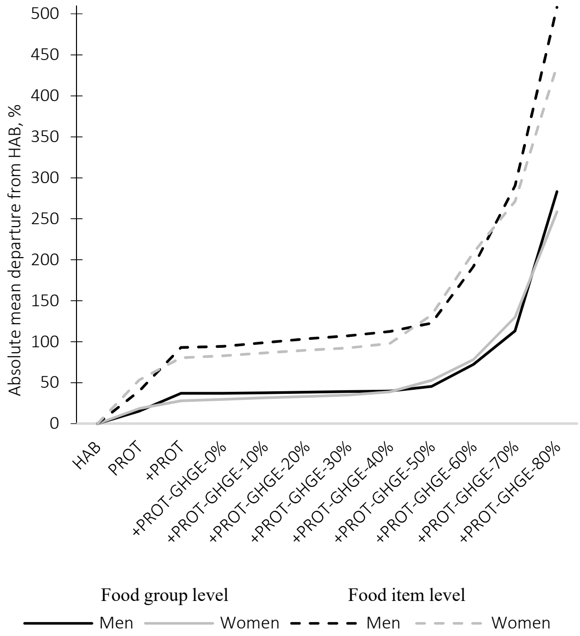


Figure 5. Absolute mean departure on food group level and food item level from habitual diet (HAB) to high-protein diet (PROT), high-protein diet aligned with the Dutch food-based dietary guidelines (+PROT), and high-protein diets aligned with the Dutch food-based dietary guidelines accounting for greenhouse gas emissions (+PROT-GHGE) in older Dutch men (n=644) and women (n=710) aged 56-101y. The percentage on the +PROT-GHGE diets is the percent reduction in GHGE applied to the diet. Abbreviations: HAB habitual diet, PROT high-protein diet, +PROT high-protein diet aligned with the Dutch food-based dietary guidelines, +PROT-GHGE high-protein diets aligned with the Dutch food-based dietary guidelines accounting for greenhouse gas emissions.

4. Discussion

A potentially new RDA for healthy older adults of 1.2 g protein · kg BW^{-1} · d^{-1} could lead to net increases (5-14%) in GHGE of the diet if environmental sustainability is not taken into account. To meet a potential higher protein recommendation and simultaneously improve the environmental sustainability of the diet in older adults, it is essential to pay particular attention to the origin of protein when customizing protein advice for this population. This diet optimization study shows that a high-protein diet aligned with the Dutch FBDG and with a 50% GHGE reduction can be achieved while still eating an ample amount of meat (500 grams per week), mainly by replacing beef and lamb and processed meat with mainly poultry and some pork. An increase in the contribution of plant-protein from whole grains, legumes, nuts, and meat/dairy alternatives to total protein is needed to meet older adults' high protein demand in the context of the FBDG and environmental constraints. The results suggest that a reduction in diet-associated GHGE up to and including 50% are potentially feasible and culturally acceptable, yet changes needed to meet more stringent GHGE reductions (>50%) risk being unacceptable due to the substantially higher departures as well as due to compromised protein quality.

The findings of the present paper are consistent with previous modeling studies that addressed the underlying challenge of simultaneously achieving a healthy and sustainable diet, supporting the need to shift away from environmentally intensive meats and energy-dense, nutrient-poor foods towards less environmentally intensive meats and more nutrient-rich plant foods [51,57,59]. Our results show that when the ratio of animal- to plant-protein becomes equal or flips to one favoring plant-protein sources, lysine, methionine, leucine and several other EAA become compromised, which is due to the lower content of these EAA in plant-based sources compared to animal-protein sources [60,61]. Findings from a recent trial in healthy older women suggest that adequate intake of particular amino acids, rather than total protein, may be important for the maintenance of skeletal muscle mass and function, pointing to the importance of leucine [62]. While bioavailability of protein and other nutrients was outside the scope of this study, it is a concern for shifting towards a more sustainable plant-based diet. However, it was previously shown in a French modeling study that there is enough diversity in the diet to ensure the quality of protein and other key nutrients despite smaller quantities of animal products in the diet [63].

Despite slight nutritional improvements after imposing constraints on food groups aligned with the FBDG, the food group constraints did not necessarily lead to a nutritionally adequate diet, with most of the modeled diets being compromised in DHA+EPA for both sexes, and in fiber and calcium for women. However, given that the nutrient profile of the modeled diets were maintained or improved relative to the habitual diet, the dietary changes found in this study indeed deliver a nutritional advantage. Similar to our findings, Salomé et al. [64] found that a higher consumption of diverse plant-protein sources including whole grains, legumes, nuts, and vegetables was associated with higher probabilities of adequacy of vitamin C and folate but lower probabilities of adequacy for DHA+EPA, calcium, and iron, underscoring the importance of animal-based protein sources for adequate intake of these nutrients.

The results of our sensitivity analysis support previous linear programming studies, which have found that fish needed to be increased to make the diet nutritionally adequate and more environmentally sustainable [50,51,57,59]. When a minimum rather than a maximum constraint on fish was placed, adequate levels of DHA+EPA were met in the modeled diets (results not shown). Particularly fatty wild caught fish types are favored as their high content of omega-3 fatty acids and protein make it a desirable component of a healthy diet, and its relatively low impact on GHGE make it favorable in GHGE-restricted diets [65]. Nevertheless, there is a need to consider a maximum consumption of fish beyond which there are few health gains. Eating more fish than what is needed for health could have unintended consequences on the environment beyond climate change, such as overfishing and aquatic biodiversity loss which are not captured by GHGE or in LCA in general [66]. To meet the HCN recommendation on DHA+EPA consumption with limited negative environmental effects, Hollander et al. [67] found that consumption of fish by-catch and discards is needed (by-catch being unwanted fish caught with the primary target species of a fishery and discards being unwanted fish caught with the primary target species of a fishery, but are usually discarded due to having little economic value). Plant-based sources of DHA+EPA, such as seaweed and algae, may be another solution for a sustainable source of DHA+EPA as well as of protein, yet such innovative products are not yet part of the current habitual Dutch diet and thus were not included in this modeling study.

This study found that synergies exist between GHGE and other environmental impacts, namely LU and FEU, yet a $\geq$50% GHGE reduction was needed to bring FEU below the habitual FEU level. An explanation of the delayed decline of FEU of the high-protein diets aligned with the FBDG and with < 50% GHGE reduction is the relative high quantities of poultry and persistence of milk and milk products, cheese, and eggs in the diet, which all experienced a reduction with $\geq$50% GHGE reduction.

This study has some strengths and limitations. Compared with other modeling studies [51,57,59], we used three markers of diet sustainability, namely GHGE, LU, and FEU, and used environmental impact data that were consistently calculated over the entire life cycle of the product. While this study used only GHGE as an environmental constraint to have a clear environmental target aligned with Dutch and European climate goals, it showed that synergies exist between GHGE and the other environmental indicators. Despite this strength, there are many more markers of environmental sustainability (e.g. water footprint, eutrophication), as well as non-environmental sustainability dimensions including animal welfare and diet affordability [68], which were outside the scope of this study. A limitation of this study is that the modeled diets were not nutritionally adequate for three nutrients that were considered in this study, suggesting further improvements could be achieved by taking nutritional quality into account. Not applying constraints for nutritional adequacy may have influenced the modeling exercise to undervalue animal-protein sources as they supply essential fatty acids and nutrients, and perhaps overvalue food products which may contain significant amount of sodium, like cheese and meat/dairy alternatives. Generalizability of results to older adults in other countries is limited as cultural differences are likely to produce different starting diets, and variations in production systems or regions can lead to different environmental estimates of the food products [69].

This study addresses two societal challenges confronting many parts of the world: meeting the protein requirement of a growing older population and meeting this need within environmental limits. The dietary changes identified in this study can start the discussion on how to increase protein intake in an environmentally sustainable way in older adults. We showed that a 50% GHGE reduction is possible with meat and other animal-based protein sources remaining in the diet, but that a change in meat type is needed to keep the diet within sound environmental limits. Increasing plant-protein from whole grains, legumes, nuts, and meat/dairy alternatives also contributed to improved protein quantity and quality for Dutch community-dwelling older adults within environmental limits.

References

1. Morley JE, Argiles JM, Evans WJ, Bhasin S, Cella D, Deutz NEP et al (2010) Nutritional recommendations for the management of sarcopenia. J Am Med Dir Assoc 11 (6):391-396. https://doi.org/10.1016/j.jamda.2010.04.014
2. Deutz NEP, Bauer JM, Barazzoni R, Biolo G, Boirie Y, Bosy-Westphal A et al (2014) Protein intake and exercise for optimal muscle function with aging: Recommendations from the ESPEN Expert Group. Clin Nutr 33 (6):929-936. https://doi.org/10.1016/j.clnu.2014.04.007
3. Paddon-Jones D, Campbell WW, Jacques PF, Kritchevsky SB, Moore LL, Rodriguez NR et al (2015) Protein and healthy aging. Am J Clin Nutr 101 (6):1339S-1345S. https://doi.org/10.3945/ajcn.114.084061
4. Moore DR, Churchward-Venne TA, Witard O, Breen L, Burd NA, Tipton KD et al (2015) Protein ingestion to stimulate myofibrillar protein synthesis requires greater relative protein intakes in healthy older versus younger men. J Gerontol A 70 (1):57-62. https://doi.org/10.1093/gerona/glu103
5. Katsanos CS, Kobayashi H, Sheffield-Moore M, Aarsland A, Wolfe RR (2005) Aging is associated with diminished accretion of muscle proteins after the ingestion of a small bolus of essential amino acids. Am J Clin Nutr 82 (5):1065-1073. https://doi.org/10.1093/ajcn/82.5.1065
6. Isanejad M, Mursu J, Sirola J, Kröger H, Rikkonen T, Tuppurainen M et al (2016) Dietary protein intake is associated with better physical function and muscle strength among elderly women. Br J Nutr 115 (7):1281-1291. https://doi.org/10.1017/S000711451600012X
7. Lemieux FC, Filion ME, Barbat-Artigas S, Karelis AD, Aubertin-Leheudre M (2014) Relationship between different protein intake recommendations with muscle mass and muscle strength. Climacteric 17 (3):294-300. https://doi.org/10.3109/13697137.2013.829440
8. Volkert D, Kiesswetter E, Cederholm T, Donini LM, Eglseer D, Norman K et al (2019) Development of a model on determinants of malnutrition in aged persons: A MaNuEL Project. Gerontol Geriatr Med 5:2333721419858438. https://doi.org/10.1177/2333721419858438
9. Mendonça N, Kingston A, Granic A, Jagger C (2019) Protein intake and transitions between frailty states and to death in very old adults: the Newcastle 85+ study. Age and Ageing 49 (1):32-38. https://doi.org/10.1093/ageing/afz142
10. Health Council of the Netherlands (Gezondheidsraad) (2001) Dietary reference intakes: energy, proteins, fats and digestible carbohydrates (in Dutch). Gezondheidsraad, The Hague.
11. EFSA (2012) Scientific opinion on dietary reference values of protein European Food Safety Authority Panel on Dietetic Products, Nutrition and Allergies (NDA), Parma.
12. WHO (2007) Protein and amino acid requirements in human nutrition. Report of a joint FAO/WHO/UNU expert consultation (WHO Technical Report Series 935). World Health Organization, Geneva.
13. Bauer J, Biolo G, Cederholm T, Cesari M, Cruz-Jentoft AJ, Morley JE et al (2013) Evidence-based recommendations for optimal dietary protein intake in older people: A position paper from the PROT-AGE study group. J Am Med Dir Assoc 14 (8):542-559. https://doi.org/10.1016/j.jamda.2013.05.021
14. Deer RR, Volpi E (2015) Protein intake and muscle function in older adults. Curr Opin Clin Nutr Metab Care 18 (3):248-253. https://doi.org/10.1097/MCO.0000000000000162
15. IPCC (2019) Climate Change and Land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Intergovernmental Panel on Climate Change (IPCC), Geneva, Switzerland.

16. Howarth RW (2004) Human acceleration of the nitrogen cycle: drivers, consequences, and steps toward solutions. Water Sci Technol 49 (5-6):7-13
17. Aiking H, de Boer J (2018) The next protein transition. Trends Food Sci Tech. https://doi.org/10.1016/j.tifs.2018.07.008
18. Willett W, Rockstrom J, Loken B, Springmann M, Lang T, Vermeulen S et al (2019) Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems. Lancet 393 (10170):447-492. https://doi.org/10.1016/s0140-6736(18)31788-4
19. Tukker A, Goldbohm RA, de Koning A, Verheijden M, Kleijn R, Wolf O et al (2011) Environmental impacts of changes to healthier diets in Europe. Ecol Econ 70 (10):1776-1788. https://doi.org/10.1016/j.ecolecon.2011.05.001
20. Hengeveld LM, Pelgröm ADA, Visser M, Boer JMA, Haveman-Nies A, Wijnhoven HAH (2019) Comparison of protein intake per eating occasion, food sources of protein and general characteristics between community-dwelling older adults with a low and high protein intake. Clin Nutr ESPEN 29:165-174. https://doi.org/10.1016/j.clnesp.2018.10.013
21. Tieland M, Borgonjen-Van den Berg KJ, Van Loon LJ, de Groot LC (2015) Dietary protein intake in Dutch elderly people: A focus on protein sources. Nutrients 7 (12):9697-9706. https://doi.org/10.3390/nu7125496
22. Kromhout D, Spaaij CJK, de Goede J, Weggemans RM (2016) The 2015 Dutch food-based dietary guidelines. Eur J Clin Nutr 70 (8):869-878. https://doi.org/10.1038/ejcn.2016.52
23. Zheng Y, Li Y, Satija A, Pan A, Sotos-Prieto M, Rimm E et al (2019) Association of changes in red meat consumption with total and cause specific mortality among US women and men: two prospective cohort studies. BMJ 365:l2110. https://doi.org/10.1136/bmj.l2110
24. Schwingshackl L, Schwedhelm C, Hoffmann G, Lampousi AM, Knuppel S, Iqbal K et al (2017) Food groups and risk of all-cause mortality: a systematic review and meta-analysis of prospective studies. Am J Clin Nutr 105 (6):1462-1473. https://doi.org/10.3945/ajcn.117.153148
25. The Netherlands Nutrition Center (Voedingscentrum) (2018) Source document: Towards a more plant-based diet (in Dutch). Voedingscentrum, The Hague.
26. The Dutch National Goverment (2019) Climate Agreement (in Dutch). Rijksoverheid, The Hague, The Netherlands.
27. The Dutch National Goverment (2019) Dit is een achtergrondnotitie ten behoeve van de sectoraltafel Landbouw en landgebruik. Rijksoverheid, The Hague.
28. European Commission (2020) Farm to Fork Strategy: For a fair, healthy and environmentally-friendly food system. European Union, Brussels.
29. European Commission (2019) Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. The European Green Deal. COM(2019) 640 final. European Commission, Brussels.
30. IPCC (2018) Global warming of 1.5°C: An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. World Meteorological Organization, Geneva, Switzerland
31. Lonnie M, Hooker E, Brunstrom JM, Corfe BM, Green MA, Watson AW et al (2018) Protein for life: Review of optimal protein intake, sustainable dietary sources and the effect on appetite in ageing adults. Nutrients 10 (3). https://doi.org/10.3390/nu10030360
32. Huisman M, Poppelaars J, van der Horst M, Beekman AT, Brug J, van Tilburg TG et al (2011) Cohort profile: the Longitudinal Aging Study Amsterdam. Int J Epidemiol 40 (4):868-876. https://doi.org/10.1093/ije/dyq219

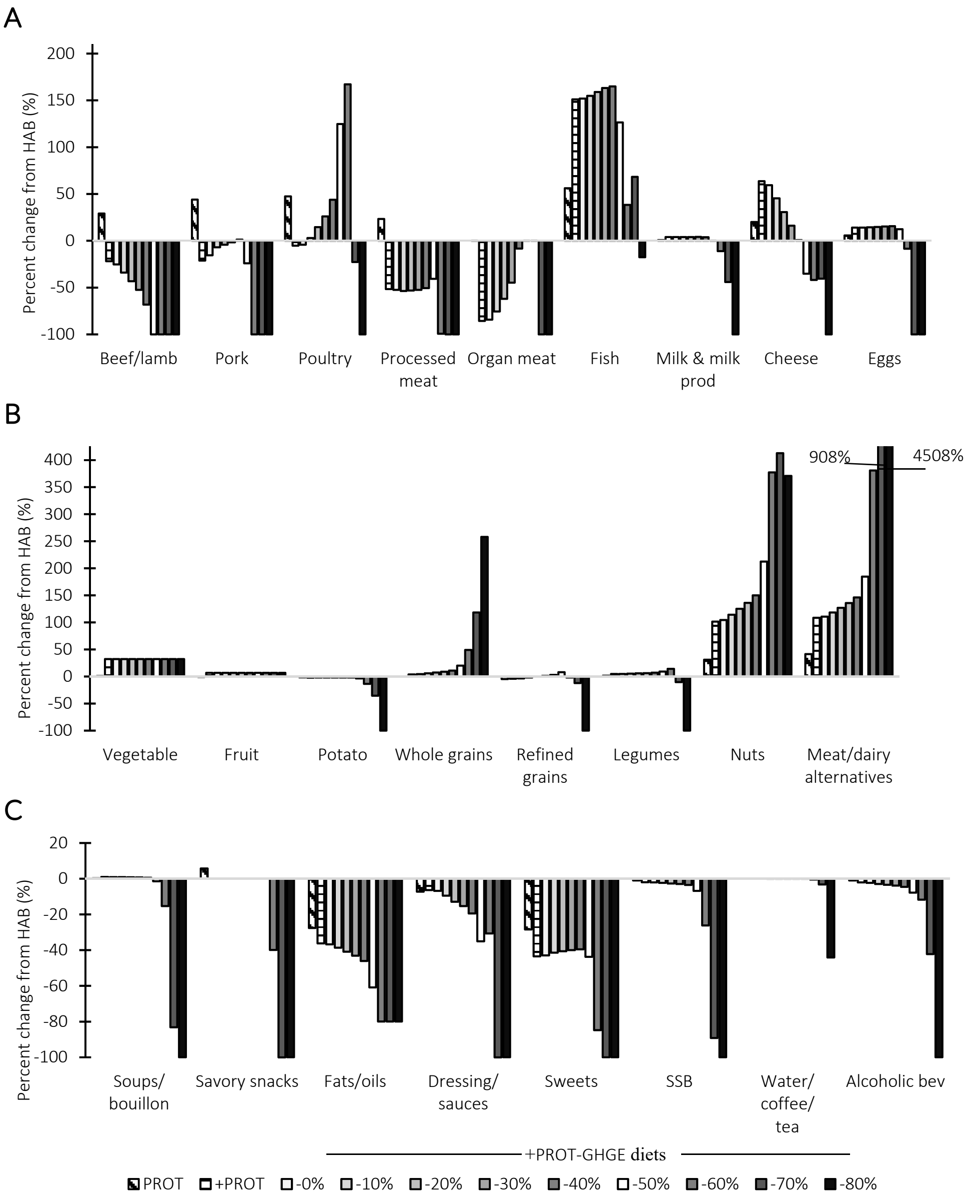
33. Hoogendijk EO, Deeg DJ, Poppelaars J, van der Horst M, Broese van Groenou MI, Comijs HC et al (2016) The Longitudinal Aging Study Amsterdam: cohort update 2016 and major findings. Eur J Epidemiol 31 (9):927-945. https://doi.org/10.1007/s10654-016-0192-0
34. Stel VS, Smit JH, Pluijm SMF, Visser M, Deeg DJH, Lips P (2004) Comparison of the LASA Physical Activity Questionnaire with a 7-day diary and pedometer. J Clin Epidemiol 57 (3):252-258. https://doi.org/10.1016/j.jclinepi.2003.07.008
35. Drewelies J, Deeg DJH, Huisman M, Gerstorf D (2018) Perceived constraints in late midlife: Cohort differences in the Longitudinal Aging Study Amsterdam (LASA). Psychol Aging 33 (5):754-768. https://doi.org/10.1037/pag0000276
36. Winkens LHH, van Strien T, Barrada JR, Brouwer IA, Penninx BWJH, Visser M (2018) The Mindful Eating Behavior Scale: Development and psychometric properties in a sample of Dutch adults aged 55 years and older. J Acad Nutr Diet 118 (7):1277-1290.e1274. https://doi.org/10.1016/j.jand.2018.01.015
37. Wijnhoven HAH, Elstgeest LEM, de Vet HCW, Nicolaou M, Snijder MB, Visser M (2018) Development and validation of a short food questionnaire to screen for low protein intake in community-dwelling older adults: The Protein Screener 55+ (Pro55+). PLOS ONE 13 (5):e0196406. https://doi.org/10.1371/journal.pone.0196406
38. Visser M, Elstgeest LEM, Winkens LHH, Brouwer IA, Nicolaou M (2020) Relative validity of the HELIUS food frequency questionnaire for measuring dietary intake in older adult participants of the Longitudinal Aging Study Amsterdam. Nutrients 12 (7):1998. https://doi.org/10.3390/nu12071998
39. Beukers MH, Dekker LH, de Boer EJ, Perenboom CWM, Meijboom S, Nicolaou M et al (2014) Development of the HELIUS food frequency questionnaires: ethnic-specific questionnaires to assess the diet of a multiethnic population in The Netherlands. Eur J Clin Nutr 69:579. https://doi.org/10.1038/ejcn.2014.180
40. RIVM (2011) Dutch Food Composition Table 2011. National Institute for Public Health and the Netherlands Nutrition Centre (RIVM), Bilthoven.
41. U.S. Department of Agriculture, Agricultural Research Service (2019) FoodData Central. fdc.nal.usda.gov. Accessed 27 February 2020
42. Frida Food Data, Version 4 (2019). National Food Institute, Technical University of Denmark,
43. RIVM (2010) Dutch National Food Consumption Survey 2007-2010. Part 1 Food groups, based on dataset FCS_2010_core_20111125 National Institute for Public Health and the Environment (RIVM), Bilthoven.
44. Huijbregts MAJ, Steinmann ZJN, Elshout PMF, Stam G, Verones F, Vieira MDM et al (2016) ReCiPe 2016: A harmonized life cycle impact assessment method at midpoint and endpoint level Report I: Characterization. National Institute for Public Health and the Environment, Bilthoven, The Netherlands.
45. van Paasen M, Braconi N, Kuling L, Durlinger B, Gual P (2019) Agri-Footprint 5.0 Part 1: Methodology and basic principles. Blonk Consultants, Gouda.
46. Van Rossum CTM, Fransen HP, Verkaik-Kloosterman J, Buurma-Rethans EJM, Ocké MC (2011) Dutch National Food Consumption Survey 2007-2010. Diet of children and adults aged 7 to 69 years. National Institute for Public Health and the Environment, Bilthoven, The Netherlands.
47. de Valk E, Hollander A, Zijp M (2016) Environmental impact of food consumption in the Netherlands (in Dutch). National Institute for Public Health and the Netherlands Nutrition Centre (RIVM), Bilthoven.
48. Gazan R, Brouzes CMC, Vieux F, Maillot M, Lluch A, Darmon N (2018) Mathematical optimization to explore tomorrow's sustainable diets: A narrative review. Adv Nutr 9 (5):602-616. https://doi.org/10.1093/advances/nmy049
49. Kramer G, Martinez EV, Tyszler M (2015) Optimeal(R) Optimizing diets on health and sustainability: User's manual. Blonk Consultants, Gouda, The Netherlands.

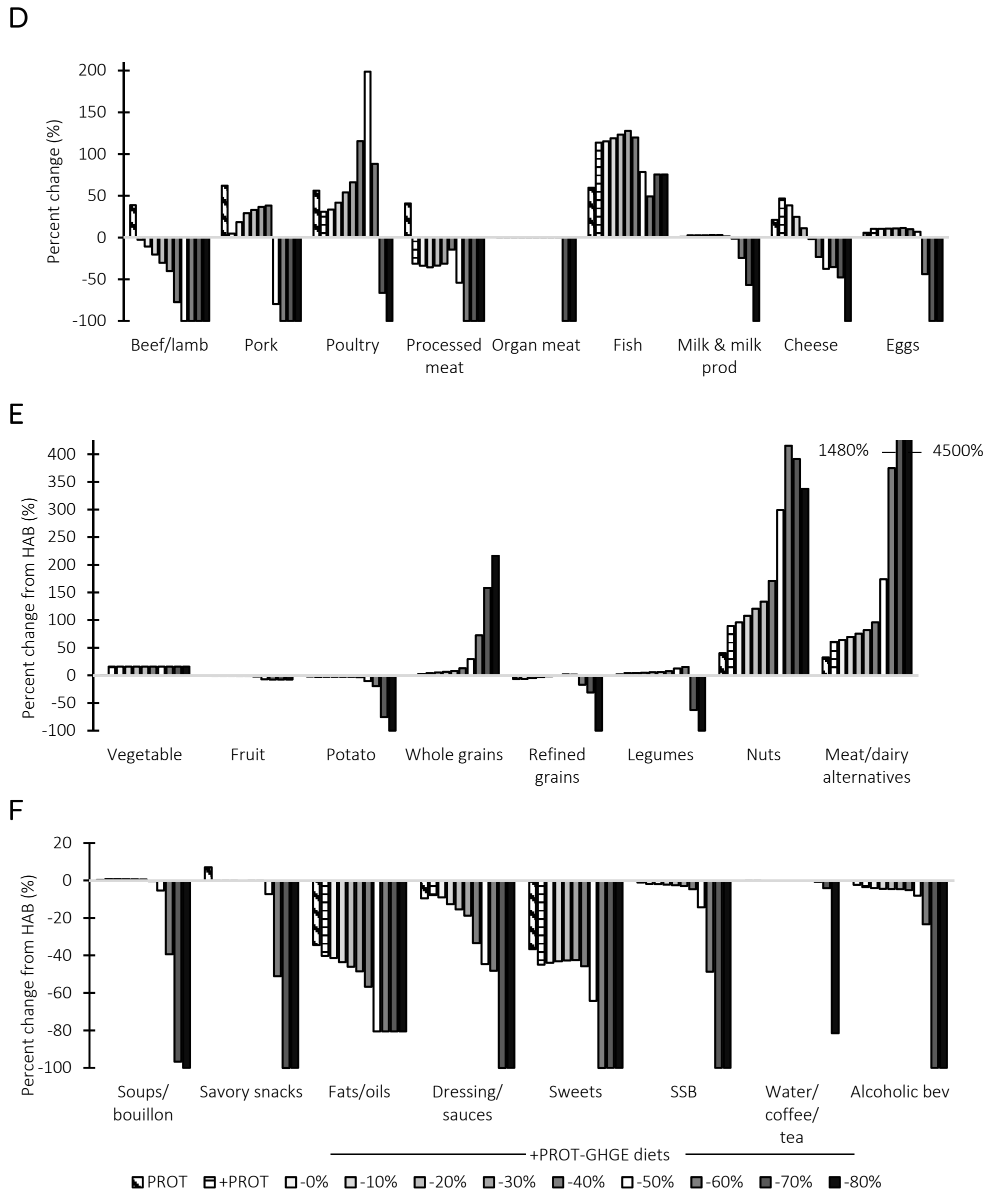
50. Kramer GF, Tyszler M, Veer PV, Blonk H (2017) Decreasing the overall environmental impact of the Dutch diet: how to find healthy and sustainable diets with limited changes. Public Health Nutr 20 (9):1699-1709. https://doi.org/10.1017/s1368980017000349
51. Vieux F, Perignon M, Gazan R, Darmon N (2018) Dietary changes needed to improve diet sustainability: are they similar across Europe? Eur J Clin Nutr 72 (7):951-960. https://doi.org/10.1038/s41430-017-0080-z
52. Nowson C, O'Connell S (2015) Protein requirements and recommendations for older people: A review. Nutrients 7 (8):6874-6899. https://doi.org/10.3390/nu7085311
53. Health Council of the Netherlands (2018) Nutritional standards for vitamins and minerals for adults (report in Dutch). Health Council of the Netherlands (Gezondheidsraad), The Hague.
54. EFSA (2017) Dietary reference values for nutrients: Summary report. EFSA supporting publication 2017:e15121. . European Food Safety Authority
55. Brink E, van Rossum C, Postma-Smeets A, Stafleu A, Wolvers D, van Dooren C et al (2019) Development of healthy and sustainable food-based dietary guidelines for the Netherlands. Public Health Nutr 22 (13):2419-2435. https://doi.org/10.1017/S1368980019001435
56. Health Council of the Netherlands (2011) Guidelines for a healthy diet: The ecological perspective. Health Council of the Netherlands (Gezondheidsraad), The Hague.
57. Perignon M, Masset G, Ferrari G, Barre T, Vieux F, Maillot M et al (2016) How low can dietary greenhouse gas emissions be reduced without impairing nutritional adequacy, affordability and acceptability of the diet? A modelling study to guide sustainable food choices. Public Health Nutr 19 (14):2662-2674. https://doi.org/10.1017/s1368980016000653
58. Maillot M, Darmon N, Drewnowski A (2010) Are the lowest-cost healthful food plans culturally and socially acceptable? Public Health Nutr 13 (8):1178-1185. https://doi.org/10.1017/s1368980009993028
59. Macdiarmid JI, Kyle J, Horgan GW, Loe J, Fyfe C, Johnstone A et al (2012) Sustainable diets for the future: Can we contribute to reducing greenhouse gas emissions by eating a healthy diet? Am J Clin Nutr 96 (3):632-639. https://doi.org/10.3945/ajcn.112.038729
60. van Vliet S, Burd NA, van Loon LJ (2015) The skeletal muscle anabolic response to plant- versus animal-based protein consumption. J Nutr 145 (9):1981-1991. https://doi.org/10.3945/jn.114.204305
61. Berrazaga I, Micard V, Gueugneau M, Walrand S (2019) The role of the anabolic properties of plant- versus animal-based protein sources in supporting muscle mass maintenance: A critical review. Nutrients 11 (8):1825. https://doi.org/10.3390/nu11081825
62. Devries MC, McGlory C, Bolster DR, Kamil A, Rahn M, Harkness L et al (2018) Leucine, not total protein, content of a supplement is the primary determinant of muscle protein anabolic responses in healthy older women. J Nutr 148 (7):1088-1095. https://doi.org/10.1093/jn/nxy091
63. Barré, T, Perignon M, Gazan R, Vieux F, Micard V et al (2018) Integrating nutrient bioavailability and co-production links when identifying sustainable diets: How low should we reduce meat consumption? PLOS ONE 13 (2):e0191767. https://doi.org/10.1371/journal.pone.0191767
64. Salomé M, de Gavelle E, Dufour A, Dubuisson C, Volatier J-L, Fouillet H et al (2019) Plant-protein diversity is critical to ensuring the nutritional adequacy of diets when replacing animal with plant protein: Observed and modeled diets of French adults (INCA3). J Nutr 150 (3):536-545. https://doi.org/10.1093/jn/nxz252
65. Parker RWR, Blanchard JL, Gardner C, Green BS, Hartmann K, Tyedmers PH et al (2018) Fuel use and greenhouse gas emissions of world fisheries. Nat Clim Chang 8 (4):333-337. https://doi.org/10.1038/s41558-018-0117-x
66. Seves SM, Temme EHM, Brosens MCC, Zijp MC, Hoekstra J, Hollander A (2016) Sustainability aspects and nutritional composition of fish: evaluation of wild and cultivated fish

species consumed in the Netherlands. Clim Change 135 (3):597-610. https://doi.org/10.1007/s10584-015-1581-1
67. Hollander A, De Jonge R, Biesbroek S, Hoekstra J, Zijp MC (2019) Exploring solutions for healthy, safe, and sustainable fatty acids (EPA and DHA) consumption in The Netherlands. Sus Sci 14 (2):303-313. https://doi.org/10.1007/s11625-018-0607-9
68. van Dooren C, Tyszler M, Kramer FG, Aiking H (2015) Combining low price, low climate impact and high nutritional value in one shopping basket through diet optimization by linear programming. Sustainability 7 (9). https://doi.org/10.3390/su70912837
69. Poore J, Nemecek T (2018) Reducing food's environmental impacts through producers and consumers. Science 360 (6392):987-992. https://doi.org/10.1126/science.aaq0216

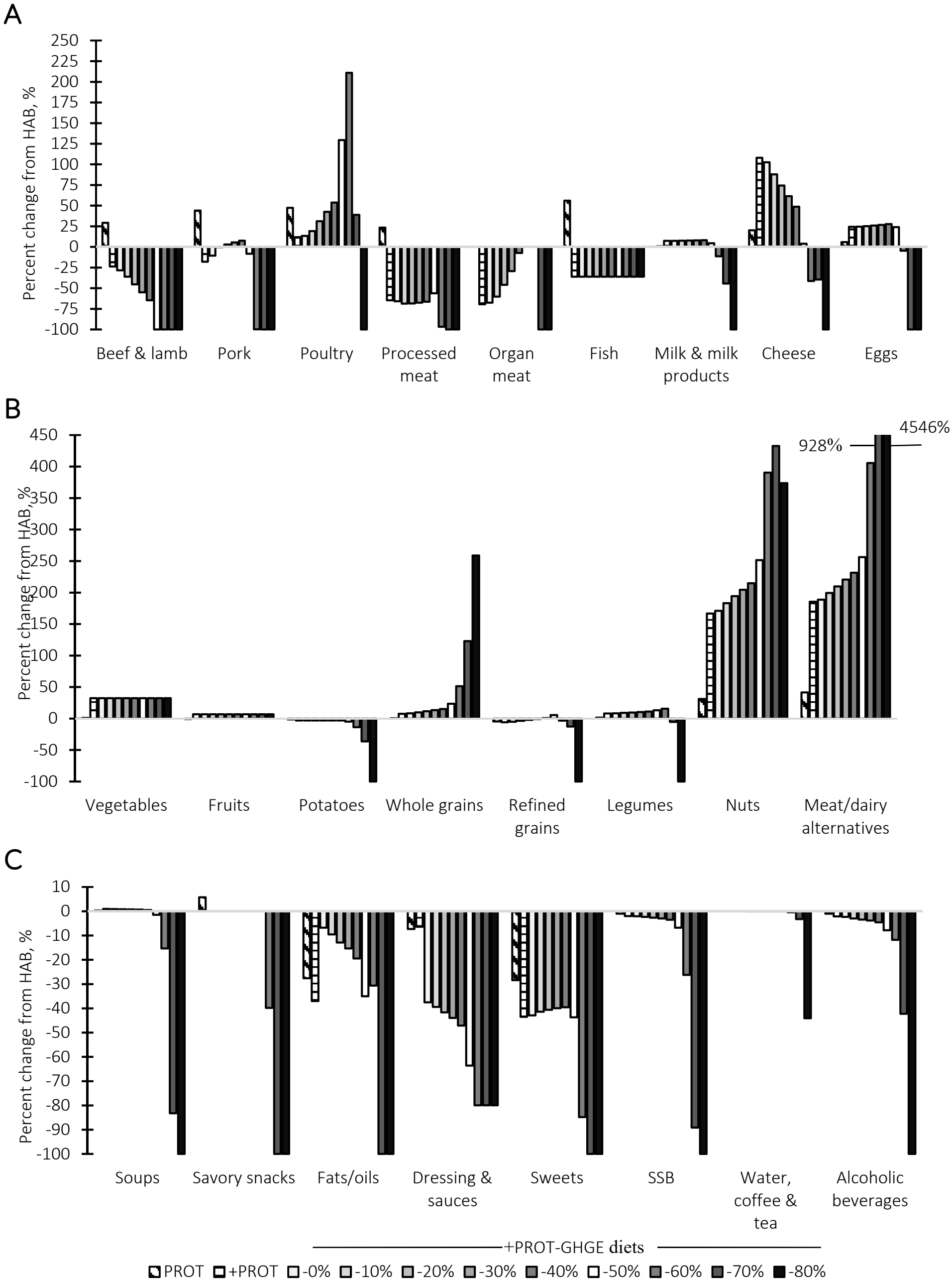
Supplementary Material

Supplementary Figure 1 Percent change in food group quantities from the habitual diet to a high-protein diet, high-protein diet aligned with the Dutch food-based dietary guidelines (with a minimum constraint of one serving of fish per week), and high-protein diets aligned with the Dutch food-based dietary guidelines accounting for greenhouse gas emissions in older Dutch men (A-C, n=644) and women (D-F, n=710) aged 56-101y. The percentage on the +PROT-GHGE diets is the percent reduction in GHGE applied to the diet. Panels A and C include protein-rich food groups derived from animals, Panels B and E include protein-rich food groups derived from plants, and Panels C and F include other food groups. Bars in panels B and E for the food group meat/dairy alternatives for +PROT-GHGE-70% and -80% were truncated in figure. Abbreviations: GHGE greenhouse gas emissions, HAB habitual diet, PROT high-prtoein diet, +PROT high-protein diet aligned with the Dutch food-based dietary guidelines, +PROT-GHGE high-protein diets aligned with the Dutch food-based dietary guidelines accounting for greenhouse gas emissions; SSB sugar-sweetened beverages.

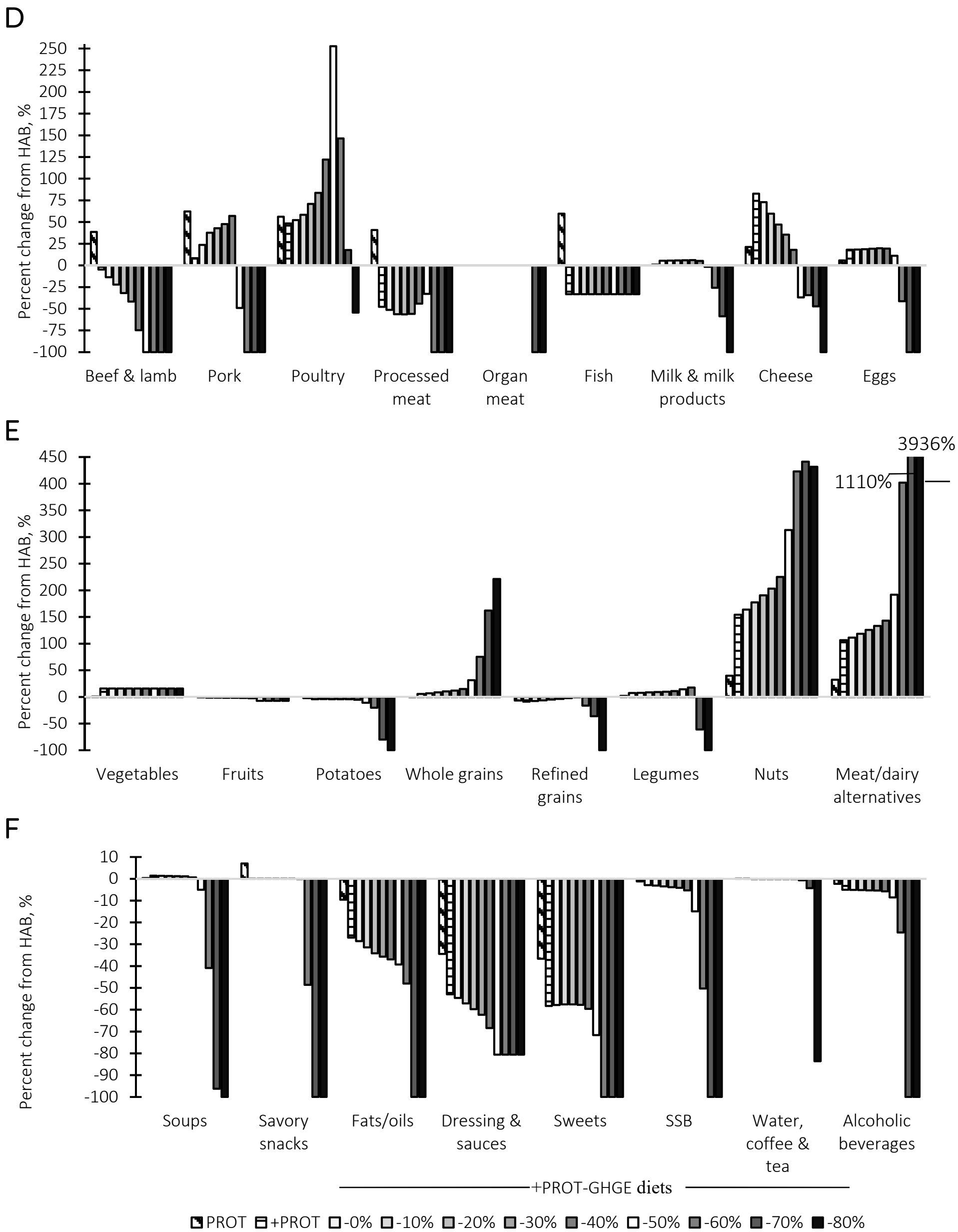

A
Percent change from HAB (%)
200
150
100
50
0
-50
-100
Beef/lamb
Pork
Poultry
Processed meat
Organ meat
Fish
Milk & milk prod
Cheese
Eggs
B
Percent change from HAB (%)
400
350
300
250
200
150
100
50
0
-50
-100
908%
4508%
Vegetable
Fruit
Potato
Whole grains
Refined grains
Legumes
Nuts
Meat/dairy alternatives
C
Percent change from HAB (%)
20
0
-20
-40
-60
-80
-100
Soups/ bouillon
Savory snacks
Fats/oils
Dressing/ sauces
Sweets
SSB
Water/ coffee/ tea
Alcoholic bev
+PROT-GHGE diets
PROT
+PROT
-0%
-10%
-20%
-30%
-40%
-50%
-60%
-70%
-80%


D
Percent change (%)
200
150
100
50
0
-50
-100
Beef/lamb
Pork
Poultry
Processed meat
Organ meat
Fish
Milk & milk prod
Cheese
Eggs
E
Percent change from HAB (%)
1480%
4500%
400
350
300
250
200
150
100
50
0
-50
-100
Vegetable
Fruit
Potato
Whole grains
Refined grains
Legumes
Nuts
Meat/dairy alternatives
F
Percent change from HAB (%)
20
0
-20
-40
-60
-80
-100
Soups/ bouillon
Savory snacks
Fats/oils
Dressing/ sauces
Sweets
SSB
Water/ coffee/ tea
Alcoholic bev
+PROT-GHGE diets
PROT
+PROT
-0%
-10%
-20%
-30%
-40%
-50%
-60%
-70%
-80%

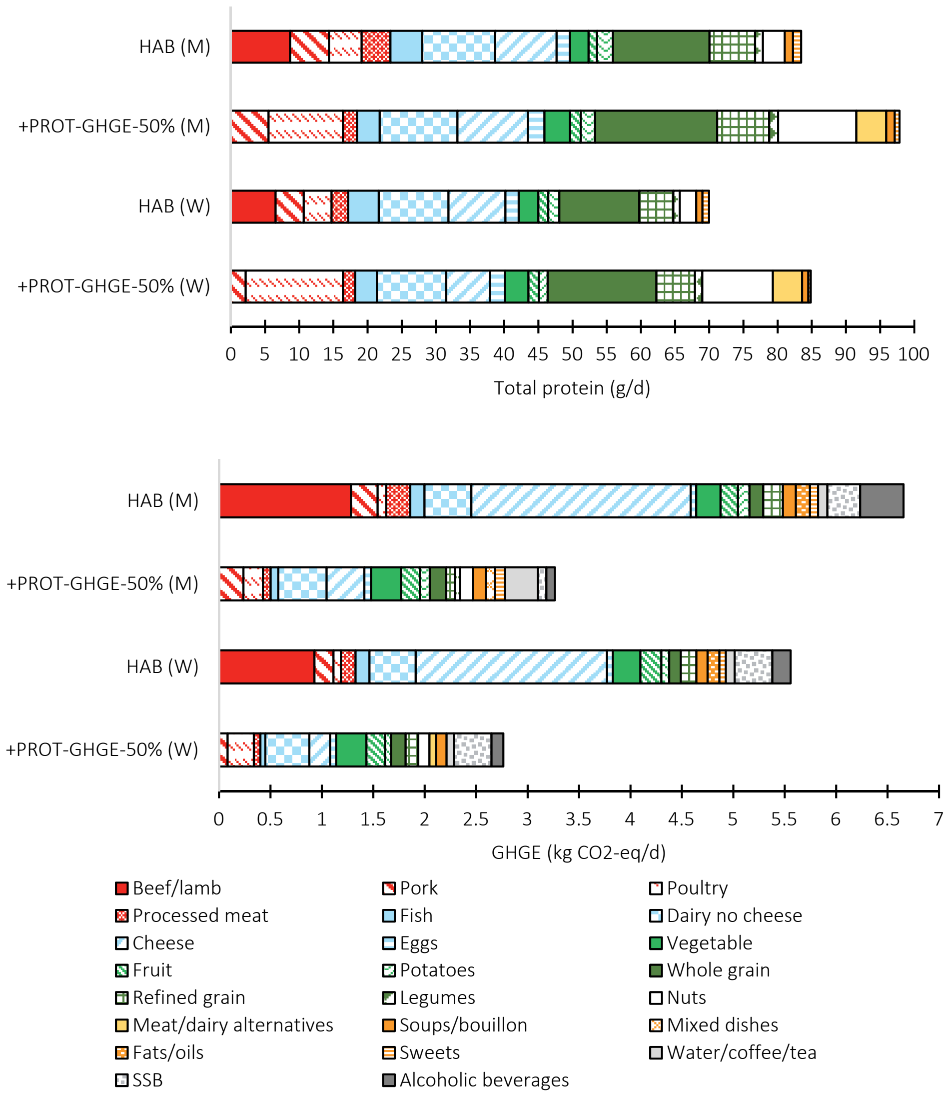
Supplementary Figure 2 Percent change in food group quantities from the habitual diet to a high-protein diet, high-protein diet aligned with the Dutch food-based dietary guidelines, and high-protein diets aligned with the Dutch food-based dietary guidelines accounting for greenhouse gas emissions in older Dutch men (A-C; n=644) women (D-F, n=710) aged 56-101y. The percentage on the +PROT-GHGE diets is the percent reduction in GHGE applied to the diet. Panels A and D include protein-rich food groups derived from animals, Panels B and E include protein-rich food groups derived from plants, and Panels C and F include other food groups. Bars in panels B and E for the food group meat/dairy alternatives for +PROT-GHGE-70% and -80% were truncated in figure. Abbreviations: GHGE greenhouse gas emissions, HAB habitual diet, PROT high-prtoein diet, +PROT high-protein diet aligned with the Dutch food-based dietary guidelines, +PROT-GHGE high-protein diets aligned with the Dutch food-based dietary guidelines accounting for greenhouse gas emissions; SSB sugar-sweetened beverages.



A
Percent change from HAB, %
250
225
200
175
150
125
100
75
50
25
0
-25
-50
-75
-100
Beef & lamb
Pork
Poultry
Processed meat
Organ meat
Fish
Milk & milk products
Cheese
Eggs
B
Percent change from HAB, %
450
400
350
300
250
200
150
100
50
0
-50
-100
928%
4546%
Vegetables
Fruits
Potatoes
Whole grains
Refined grains
Legumes
Nuts
Meat/dairy alternatives
C
Percent change from HAB, %
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
Soups
Savory snacks
Fats/oils
Dressing & sauces
Sweets
SSB
Water, coffee & tea
Alcoholic beverages
+PROT-GHGE diets
PROT
+PROT
-0%
-10%
-20%
-30%
-40%
-50%
-60%
-70%
-80%


D
Percent change from HAB, %
250
225
200
175
150
125
100
75
50
25
0
-25
-50
-75
-100
Beef & lamb
Pork
Poultry
Processed meat
Organ meat
Fish
Milk & milk products
Cheese
Eggs
E
Percent change from HAB, %
450
400
350
300
250
200
150
100
50
0
-50
-100
3936%
1110%
Vegetables
Fruits
Potatoes
Whole grains
Refined grains
Legumes
Nuts
Meat/dairy alternatives
F
Percent change from HAB, %
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
Soups
Savory snacks
Fats/oils
Dressing & sauces
Sweets
SSB
Water, coffee & tea
Alcoholic beverages
+PROT-GHGE diets
PROT
+PROT
-0%
-10%
-20%
-30%
-40%
-50%
-60%
-70%
-80%

Supplementary Figure 3 Contribution of the food groups to total protein intake (g/d) and GHGE (kg CO_2eq/d) in the habitual diet (HAB) and the high-protein diet aligned with the Dutch food-based dietary guidelines accounting for a 50% GHGE reduction in older Dutch men (M, n=644) and women (W, n=710) aged 56-101y. For clarity purposes, values < 1 g protein and < 0.05 kg CO_2-eq are not shown. Abbreviations: GHGE greenhouse gas emissions; HAB habitual diet; M men; +PROT-GHGE-50% high-protein diet aligned with the Dutch food-based dietary guidelines with a 50% GHGE reduction; W women.



Supplementary Table 1 Habitual intake of 254 food items of older Dutch men (M, n=644) and women (W, n=710) aged 56-101y, assessed using a validated food frequency questionnaire during the LASA side study Nutrition and Food-Related Behavior study.

Food item	Food group	Intake M (g/d)	Intake W (g/d)	Portion size (g)
Muesli, cruesli	Whole grains	5.0	5.1	10
Porridge	Whole grains	2.0	1.5	6
Cornflakes or other cereal	Refined grains	0.5	0.6	4
Full-fat milk with breakfast	Dairy except cheese	1.2	0.7	34
Skim milk, buttermilk for breakfast	Dairy except cheese	2.1	2.0	47
Soy milk/yogurt for breakfast	Meat/dairy alternative	3.3	3.7	21
Yogurt full-fat	Dairy except cheese	4.0	3.3	21
Yogurt half-fat	Dairy except cheese	4.0	6.8	21
Yogurt skim	Dairy except cheese	4.7	7.1	21
Yogurt/quark with fruit for breakfast	Dairy except cheese	2.0	1.0	21
Sweets added with breakfast	Sugar and confectionary	1.2	0.8	14
Breakfast drink prepared	Dairy except cheese	3.3	2.3	200
Rusks, crackers, etc. light	Refined grains	1.1	1.5	10
Rusks, crackers, etc. dark	Whole grains	3.1	4.4	10
Croissants	Refined grains	2.2	1.0	62
Bread rolls white	Refined grains	4.3	2.0	47
Bread rolls brown/corn	Whole grains	3.3	2.3	49
Bread rolls whole wheat	Whole grains	2.2	0.8	50
Bread rolls grain	Whole grains	1.8	1.3	49
Bread rolls with dried fruit and muesli	Refined grains	2.6	1.7	50
Bread white	Refined grains	6.8	3.2	30
Bread brown/wheat/ corn	Whole grains	28.5	18.1	35
Bread brown whole wheat	Whole grains	38.3	34.5	35
Bread grain with seeds average	Whole grains	31.5	27.1	35
Bread with dried fruit and muesli	Refined grains	5.7	4.7	38
Bread rye	Whole grains	7.6	5.8	41
Breakfast cookie	Refined grains	4.8	6.3	21
Butter with herbs/garlic	Fats/oils	2.6	2.4	6
Butter half-fat	Fats/oils	0.6	0.9	6
Spread extra light	Fats/oils	0.7	0.7	6
Halvarine diet	Fats/oils	5.4	4.9	6
Halvarine/light margarine	Fats/oils	6.8	4.6	6
Margarine in package	Fats/oils	0.2	0.2	6
Margarine in tub	Fats/oils	2.8	1.4	6
Margarine diet	Fats/oils	3.0	2.7	6
Hard Dutch Cheese 48+ or 40+	Cheese	17.5	15.0	23
Hard Dutch Cheese 20+ or 30+	Cheese	8.4	7.5	23
Cheese spread 40+ or 48+	Cheese	1.5	0.8	23
Cheese spread 20+ or 30+	Cheese	0.6	2.2	23
Cream cheese with herbs	Cheese	0.2	0.6	23
Other cheese	Cheese	0.8	1.8	23
Liver products	Organ meat	2.5	1.4	14
Meat ham, chicken fillet, smoked meat, roast beef, fricandeau and the like.	Processed meat	7.7	5.7	14
Meat products cervelat sausage, bacon, bacon, luncheon meat and the like.	Processed meat	5.2	1.5	14
Meat products luncheon meat, corned beef, roast minced meat, cooked sausage and the like.	Processed meat	3.3	1.1	14
Meat products vegetarian	Meat/dairy alternatives	0.1	0.1	14
Meat products excluding liver products average	Processed meat	0.6	0.7	14
Peanut butter	Nuts	3.1	2.0	15
Chocolate sandwich filling	Sugar and confectionary	4.4	3.0	15
Sweet sandwich filling	Sugar and confectionary	8.4	8.1	18
Sandwich spread	Condiments and sauces	0.3	0.4	15
Fish salad for lunch/snack	37% Fish and shellfish 63% Condiments and sauces	1.3	1.2	30

Food item	Food group	Intake M (g/d)	Intake W (g/d)	Portion size (g)
Salad other for lunch/snack	9% Vegetables 5.5% Poultry 5.5% Pork 34% Egg 46% Condiments and sauces	0.8	1.0	30
Egg cooked average	Egg	15.4	15.5	50
Milk full-fat	Dairy except cheese	8.5	8.6	200
Milk skim	Dairy except cheese	5.8	10.5	200
Buttermilk	Dairy except cheese	41.5	52.2	200
Soy milk	Meat/dairy alternative	4.1	3.6	200
Drink yogurt with sweetener	Dairy except cheese	10.8	7.2	200
Drink yogurt with less sugar	Dairy except cheese	2.2	2.8	200
Drink yogurt with sugar	Dairy except cheese	3.1	1.0	200
Milk and fruit	Dairy except cheese	2.1	0.5	200
Dairy drink with fruit flavor other	Dairy except cheese	1.8	1.6	200
Chocolate milk full-fat	Dairy except cheese	3.0	2.8	200
Chocolate milk half-fat	Dairy except cheese	6.8	5.2	200
Chocolate milk skim	Dairy except cheese	2.3	1.0	200
Chocolate milk from dispenser	Dairy except cheese	0.7	0.8	200
Soy milk diverse flavors	Meat/dairy alternative	0.2	1.4	200
Pudding, bavarois, mousse	Dairy except cheese	4.5	4.4	150
Custard	Dairy except cheese	19.4	14.1	150
Yogurt/quark full-fat	Dairy except cheese	8.1	11.4	150
Yogurt/quark half-fat	Dairy except cheese	13.8	13.5	150
Yogurt/quark skim	Dairy except cheese	10.1	17.0	150
Yogurt/quark with fruit full-fat	Dairy except cheese	2.3	2.1	150
Yogurt/quark with fruit/vanilla half-fat	Dairy except cheese	9.3	11.5	150
Yogurt/quark with fruit skim	Dairy except cheese	4.9	7.8	150
Yogurt/quark with fruit with sweetener	Dairy except cheese	0.5	0.4	150
Soy dessert/yogurt/ice	Meat/dairy alternative	0.7	2.9	150
Sweetener for dessert	Sugar and confectionary	1.6	1.6	14
Ice cream milk	Sugar and confectionary	4.5	3.4	40
Ice cream water	Sugar and confectionary	0.4	0.4	40
Whipped cream	Dairy except cheese	0.9	0.8	10
Soup with pulses/legumes	25% Legumes 75% Soup and bouillon	15.5	9.6	225
Soup other	Soups, bouillon	47.4	41.7	225
Pizza	21% Vegetables 12% Cheese 54% Refined grains 8% Processed meat 2% Fish and shellfish 3% Condiments and sauces	8.6	4.9	375
Pancakes	Refined grains	5.7	3.7	82
Pasta white, bami	Refined grains	21.3	13.7	188
Whole wheat pasta cooked	Whole grains	8.7	7.5	188
Rice white, nasi	Refined grains	14.0	8.3	163
Rice brown, other grain	Whole grains	8.0	7.0	163
Pulses/legumes	Legumes	15.0	12.6	179
Fries/potato dish prepared	Potatoes	3.6	2.2	132
Fried/potato fish fried at home	Potatoes	6.1	3.5	132
Fried/potato fish prepared in oven at home	Potatoes	2.0	1.6	132
Potatoes cooked, baked, puree	Potatoes	92.2	65.0	157
Eggplant cooked	Vegetables	1.8	1.8	166
Courgette cooked	Vegetables	3.7	5.1	166
Onion, leek warm	Vegetables	5.7	6.4	166
Tomato warm	Vegetables	17.1	24.3	166
Paprika warm	Vegetables	11.9	13.7	166
Cauliflower cooked	Vegetables	10.0	9.9	166
Broccoli cooked	Vegetables	8.0	9.8	166
Carrots warm	Vegetables	10.5	12.5	166
Peas warm	Vegetables	6.3	5.5	166
Green beans warm	Vegetables	14.5	13.8	166

Food item	Food group	Intake M (g/d)	Intake W (g/d)	Portion size (g)
Garden beans warm	Vegetables	2.6	2.4	166
Brussel sprouts cooked	Vegetables	7.2	7.8	166
Spinach warm	Vegetables	7.8	7.6	166
Other vegetables warm	Vegetables	13.5	16.9	166
Lettuce raw	Vegetables	3.4	3.5	0
Carrots raw average	Vegetables	2.2	2.5	1
Cabbage varieties raw	Vegetables	1.5	1.1	1
Cucumber raw	Vegetables	6.3	8.0	2
Onion, spring onion raw	Vegetables	2.7	3.0	1
Tomato raw	Vegetables	9.2	12.0	2
Other vegetables raw	Vegetables	3.2	3.7	1
Vinegar or dressing without oil	Condiments and sauces	0.2	0.2	0
Dressing with oil and vinegar	Condiments and sauces	1.4	1.7	0
Salad dressing	Condiments and sauces	0.8	1.0	0
Mayonnaise as dressing	Condiments and sauces	0.1	0.1	0
Dressing other	Condiments and sauces	0.4	0.6	0
Applesauce/fruit compote	Fruit	14.1	9.5	39
Mussels cooked	Fish and shellfish	1.6	1.6	100
Shellfish other	Fish	2.2	1.8	100
Herring	Fish	2.5	1.9	77
Mackerel, salmon, eel, sardines, etc.	Fish	4.9	5.0	120
Cod, plaice, tuna, pangasius, etc.	Fish	5.4	5.6	120
Trout, salmon trout, tilapia, etc.	Fish	1.7	1.5	120
Fish sticks, etc.	Fish	2.4	2.5	120
Tilapia prepared without fat	Fish	0.4	0.3	120
Liver	Organ meat	0.6	0.2	97
Beef kidney raw	Organ meat	0.1	0.0	97
Chicken raw	Poultry	10.3	9.1	93
Chicken with skin	Poultry	3.0	2.0	93
Chicken without skin	Poultry	1.7	1.5	93
Chicken products breaded	Poultry	1.0	1.1	93
Minced beef	Beef/lamb	8.8	9.3	93
Minced meat half/half	50% Beef/lamb 50% Pork	5.5	3.2	93
Minced meat other	50% Beef/lamb 50% Pork	0.3	0.3	93
Lean beef	Beef/lamb	8.7	5.9	93
Fatty beef	Beef/lamb	8.8	6.3	93
Other beef	Beef/lamb	1.5	0.8	93
Lean pork	Pork	6.2	4.4	95
Average pork	Pork	5.6	4.1	95
Fatty pork	Pork	5.1	4.0	95
Other pork	Pork	0.6	0.6	95
Smoked sausage, frankfurters	Processed meat	5.7	3.7	95
Other meat	Beef/lamb	3.1	2.0	97
Vegetarian unprepared	Meat/dairy alternative	0.6	0.8	100
Tahoe, tempeh	Meat/dairy alternatives	0.7	0.9	100
Soy products other	Meat/dairy alternatives	0.8	0.9	100
Meat substitute products other	Meat/dairy alternative	0.7	1.0	100
Nuts, seeds with warm meal	Nuts	1.1	1.5	16
Cheese with warm meal	Cheese	2.4	2.9	11
Cream with warm meal	Dairy except cheese	0.9	0.9	17
Tomato sauce from fresh tomatoes	Condiments and sauces	0.9	0.8	12
Tomato sauce prepared in jar	Condiments and sauces	1.4	1.1	12
Peanut/sate sauce	Condiments and sauces	1.0	0.7	15
Sauce warm other	Condiments and sauces	0.8	1.0	12
Mayonnaise with warm meal	Condiments and sauces	0.8	0.6	20
Garlic sauce with warm meal	Condiments and sauces	0.8	0.7	20
Ketchup or other red sauce with warm meal	Condiments and sauces	1.0	0.7	25
Other sauce with warm meal	Condiments and sauces	0.1	0.2	20
Fat used for frying outside home	Fats/oils	0.0	0.0	11
Olive oil	Fats/oils	5.2	3.6	11
Sunflower oil	Fats/oils	2.0	1.4	11

Food item	Food group	Intake M (g/d)	Intake W (g/d)	Portion size (g)
Oil other for frying	Fats/oils	0.0	0.0	11
Frying fat liquid <24 g saturated fatty acids	Fats/oils	0.4	0.2	11
Frying fat solid> 24 g saturated fatty acids <10 g trans fatty acids	Fats/oils	0.0	0.0	11
Other oil for preparing	Fats/oils	0.4	0.4	11
Butter for preparing	Fats/oils	1.4	1.4	11
Margarine in package for preparing	Fats/oils	1.4	1.1	11
Margarine in tub for preparing	Fats/oils	0.2	0.1	11
Margarine diet for preparing	Fats/oils	0.2	0.3	11
Margarine liquid for preparing	Fats/oils	1.0	1.0	11
Margarine light liquid for preparing	Fats/oils	0.5	0.3	11
Baking and frying fat in package for preparing	Fats/oils	1.7	0.8	11
Baking and frying fat liquid for preparing	Fats/oils	3.0	2.9	11
Apples	Fruits	39.2	42.0	127
Banana	Fruits	29.2	30.5	130
Orange	Fruits	27.6	29.9	140
Mandarin	Fruits	28.6	34.4	128
Grapefruit	Fruits	1.8	3.7	150
Kiwi	Fruits	8.1	12.7	75
Strawberries	Fruits	5.1	9.5	100
Grapes with skin average	Fruits	19.4	22.7	119
Other fruit varieties	Fruits	13.5	20.9	128
Food biscuit, muesli/cereal bar	Refined grains	1.1	1.1	18
Pie/pastry	Refined grains	7.2	7.6	98
Cake/big cookie	Refined grains	10.8	10.3	46
Small cookies	Refined grains	9.3	9.2	9
Candy bars	Sugar and confectionary	1.3	0.9	18
Chocolate pure	Sugar and confectionary	3.1	3.7	9
Chocolate milk	Sugar and confectionary	1.7	1.8	9
Chocolate white	Sugar and confectionary	0.3	0.2	9
Candy	Sugar and confectionary	3.8	3.3	4
French fries as snack or lunch	Potatoes	2.5	1.5	150
Fried snacks	Warm savory snack	3.6	2.2	69
Spring roll prepared	Warm savory snack	0.8	0.5	69
Sausage/cheese roll	Warm savory snack	0.8	0.4	72
Shawarma/hamburger/meatball roll	15% Vegetables 7% Cheese 30% Refined grain 42% Processed meat 6% Condiments and sauces	0.8	0.3	161
Satay	40% Pork 60% Condiments and sauces	0.7	0.3	143
Warm hearty snacks other	Warm savory snack	0.4	0.4	111
Mayonnaise, French fry sauce, garlic sauce with snacks	Condiments and sauces	0.9	0.5	25
Ketchup or other red sauce with snacks	Condiments and sauces	0.5	0.2	25
Satay sauce prepared in jar	Condiments and sauces	0.3	0.1	25
Other sauce with snacks	Condiments and sauces	0.2	0.1	25
Salad	56% Potatoes 14% Vegetables 3% Pork 3% Poultry 4% Fish and shellfish 20% Condiments and sauces	1.4	1.2	50
Peanuts, nuts as snack	Nuts	6.6	3.2	28
Walnuts unsalted	Nuts	1.5	2.1	25
Nut dried fruit mix	50% Nuts 50% Fruits	1.2	0.9	25
Mixed nuts/other as snacks	Nuts	3.1	3.1	20
Potato chips, other salty snacks	Refined grains	3.9	3.1	11
Salty biscuits, cheese cookies	Refined grains	0.7	0.7	5
Cheese as snack	Cheese	4.5	3.3	10
Liver sausage	Processed meat	0.8	0.5	10

Food item	Food group	Intake M (g/d)	Intake W (g/d)	Portion size (g)
Sausage other as snack	Processed meat	1.4	1.0	11
Toasts with fish, fish salad	23% Refined grains 54% Fish and shellfish 23% Condiments and sauces	0.9	1.1	13
Toasts with pate	27% Refined grains 73% Organ meat	0.4	0.3	11
Toasts with cheese	25% Refined grains 75% Cheese	1.3	1.3	12
Toasts with other spread	4% Vegetables 18% Refined grains 21% Processed meat 21% Poultry 16% Egg 5% Cheese 20% Condiments and sauces	1.1	1.5	17
Coffee prepared	Water, coffee, tea	497.0	416.7	140
Sugar	Sugar and confectionary	6.1	1.9	5
Coffee milk diet	Dairy except cheese	0.8	1.2	8
Coffee creamer	Dairy except cheese	0.4	0.2	3
Coffee milk full-fat	Dairy except cheese	1.8	1.3	8
Coffee milk half-fat	Dairy except cheese	6.9	5.5	8
Milk full-fat in coffee	Dairy except cheese	1.8	2.3	140
Milk skim	Dairy except cheese	2.3	1.7	140
Soy milk in coffee	Meat/dairy alternative	0.8	0.3	140
Milk half-fat	Dairy except cheese	105.2	69.4	140
Tea prepared	Water, coffee, tea	279.6	450.6	170
Sugar/honey in tea	Sugar and confectionary	1.9	1.3	5
Water, mineral water	Water, coffee, tea	363	544	170
Orange juice	Sugar-sweetened beverages	37.1	39.5	175
Other fruit juice	Sugar-sweetened beverages	22.1	22.0	175
Fruit juice with sweetener	Sugar-sweetened beverages	11.9	8.0	175
Fruit juice with sugar	Sugar-sweetened beverages	14.2	11.0	175
Syrup lemonade- Karvan Cévitam prepared average	Sugar-sweetened beverages	8.2	8.2	200
Syrup rosehip, fruit mix, multivitamin syrup prepared	Sugar-sweetened beverages	4.2	3.3	200
Syrup fruit lemonade light prepared on average	Sugar-sweetened beverages	4.1	6.5	200
Syrup fruit limp sugar and sweetest prepared Raak	Sugar-sweetened beverages	0.4	1.7	200
Syrup fruit lemonade prepared with sugar and sweetener	Sugar-sweetened beverages	0.5	0.3	200
Syrup Roosvicee Lessini light prepared average	Sugar-sweetened beverages	0.3	1.9	200
Syrup (fruit) lemonade- made with sugar	Sugar-sweetened beverages	3.1	5.2	200
Soft drink with sugar	Sugar-sweetened beverages	14.2	7.6	200
Soft drink with sugar and sweetener	Sugar-sweetened beverages	9.7	2.2	200
Soft drink with sweetener	Sugar-sweetened beverages	26.4	14.8	200
Energy or sport drink	Sugar-sweetened beverages	2.5	0.4	200
Beer	Alcohol	120.7	14.1	200
Wine, sherry, port, vermouth	Alcohol	78.5	82.1	114
Liquor, berry/lemon gin	Alcohol	2.6	1.3	50
Distilled	Alcohol	11.7	2.0	50
Breezer	Alcohol	5.7	1.9	175

Abbreviations: LASA Longitudinal Aging Study Amsterdam; M men; W women.

Supplementary Table 2 Diet properties of habitual diet, high-protein diet, high-protein diet aligned with the Dutch food-based dietary guidelines, and high-protein diets aligned with the Dutch food-based dietary guidelines accounting for greenhouse gas emissions in older Dutch men (n=644) and women (n=710) aged 56-101y. [1]

				% GHGE reduction (+PROT-GHGE) [2]								
	HAB	**PROT**	**+PROT**	**0%**	**-10%**	**-20%**	**-30%**	**-40%**	**-50%**	**-60%**	**-70%**	**-80%**
Men												
Energy (kcal/d)	2300 ± 600	2300	2300	2300	2300	2300	2300	2300	2300	2300	2300	2300
Protein (E%/d)	15.1 ± 2.4	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5
Total fat (E%/d)	34.2 ± 5.8	33.9	33.8	33.6	33.2	32.8	32.5	32.1	31	30	29	29.7
MUFA (E%/d)	13.0 ± 2.7	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1
PUFA (E%/d)	7.5 ± 2.2	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	8.7	9.2	11.3
SFA (E%/d)	12.8 + 3.1	12.3	12.2	12	11.7	11.3	10.9	10.6	9.6	7.8	6.2	5
Total carbohydrates (E%/d)	40.5 ± 6.8	38.6	38.6	38.8	39.3	39.7	40.2	40.6	42.1	43.1	45.5	46.2
Fiber (g/d)	24.4 ± 7.6	24.6	28	28.1	28.5	28.9	29.3	29.7	31.2	35.4	41.9	49.4
DHA+EPA (mg/d)	240 ± 247	333	240	240	240	240	240	240	240	308	240	240
Folate equivalents (mg/d)	290 ± 87	303	348	348	351	355	359	363	368	387	404	448
Vitamin C (mg/d)	131 ± 69	133	141	141	141	141	141	140	138	129	124	112
Calcium (mg/d)	1048 ± 418	1122	1425	1411	1376	1343	1310	1278	1176	1048	1048	1048
Iron (mg/d)	11.9 ± 3.1	12.7	12.8	12.9	13	13.2	13.4	13.6	14	15.1	14.8	16.2
Dry matter (g/d)	471 ± 118	471	479	479	481	482	483	485	490	497	514	522

[1] Presented as mean intake per day, with ± standard deviation provided for habitual intakes. Dark grey cells represent levels of nutrients below dietary reference intake (DRI) and light grey cells represent levels of nutrients above DRI as outlined in Table 1. [2] The percentage under +PROT-GHGE is the percent reduction in GHGE applied to the diet. Abbreviations: %E percent of total energy intake; GHGE greenhouse gas emissions; HAB habitual diet; PROT high-protein diet; +PROT high-protein diet aligned with the Dutch food-based dietary guidelines; +PROT-GHGE high-protein diets aligned with the Dutch food-based dietary guidelines accounting for greenhouse gas emissions; SFA saturated fatty acids.

Supplementary Table 2 Diet properties of habitual diet, high-protein diet, high-protein diet aligned with the Dutch food-based dietary guidelines, and high-protein diets aligned with the Dutch food-based dietary guidelines accounting for greenhouse gas emissions in older Dutch men (n=644) and women (n=710) aged 56-101y. [1]

				% GHGE reduction (+PROT-GHGE) [2]								
	HAB	PROT	+PROT	0%	-10%	-20%	-30%	-40%	-50%	-60%	-70%	-80%
Women												
Energy (kcal/d)	1900 ± 480	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Protein (E%/d)	15.5 ± 2.6	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4
Total fat (E%/d)	34.0 ± 5.9	33.8	33.9	33.5	33.1	32.7	32.3	31.8	30.3	29.3	29.3	30
MUFA (E%/d)	12.5 ± 2.7	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6
PUFA (E%/d)	7.6 ± 2.4	7.7	7.7	7.7	7.7	7.7	7.7	7.7	8.1	9.2	10.1	12.1
SFA (E%/d)	12.9 ± 3.2	12.4	12.5	12.2	11.8	11.4	11.1	10.6	8.8	6.9	6.1	4.9
Total carbohydrates (E%/d)	41.7 ± 6.9	39.1	39	39.3	39.8	40.2	40.5	41	42.5	43.4	46	44.9
Fiber (g/d)	21.6 ± 6.3	21.7	23.5	23.7	24.1	24.4	24.7	25.2	27.2	31.7	36.4	40.3
DHA+EPA (mg/d)	229 ± 214	323	229	229	229	229	229	229	288	274	229	229
Folate equivalents (mg/d)	273 ± 77	285	313	314	315	316	318	319	325	348	370	404
Vitamin C (mg/d)	141 ± 62	142	144	144	143	143	142	141	133	123	127	140
Calcium (mg/d)	984 ± 363	1056	1249	1226	1196	1167	1139	1102	983	983	983	983
Iron (mg/d)	10.3 ± 2.7	11.1	11.2	11.3	11.4	11.5	11.6	11.6	12.3	13.1	12.8	12.9
Dry matter (kg/d)	389 ± 95	389	393	394	395	396	397	398	404	414	425	426

[1] Presented as mean intake per day, with ± standard deviation provided for habitual intakes. Dark grey cells represent levels of nutrients below dietary reference intake (DRI) and light grey cells represent levels of nutrients above DRI as outlined in Table 1. [2] The percentage under +PROT-GHGE is the percent reduction in GHGE applied to the diet. Abbreviations: %E percent of total energy intake; GHGE greenhouse gas emissions; HAB habitual diet; PROT high-protein diet; +PROT high-protein diet aligned with the Dutch food-based dietary guidelines; +PROT-GHGE high-protein diets aligned with the Dutch food-based dietary guidelines accounting for greenhouse gas emissions; SFA saturated fatty acids.

CHAPTER 6

Effect of food-related behavioral activation therapy on food intake and the environmental impact of the diet: results from the MooDFOOD trial

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Abstract

Purpose Food-based dietary guidelines are proposed to not only improve diet quality, but to also reduce the environmental impact of diets. The aim of our study was to investigate whether food-related behavioral activation therapy (F-BA) applying Mediterranean-style dietary guidelines altered food intake and the environmental impact of the diet in overweight adults with subsyndromal symptoms of depression.

Methods In total 744 adults who either received the F-BA intervention (F-BA group) or no intervention (control group) for 12 months were included in this analysis. Food intake data were collected through a food frequency questionnaire at baseline and after 6 and 12 months. Greenhouse gas emissions (GHGE), land use (LU) and fossil energy use (FEU) estimates from life cycle assessments and a weighted score of the three (*p*ReCiPe score) were used to estimate the environmental impact of each individual diet at each time point.

Results The F-BA group reported increased intakes of vegetables (19.7 g/d; 95% CI: 7.8 to 31.6), fruit (23.0 g/d; 9.4 to 36.6), fish (7.6 g/d; 4.6 to 10.6), pulses/legumes (4.0 g/d; 1.6 to 6.5) and whole grains (12.7 g/d; 8.0 to 17.5) and decreased intake of sweets/extras (-6.8 g/d; -10.9 to -2.8) relative to control group. This effect on food intake resulted in no change in GHGE, LU and *p*ReCiPe score, but a relative increase in FEU by 1.6 MJ/d (0.8, 2.4).

Conclusions A shift towards a healthier Mediterranean-style diet does not necessarily result in a diet with reduced environmental impact in a real-life setting.

1. Introduction

A transition from traditional to current dietary patterns has contributed to a rise in global prevalence of chronic diseases and to unprecedented changes in ecosystems, both of which are threatening public health [1]. Food production is largely responsible for the environmental burdens associated with the human diet, including climate change, biodiversity loss, and pollution [2], with the other stages in the supply chain (i.e. processing, distribution, retailing, home food preparation and waste) playing a part. Food production contributes to approximately 16-25% of total global greenhouse gas emissions (GHGE) [3], and it is estimated that this will increase by 51% from 2005/07 to 2050 if dietary patterns do not change [4]. Currently croplands and pastures cover 37% of total land area [5], making agriculture the largest use of land on the planet. It is estimated that food production will need to increase by 25-70% to meet 2050 food demand [6]. While sustainable intensification of agriculture is proposed as a solution to increase food production with reduced environmental risks, it will not prevent further agricultural expansion driven by the projected demand [7]. Thus, dietary change has been identified as an essential counterpart to reduce the environmental pressures associated with the diet and to provide food security for future generations [8-10].

Recent research has increasingly focused on evaluating the environmental impact of habitual dietary choices, predefined diets and alternative dietary patterns in order to propose more sustainable dietary patterns [1,11-13]. An assortment of sustainable diets have been proposed, such as vegan and Mediterranean, as well as following national food-based dietary recommendations. Environmental as well as health benefits of these diets have been attributed to partial substitution of animal-based foods with plant-based foods [1,12,14,15], and also to reduced caloric intake [16-19]. While these studies have predominately examined the environmental impact of hypothetical change from current to proposed diets, there is limited research on the environmental impact of dietary change in a real-life setting. Only one previous study has examined changes in GHGE related to changes in food choice in overweight women who received a diet plan based on the Nordic Nutrition Recommendations 2004 and found no effect on diet-associated GHGE, although the women increased their fruit and vegetable intake and decreased total caloric intake compared to those who didn't receive the diet plan [20]. Thus the environmental impact of dietary change in line with dietary guidelines in a real-life setting needs further investigation.

In the recent MooDFOOD (Multi-country cOllaborative project on the rOle of Diet, FOod-related behavior, and Obesity in the prevention of Depression) trial [21], 1,025 overweight adults aged 18-75 years with subsyndromal symptoms of depression were randomized to a 12-month food-related behavioral activation therapy (F-BA) intervention (F-BA group) and were provided with dietary guidelines based on a Mediterranean-style diet (Table 1), or to a control group that received no F-BA intervention. Although the F-BA intervention was designed to change diet and behavior in order to prevent the onset of depression, we hypothesized that the F-BA intervention would improve the environmental sustainability of the diet as it focused on shifting habitual eating patterns to a Mediterranean-style diet [22]. Therefore, this study aimed to investigate whether the F-BA intervention changed food intake and to assess the environmental impact of the observed dietary change.

2. Methods

2.1. Study design and subjects

The MooDFOOD trial was a 12-month randomized controlled prevention trial that investigated the feasibility and effectiveness of two different nutritional strategies for the prevention of depression: multi-nutrient supplementation and F-BA. The design, methods and primary outcomes of the trial are described in detail elsewhere [21,23], and summarized below. A sample of 1,025 adults aged 18-75 years with a body mass index (BMI) of 25-40 kg/m^2 and elevated symptoms for depression (Patient Health Questionnaire-9 score ≥ 5) [24] were recruited from The Netherlands, United Kingdom, Germany and Spain and randomized to one of four trial arms according to a 2 x 2 factorial design: 1) multi-nutrient supplement with F-BA intervention (n=256), 2) placebo supplement with F-BA intervention (n=256), 3) multi-nutrient supplement without F-BA intervention (n=256) or 4) placebo supplement without F-BA intervention (n=257). Randomization was stratified according to recruitment site (i.e. country) and participants' history of depression status at the baseline assessment. Participants, therapists and researchers were blind to supplement allocation, and researchers were blind to behavioral intervention status when conducting analyses. The four trial arms were condensed to two trial arms to make comparisons in food intake between participants who received the F-BA intervention (F-BA group) and participants who did not receive the F-BA intervention (control group). We assumed that the multi-nutrient supplement had a null effect on food intake and thus wasn't a focus in this study. We confirmed this by adding supplement status to the statistical models when analyzing intervention effect and it did not affect results.

2.2. F-BA intervention

The F-BA intervention consisted of up to 21 therapy sessions, of which up to 15 were individual sessions and up to 6 were group sessions. The individual sessions were provided in single 30-minute or double 1-hour meetings occurring at first weekly and then every two weeks, while the group sessions included up to 10 people and lasted about 1 hour, occurring at first monthly and then bimonthly. Among the 512 participants randomized to the F-BA group, 71% attended at least 8 out of the 21 sessions and were considered compliant (this cut-off for compliance is described by Bot et al. [23]). Participants attended a median of 14 out of 15 individual sessions (interquartile range (IQR) 6-15) and a median of 0 out of 6 group sessions (IQR 0-4) [23]. The control group received no F-BA intervention (n=513 participants).

The F-BA intervention focused on changing food-related behaviors and shifting habitual dietary patterns to improve diet in order to prevent the onset of depressive episodes; environmental impact of diet was not considered in the design of the intervention. The F-BA intervention incorporated standard approaches of behavioral activation, which focuses on reducing avoidant behaviors and building routines and behaviors that are rewarding and/or pleasant, proven effective in the treatment of depression [25]. Psychologists familiar with behavioral activation were trained and delivered the F-BA intervention under supervision of a dietician. The psychologists helped participants to set goals on introducing healthy foods into their diets as well as reducing consumption of foods considered to be eaten in excess, taking into account baseline records. Goals were revisited and modified when necessary during subsequent sessions. During the intervention participants kept a record of daily activities and habits, and were able to take notes about their mood and foods eaten during the day. The records aimed to help in the identification of triggers to habits and engagement in self-monitoring to improve food-related behaviors (e.g. regular meals per day, less snacking) and habitual dietary patterns. The participants were provided with a participant manual with detailed information about what was discussed.

2.3. MooDFOOD dietary guidelines

An introduction to healthy eating associated with mood improvement was provided in the third therapy session, which involved the provision of dietary guidelines based on a Mediterranean-style dietary pattern, referred to as the MooDFOOD dietary guidelines (Table 1). The Mediterranean diet served as the basis for the guidelines because evidence indicates that following such a dietary pattern may prevent the onset of depression [26-31]. The guidelines were adjusted to be more consistent with the national dietary recommendations of the MooDFOOD prevention trial sites [32-36]. The MooDFOOD dietary guidelines consisted of general advice (e.g. limit meat intake to 300 grams per week) and more detailed recommendations, and presented examples of 'good' and 'bad' food choices as well as food exchanges, for example, increase vegetable intake by decreasing intake of potatoes, rice and/or bread; replace sugared drinks and sweet snacks by fruit; and replace processed sandwich meats by other sandwich toppings like low-fat cheese, hummus, egg and fish. No total calorie restriction was advised. In addition to the MooDFOOD dietary guidelines, a description of the link between diet and depression was provided in the F-BA participant manual, with greatest emphasis on the association between consumption of sweets, cakes, pastries and fast foods and increased risk of depression and consumption of fruit, vegetables, fish and whole grains and decreased risk of depression. Other foods in the MooDFOOD dietary guidelines such as low-fat dairy, meat, pulses/legumes and olive oil were only described as part of a healthy diet, and no direct linkage between these foods and depression was made in the manual.

Table 1 MooDFOOD dietary guidelines[a]

Food group	Guideline
Vegetables *Examples*[b]: green leafy and salad vegetables, fruit vegetables (e.g. cucumber and courgette), flower and flower buds (e.g. broccoli), bulb and stem vegetables (e.g. onion); root and tubers; sea vegetables. Excludes potatoes.	300-400 grams/day
Fruit *Examples*: core fruit, stone fruit, berries, citrus fruits, tropical fruits, dried fruit	2-3 pieces/day
Fish *Examples*: freshwater fish, salt water fish, white fish, oily fish, shell fish, sustainable fish	3 times/week
Meat *Examples of good meat*: chicken, turkey *Examples of protein-rich alternatives:* eggs, nuts, soy products like tofu, fish	Reduce to 300 grams/week
Pulses or legumes *Examples*: soy beans, peanuts, fresh peas/beans, dried beans/peas, chickpeas, lentils	3 times/week
Whole grain products *Examples*: whole grain pasta & bread, brown rice, oatmeal, muesli, couscous	Choose
Low-fat dairy products *Examples*: low-fat milk & yogurt, mature cheese, fresh cheese, soy products, cottage cheese	3 servings/day
Olive oil *Examples of use*: in frying food, tossed vegetables, salads, pasta sauces	Use as principal source for cooking
Processed foods and soft drinks *Examples*: (frozen) ready-to-eat meals, processed sandwich meats, sausages, savory snacks, sweet snacks, fried food, sugar-sweetened beverages, sugar added to coffee/tea, fruit juice *Examples of healthy alternatives*: fruit, vegetables, nuts, fish, water, tea or coffee	Limit
Alcoholic beverages *Moderate consumption defined as:* for men, maximum 2 standard glass per day; for women, maximum of 1 standard glass per day	Drink in moderation

[a] MooDFOOD dietary guidelines were based on a Mediterranean-style dietary pattern and provided in the food-related behavioral activation therapy (F-BA) intervention during the 12-month MooDFOOD depression prevention trial. Guidelines were provided orally and in the form of a pamphlet to the intervention participants [21]. [b] Examples of all food groups were provided with pictures along with practical tips to achieve the guideline.

2.4. Dietary data

Participants reported their usual food intake during the previous month by completing an online self-administered food frequency questionnaire (FFQ) at baseline (T0), six months (T6) and at 12 months (T12; end of trial). The FFQ was based on the validated

GA2LEN FFQ as it showed to be an appropriate tool to estimate food intake across Europe regardless of cultural and linguistic differences [37]. The FFQ included 210 food items which were categorized into 18 food groups based on food groups for which dietary recommendations were made in the F-BA intervention: 1. vegetables, 2. fruit, 3. fish, 4. meat, 5. egg/soy, 6. pulses/legumes, 7. nuts, 8. potatoes, 9. whole grains, 10. refined grains, 11. low-fat dairy products, 12. high-fat dairy products, 13. olive oil, 14. other fats/oils, 15. sweets/extras, 16. soft drinks (including fruit juices), 17. alcoholic beverages, 18. water/coffee/tea (See Online Resource, Table 1 for FFQ food items and corresponding food group classification). Standard portion sizes following the Food Standard Agency Food Portion Sizes Guidelines were used [38]. Consumption frequency and portion size data were linked with food composition data from the McCance and Widdowson's composition of foods dataset (2015) to calculate total energy intake in kilocalories (kcal) per gram (g) [39]. The percentage of total energy intake (E%) contributed by each food group was calculated as the food group energy intake divided by the total energy intake. Food intake was considered missing if a participant completed <15% of the FFQ. Among the 1,025 participants randomized in the MooDFOOD depression prevention trial, 86 had missing dietary data at T0 and 186 had missing dietary data at both follow-up measurements and were excluded from this study. In addition, individuals who under-/over-reported caloric intake were excluded from the analysis. Energy under-/over-reporting was classified as an energy intake spanning above or under the mean plus/minus three standard deviations (sd). Median intakes are reported along with the 25th and 75th percentile.

2.5. Environmental data

Various measures were investigated to estimate the environmental impact of the diet, namely GHGE expressed in kilograms of carbon dioxide equivalents (kg CO_2-eq), land use (LU) in square meter-year (m^{2}*y), fossil energy use (FEU) in mega joules (MJ) and a weighted score of the three (*p*ReCiPe score) [40]. GHGE, LU and FEU were used as indictors due to their availability in reliable datasets and their frequent application in studies examining the environmental impact of diets [41]. Environmental impacts were calculated per 100g food with life cycle assessments (LCA) from cradle-to-grave by Blonk Consultants (Gouda, The Netherlands) using ReCiPe 2016 Midpoint v1.00 method [42]. LCA is a methodological framework for assessing the environmental impacts over the entire life cycle of a product, from cultivation to packing, consumption and final disposal [43]. For each food item, GHGE, LU and FEU data were obtained either from a LCA database containing 94 commonly eaten food products based on European Food Safety Authority's Comprehensive European Food Consumption Database (PROMISS dataset 2017) [44] or a database containing 207 commonly eaten food products in The Netherlands, based on the Dutch Consumption Survey 2007-2010 (Optimeal dataset 2015) [45]. A weighted combination of GHGE, LU and FEU was used to calculate a *p*ReCiPe score, a simplified environmental impact score, adapted from the *p*ReCiPe score developed by Tyszler et al. [40]. The *p*ReCiPe score of each food item was calculated by:

$$p\text{ReCiPe}_i = \mathbf{0.0459} \times \text{ GHGE}_i + \mathbf{0.0439} \times \text{LU}_i + \mathbf{0.0025} \times \text{FEU}_i$$

where i is a food item and GHGE is expressed in kg CO_2-eq/100g, LU in m^2*y/100g and FEU in MJ/100g. This calculation is based on the ReCiPe method which aggregates fourteen LCA impact categories, such as eutrophication and land transformation [46]. The *p*ReCiPe score only includes three of the sixteen LCA impact categories (i.e. GHGE, LU and FEU) as they were found to have the most weight in the end score in LCAs of agricultural products [15,41,47]. Data were expressed per 100g food and were used to estimate the overall GHGE, LU, FEU and *p*ReCiPe score for each individual diet. Environmental data sources and values are available in Online Resource 2.

2.6. Statistical analysis

To analyze the difference in change in food intake and in environmental impact of the diet from T0 to T12 between the F-BA and control groups, longitudinal analysis of covariance using mixed model analysis was used. Participants with missing dietary data at T0 were excluded in the analyses as the baseline value of the outcome variable was included as a covariate, as well as participants with missing dietary data at both T6 and T12 as individuals with only a baseline measurement are not part of the analysis [48]. Those with missing dietary data at either T6 or T12 were included in the analysis and no imputations were conducted as mixed model analysis estimated with the maximum likelihood estimator accounts for missing data [49]. In addition to baseline outcome values, adjustment was made for sex (male or female), age (years, continuous), and site (added as another level to the model) for all outcomes. In order to assess the difference in change in environmental impact of the diet due to change in diet composition between the F-BA and control groups, adjustment for total caloric intake in kcal/d (continuous, time-dependent) was applied. However, since the environmental impact associated with the diet is influenced not only by diet composition but also caloric quantity [17], the main environmental results presented do not control for caloric intake. To avoid the increased risk of type I error due to multiple testing of the 18 food groups, Holm-Bonferroni correction of the *P*-value was done [50]. This procedure is a sequential approach taking into account the total number of hypotheses (18 for 18 food groups), and original *P*-values, so that the corrected *P*-value for the *i*th-test is computed as $P_{Holm\text{-}Bonferroni} = (18 - i + 1) \times p$ [51]. This was tested in order from the smallest to largest *P*-value and stopped when the first non-significant *P*-value was observed based on a 0.05 α level. While original *P*-values are reported along with 95% confidence intervals (CI), statistical significance is determined by the Holm-Bonferonni adjusted *P*-value. The analyses were performed on an intention-to-treat (ITT) basis. Data were analyzed using Stata version 14.2 (StataCorp, TX, USA).

A post-hoc per protocol (PP) analysis was done in order to examine whether those who were more compliant to the F-BA intervention had a greater change in diet and environmental impact of the diet. The cut-off for compliance was attending at least 8 out of the 21 sessions [23]. The same methods were used as in the ITT analysis, but the PP analyses measured the difference in change in food intake and environmental impact of the diet between a subgroup of compliant persons in the F-BA group and the control group over the 12-month period.

3. Results

3.1. Study participants and baseline characteristics

In total 753 participants randomized in the MooDFOOD depression prevention trial had dietary data at T0 and at T6 or T12. The baseline mean ± standard deviation of total caloric intake was 2,483.9 ± 2,269.9 kcal/d for men and 2,347. 2 ± 1,245.9 kcal/d for women in both groups, resulting in an upper cut-off for implausible caloric intake of 9,293.71 kcal/d and 6,084.78 kcal/d, respectively. This led to the exclusion of 9 participants due to over-reporting caloric intake at either T0 or at both T6 and T12. Therefore a total of 744 participants were included in the analyses measuring the intervention effect (flow diagram is available as Online Resource, Fig 1). In general, baseline characteristics of those included in the analysis and those excluded from the analysis were comparable (Online Resource, Table 2).

Similar baseline characteristics of the two study groups were found and are presented in Table 2. The majority of the study participants were female (75.4%) with a mean age of 47.6 years and BMI of 31.2 kg/m^2. The baseline median total caloric intake of the study participants at baseline was 2,159.2 kcal/d. The baseline median value of GHGE was 5.8 kg CO2-eq/d, LU 4.5 m^{2*}y/d, FEU 40.8 MJ/d and *p*ReCipe 0.6 points in both groups. While contributing to 11.2 E%, total meat intake accounted for approximately 35.1% of daily diet-associated GHGE, 39.1% of LU and 21.2% FEU in the F-BA group at baseline, with similar contributions in the control group (Table 3). The impact of dairy on GHGE, fat on LU and fish and vegetables on FEU was substantial (dairy: 14.1% of GHGE; fat: 10.9% of LU; fish: 16.5% of FEU and vegetables: 15.1% of FEU). Sweets/extras contributed most to total caloric intake in both groups at baseline (19 E%), yet had a relatively low impact on GHGE (5.5%), LU (7.0%) and FEU (6.3%).

Table 2 Baseline characteristics of participants who received food-related behavioral activation therapy (F-BA) intervention (F-BA group) and participants who did not receive the F-BA intervention (control group) (N=744)

Characteristic	F-BA group (N=373)	Control group (N=371)
Sex[a]		
Female	78.3 (292)	72.5 (269)
Male	21.7 (81)	27.5 (102)
Age (years)[b]	47.9 ± 12.6	47.2 ± 13.4
Education[a]		
Low	8.6 (32)	10.8 (40)
Middle	47.5 (177)	46.9 (174)
High	44.0 (164)	42.3 (157)
Site[a]		
Germany	29.0 (108)	31.8 (118)
United Kingdom	24.1 (90)	25.3 (94)
Spain	20.6 (77)	22.1 (82)
The Netherlands	26.3 (98)	20.8 (77)
History of depression[a]		
Yes	31.1 (116)	33.4 (124)
No	68.9 (257)	66.6 (247)
Supplement status[a]		
Multi-nutrient supplement	47.5 (177)	49.1 (182)
Placebo	52.5 (196)	50.9 (189)
BMI (kg/m^2)[b]	31.2 ± 3.8	31.2 ± 4.1
Total energy intake (kcal/day)[c]	2167.8 (1689.6; 2632.7)	2155.0 (1701.6; 2701.7)
Food intake (grams/day)[c]		
Vegetables	292.0 (181.6; 437.1)	302.5 (219.6; 456.2)
Fruit	255.9 (166.7; 412.6)	260.0 (165.7; 448.6)
Fish	44.3 (27.1; 74.9)	42.9 (24.3; 70.0)
Meat	122.4 (79.3; 185.6)	135.0 (86.1; 201.2)
Egg/soy	25.0 (10.7; 42.9)	27.9 (14.3; 49.4)
Pulses/legumes	37.9 (22.5; 62.1)	35.7 (21.8; 62.9)
Nuts	2.1 (0.7; 5.0)	2.1 (0.7; 5.0)
Potatoes	24.5 (13.9; 43.6)	24.3 (12.1; 46.5)
Whole grains	90.6 (46.5; 156.6)	92.8 (43.6; 170.4)
Refined grains	98.6 (62.6; 166.4)	100.4 (57.1; 163.3)
Low-fat dairy	120.0 (17.1; 220.0)	97.1 (17.1; 237.1)
High-fat dairy	89.3 (39.3; 160.4)	94.3 (46.1; 175.4)
Olive oil	9.4 (3.1; 17.3)	8.6 (3.1; 13.4)
Other fats/oils	15.1 (8.0; 27.5)	14.8 (7.1; 27.1)
Sweets/extras	117.0 (70.3; 187.3)	125.2 (77.9; 189.9)
Soft drinks	85.7 (28.6; 197.1)	68.6 (25.7; 200.0)
Alcoholic beverages	42.9 (17.9; 114.3)	45.4 (8.9; 119.6)
Water/coffee/tea	1314.3 (971.4; 1657.1)	1300.0 (914.3; 1700.0)
Environmental indicators[c]		
GHGE[d] (kg CO_2-eq/day)	5.73 (4.47; 7.44)	5.94 (4.50; 7.84)
LU[e] (m^2*y/day)	4.51 (3.49; 5.81)	4.61 (3.49; 6.12)
FEU[f] (MJ/day)	40.33 (31.89; 52.35)	41.28 (33.09; 56.95)
*p*ReCiPe score[g] (points/day)	0.55 (0.44; 0.74)	0.58 (0.45; 0.77)

[a] Values displayed as percentage (frequency); [b] Values displayed as mean ± sd; [c] Values displayed as median with interquartile range (25; 75th percentile); [d] Greenhouse gas emission; [e] Land use; [f] Fossil energy use; [g] Weighted average of GHGE, LU and FEU.

Table 3 Food group contributions to total caloric intake (E%) and to daily diet-associated greenhouse gas emissions (GHGE) (% of total kg CO2-eq/d), land use (LU) (% of total m^{2}*y/d) and fossil energy use (FEU) (% of total MJ/d) in the food-based behavioral activation therapy (F-BA) group and control group at baseline

Food group	F-BA group (N=373)				Control group (N=371)			
	E%	GHGE	LU	FEU	E%	GHGE	LU	FEU
Vegetables	4.2	8.9	4.3	15.1	4.3	9.5	4.5	16.1
Fruit	7.3	5.3	6.7	6.6	7.4	5.4	6.8	6.6
Fish	3.4	9.6	1.6	16.5	3.2	8.9	1.4	15.3
Meat								
Red meat	8.7	30.0	31.8	15.9	9.3	30.5	33.0	16.6
Poultry	2.5	5.1	7.3	5.3	2.5	5.1	7.4	5.3
Egg/soy	2.5	1.3	2.3	1.7	2.7	1.4	2.5	1.9
Pulses/legumes	2.1	1.2	3.8	1.7	2.2	1.2	3.9	1.7
Nuts	1.3	0.2	1.0	0.3	1.4	0.3	0.9	0.3
Potatoes	1.7	0.6	0.5	0.8	1.6	0.5	0.4	0.7
Cereals								
Whole grains	8.4	2.3	4.7	2.4	8.5	2.4	5.0	2.5
Refined grains	9.0	3.0	2.5	3.6	8.8	2.9	2.4	3.4
Dairy								
Low-fat dairy	4.6	6.1	3.1	3.6	4.7	6.2	3.2	3.7
High-fat dairy	8.1	8.0	4.4	3.9	7.9	7.7	4.3	3.8
Fat								
Olive oil	4.7	0.6	7.8	0.4	4.2	0.5	6.9	0.3
Other fats/oils	5.2	1.9	3.1	1.3	5.0	1.8	3.0	1.2
Sweets/extras	19.0	5.5	7.0	6.3	18.9	5.3	6.8	6.2
Beverages								
Soft drinks	0.8	1.6	1.8	2.8	0.8	1.5	1.6	2.5
Alcoholic	2.5	2.4	2.4	3.3	2.5	2.5	2.4	3.4
Water/coffee/tea	3.4	5.9	3.4	8.1	3.5	5.9	3.2	8.0

3.2. Changes in food intake and environmental impact of the diet during the intervention

No difference in change in total caloric intake was apparent between the groups after 12 months (22.9 kcal/d; 95% CI: -10.1 to 55.9; P=0.173). Significant increases in reported daily intake from T0 to T12 were observed for vegetables (19.7 g/d; 7.8 to 31.6; P=0.001), fruit (23.0 g/d; 9.4 to 36.6; P=0.001), fish (7.6 g/d; 4.6 to 10.6; P<0.001), pulses/legumes (4.0 g/d; 1.6 to 6.5, P=0.001) and whole grains (12.7 g/d; 8.0 to 17.5, P<0.001), and while a significant decrease was observed for sweets/extras (-6.8 g/d; -10.9 to -2.8; P=0.001) in the F-BA group relative to the control group (Figure 1). Differences in change in reported intake of olive oil (0.8 g/d; 0.2 to 1.4, P=0.006) and soft drinks (-9.1 g/d; -18.1 to -0.1, P=0.048) in the F-BA group relative to the control group were not significant after Holm-Bonferroni correction. No difference in change in reported meat consumption was evident, also when specifying red meat (-3.4 g/d; -6.7 to -0.04; P=0.047) and poultry (1.7 g/d; -0.9 to 4.4; P=0.197). The difference in change in red meat consumption was non-significant after Holm-Bonferroni correction.

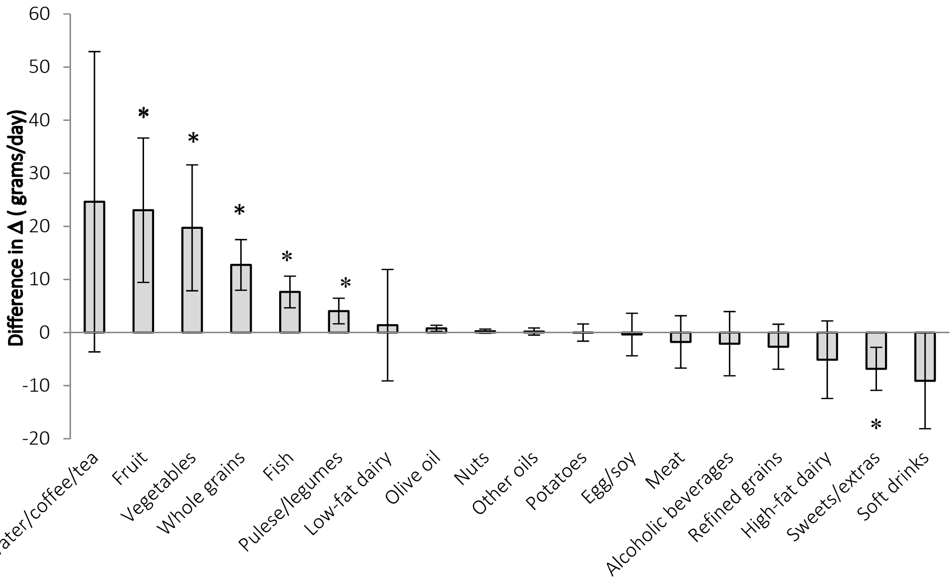


Figure 1 Effect of the food-related behavioral activation therapy (F-BA) intervention on intake of 18 food groups in overweight adults with subsyndromal symptoms for depression during the 12-month MooDFOOD depression prevention trial (N=744). The bars represent the difference in change in intake from baseline to 12 months between participants who received F-BA intervention (F-BA group) and participants who did not receive F-BA intervention (control group) when controlling for baseline value of outcome, age, sex and site. The lines represent 95% confidence intervals. * Significant at Holm-Bonferroni-corrected *P*-value.

These changes in food intake had no effect on diet-associated GHGE, LU or the *p*ReCiPe score, but led to a statistically significant 3.6% increase in FEU (1.6 MJ/d, 0.8 to 2.4, $P<0.001$) in the F-BA group compared to the control group (Table 4). When the differences in change in environmental outcomes were controlled for total caloric intake, i.e. difference in change when energy intake would remain constant over the 12-month period between the F-BA group and the control group, the results were attenuated. However, the difference in change in FEU of the diet remained significant (1.2 MJ/d; 0.5 to 1.8; $P<0.001$) and differences in change in GHGE, LU and *p*ReCiPe score remained insignificant.

Table 4 Effect of the food-related behavioral activation therapy (F-BA) intervention on environmental impact of diet in overweight adults with subsyndromal symptoms for depression during the 12-month MooDFOOD depression prevention trial (N=744)

Environmental outcomes	β[a]	SE	95% CI	*P*-value
GHGE[b] (kg CO_2-eq/day)				
Model 1[f]	0.060	0.060	-0.058 to 0.179	0.320
Model 2[g]	0.004	0.045	-0.084 to 0.092	0.933
LU[c] (m^2*y/day)				
Model 1	0.024	0.049	-0.071 to 0.119	0.622
Model 2	-0.017	0.035	-0.084 to 0.051	0.630
FEU[d] (MJ/day)				
Model 1	1.625	0.418	0.807 to 2.444	<0.001[*]
Model 2	1.118	0.323	0.547 to 1.815	<0.001[*]
*p*ReCiPe score[e] (points)				
Model 1	0.008	0.006	-0.003 to 0.019	0.173
Model 2	0.002	0.004	-0.006 to 0.010	0.460

[a] Unstandardized beta coefficient of difference in change from baseline to 12 months between participants who received the F-BA intervention (F-BA group) and participants who did not receive the F-BA intervention (control group). [b] Greenhouse gas emissions; [c] Land use; [d] Fossil energy use; [e] Weighted average of GHGE, LU and FEU. [f] Model 1 controls for baseline value of outcome, age, sex and site. [g] Model 2 is Model 1 plus total caloric intake as a covariate. [*] Significant at Holm-Bonferroni-corrected *P*-value.

The difference in change in GHGE, LU, FEU and *p*ReCiPe of each food group as well as the overall diet are shown in the Online Resource, Fig 2-5. The increase in fish intake by the F-BA group relative to the control group contributed the most to the increasing effect of the F-BA intervention on diet-associated FEU (Online Resource, Fig 4). The relative increase in intake of fish contributed to an increase in FEU by 1.2 MJ/d (0.7 to 1.6; $P<0.001$), vegetables to an increase by 0.4 MJ/d (0.1 to 0.6; $P=0.008$), fruit to an increase by 0.2 MJ/d (0.1 to 0.04; $P<0.001$), whole grains to an increase by 0.1 MJ/d (0.1 to 0.2; $P<0.001$), and pulses/legumes to an increase by 0.1 MJ/d (0.03 to 0.10; $P=0.001$), while the relative decrease in intake of sweets/extras contributed to a decrease by 0.1 MJ/d (-0.2 to -0.1; $P=0.001$) in the F-BA group compared to the control group during the intervention.

3.3. Post-hoc per protocol analysis results

In total, 365 out of 512 participants randomized to the F-BA intervention attended at least 8 therapy sessions and were considered compliant. Among those who attended at least 8 therapy sessions, 6 had missing dietary data at T0 and 45 had missing dietary data at both T6 and T12. In addition, 3 participants had over-reported energy intake at T0 and 1 participant at T6 and T12 were excluded from the analysis. Thus 310 participants were included in the F-BA compliant subgroup. Indeed, the effect of the intervention was stronger among those who were most compliant to the F-BA intervention compared to the control group, i.e. a greater change in intake of the same food groups were observed compared to ITT analysis. Significant increases in reported daily intake from T0 to T12 were observed for vegetables (27.1 g/d; 14.9 to 39.3; $P<0.001$), fruit (26.1 g/d; 12.0 to 40.2; $P<0.001$), fish (9.9 g/d; 6.7 to 13.0; $P<0.001$), pulses/legumes (5.2 g/d; 2.7 to 7.8, $P<0.001$) and whole grains (14.8 g/d; 9.7 to 19.9, $P<0.001$), while a significant decrease was observed for sweets/extras (-7.5 g/d; -11.7 to -3.2; $P=0.001$) in the F-BA subgroup relative to the control group. This in turn led to a statistically significant 4.8% increase in diet-associated FEU (2.2 MJ/d; 1.3 to 3.0; $P<0.001$), and no change in GHGE, LU and *p*ReCiPe score.

4. Discussion

We found that the F-BA intervention led to changes in food intake among overweight adults with subsyndromal symptoms of depression according to the MooDFOOD dietary guidelines: significant increases in consumption were reported for some of the food groups promoted (i.e. vegetables, fruit, fish, pulses/legumes and whole grains) and a significant decrease was reported for one of the food groups discouraged (i.e. sweets/extras) by the guidelines. The differences in change are roughly equivalent to eating an additional ¾ tablespoon of mixed vegetables a day, ¾ of an apple a day, ½ slice of whole grain bread a day, 1½ servings of salmon a month and 3¼ tablespoons of legumes a month, while refraining from eating about 2 teaspoons of sugar a day [52,53]. However, these dietary improvements resulted in an unfavorable increased FEU of the overall diet equivalent to an additional 1.5 liter of petrol a month [54], and no difference in change in diet-associated GHGE, LU or *p*ReCiPe score. Our results indicate that a shift towards a healthier Mediterranean-style diet does not necessarily reduce diet-associated environmental impact in a real-life setting.

Our findings are consistent with other studies that modeled hypothetical dietary changes towards a healthier diet and observed either no change or an increase in environmental impact of the healthy diet scenarios [40,55-58]. Such studies have found that there is a greater need for increasing consumption of vegetables, fruit, legumes and fish than decreasing consumption of meat and dairy products in order to achieve a healthy diet, resulting in a net-positive effect on environmental impact of the diet (i.e. higher environmental impact). Yet when meat consumption is substantially reduced, then the environmental benefits of reducing meat consumption outweigh the increase in environmental impact due to increased intake of vegetables, fruit, legumes and fish when shifting towards a recommended healthy diet [15,19]. Although the MooDFOOD dietary guidelines recommended to limit meat intake to 300 grams per week, which was substantially lower than the baseline median intake of 857 grams per week in the F-BA group, the intervention did not lead to changes in meat intake. Because the current study observed the environmental impact of dietary changes in a *real-life* setting, it may inherently consider constraints such as individual preferences, values and personal efficacy not accounted for in previous studies examining the environmental impact of *hypothetical* dietary change. Consumer behavior studies that have explored attitudes and intentions towards meat consumption have found that there is low willingness to change meat consumption behavior in terms of reducing or substituting meat in Europe [59,60]. For many people meat holds an important place in the diet as it is associated with pleasure and various personal, social and cultural-oriented values such as health and strength [60,61]. Therefore future dietary interventions should consider current values attached to meat and other constraints opposing changes in meat consumption if healthy, sustainable diets are to be achieved.

We found that the increased impacts on GHGE and LU from the increased intake of fruit, vegetables, fish, pulses/legumes and whole grains were collectively offset by the reduced impacts on GHGE and LU from the decreased intake of sweets/extras. Our results are in line with the weight loss trial which found that a reduction in intake of sweets, snacks and soft drinks and an increase in intake of fruit and vegetables led to no change in overall carbon footprint of the diet [20]. However, we found that observed dietary change led to an increase in FEU of the overall diet, which may be attributable to the relative increase in fish, as fisheries are generally energy-intensive operations [62,63]. An additional explanation for finding an increase in FEU of the overall diet may be due to the relative increase in vegetable consumption combined with the use of Dutch environmental data, where the impact of vegetables on FEU is relatively high because of the use of greenhouses running on fossil energy [64]. Similar changes in FEU were found in two modeling studies, which found that switching from the current average American diet to a healthy diet recommended in the Dietary Guidelines for Americans would increase FEU, mainly caused by the recommendation to substantially increase the intake of fruits, vegetables and dairy products [57,58]. Thus, while the increase in consumption of fruit, vegetables, fish, pulses/legumes and whole grains may make a diet healthier, it may make it less sustainable unless replacing other food groups with similar or higher environmental impact, i.e. meat.

The actual change in the environmental impact of the diet is highly sensitive to the change in food choices since there is very large variation in the GHGE, LU and FEU levels per unit food within both the animal-based and plant-based food groups [11,55]. To achieve healthy and sustainable diets, future dietary interventions must consider the environmental impact associated with different food groups (e.g. high-impact meat versus low-impact legumes), and also the environmental impact of various foods within food groups, such as beef (high impact) and poultry (lower impact) or tomatoes grown in a greenhouse (high impact) or in a field (lower impact) [55,65]. As there are many different ways to follow the dietary guidelines provided by the MooDFOOD trial, different choices within food groups, for example how to meet 300-400 g of vegetables per day, can lead to different environmental impacts. This was illustrated by Van Kamp and colleagues who found that compared to the current average Dutch diet, two healthy diets defined by the Dutch dietary recommendations resulted in either a 3% or 28% reduction in GHGE, with greater reductions in GHGE when dietary recommendations were met by including only foods with low impact on GHGE [55]. Furthermore, a reduction in overall caloric intake without changing the composition of the diet has been shown to result in lower environmental impact of the diet [16,58]. Thus, for dietary guidelines to have a positive impact on the environment as well as health, consideration of the environmental impact of individual foods and food groups as well as total caloric intake is needed in addition to health considerations.

Our study has some limitations. First, FFQs are prone to recall bias and selective misreporting of consumption of certain foods [66]. In particular, the potential of differential response bias is high as exposure to the intervention itself can create differential error in reporting, with the treatment group possibly over-reporting foods promoted during the F-BA intervention (e.g. vegetables) and under-reporting foods that were discouraged (e.g. sweets) compared to the control group [67]. Second, the study population was overweight and at high risk of depression, limiting the generalizability of our findings to other populations. Third, the LCA data used to estimate the environmental impact of the diet comprised of a mix of data representative of an average Dutch diet as well as an average European diet. There are differences in geography, climate and production, processing and distribution systems in Germany, UK, Spain and The Netherlands which may influence the actual environmental impact of diets in each country. Thus while the LCA data used does not explicitly represent the production practices in each country, in the absence of country-specific data this data serves as a proxy to provide a rough estimation on diet-level impacts. Fourth, while the LCA datasets used allowed us to study multiple environmental impact indicators, namely GHGE, LU and FEU, other important aspects such as water use, eutrophication and biodiversity loss are missing in this analysis because reliable data were not available. For instance, GHGE, LU and FEU do not reflect the sustainability concerns of increasing fish consumption with regard to marine biodiversity loss and overfishing. Finally, the studied environmental indicators also have limitations. The LU indicator does not differentiate between different types and quality of land, which will bias livestock products to having higher impacts even if they graze on land unsuitable for cropping [2]. Furthermore, GHGE and FEU are strongly correlated (0.913, P<0.001) as carbon dioxide emitted from fossil fuels used in the food chain directly contribute to GHGE of the diet [63]. Despite the considerable overlap between these two indicators, they measure different pressures, i.e. GHGE is a proxy for polluting emissions and FEU is a proxy for resource depletion [41,68]. The strengths of this study include the use of an FFQ validated to measure food intake across different European countries [37], its large sample size compared to other dietary interventions looking at changes in food intake [69] and the use of three environmental impact indicators in addition to a weighted score measuring the overall environmental impact. Most importantly, the MooDFOOD trial allowed for the assessment of environmental impact of dietary change under real-life circumstances, while previous studies have mainly measured the environmental impact of hypothetical dietary change.

5. Conclusion

Our research shows that the food-related behavioral activation therapy led to favorable changes in food intake according to the Mediterranean-style dietary guidelines, but to no change in GHGE, LU or *p*ReCiPe score and a small unfavorable change in FEU of the diet. To generate dietary change that is favorable for both health and the environment, dietary interventions must focus specifically on incorporating environmental sustainability aspects, in particular focusing on reducing and replacing meat consumption, choosing foods within a healthy diet that have low environmental impact and reducing total caloric intake. Furthermore, cultural, social and personal values around eating meat should be integrated. Future research should evaluate the environmental impact of dietary change in individuals who receive dietary guidelines especially designed to decrease the environmental impact of the diet and improve health, simultaneously.

References

1. Tilman D, Clark M (2014) Global diets link environmental sustainability and human health. Nature 515:518-522. https://doi.org/10.1038/nature13959
2. Foley JA, Ramankutty N, Brauman KA, Cassidy ES, Gerber JS, Johnston M et al (2011) Solutions for a cultivated planet. Nature 478:337-342. https://doi.org/10.1038/nature10452
3. Vermeulen SJ, Campbell BM, Ingram JSI (2012) Climate change and food systems. Annu Rev Environ Resour 37 (1):195-222. https://doi.org/10.1146/annurev-environ-020411-130608
4. Springmann M, Godfray HCJ, Rayner M, Scarborough P (2016) Analysis and valuation of the health and climate change cobenefits of dietary change. Proc Natl Acad Sci USA 113 (15):4146-4151. https://doi.org/10.1073/pnas.1523119113
5. FAOSTAT (2015) FAO Statistical Databases (FAOSTAT). http://faostat.fao.org/. Accessed 05 July 2018
6. Hunter MC, Smith RG, Schipanski ME, Atwood LW, Mortensen DA (2017) Agriculture in 2050: Recalibrating targets for sustainable intensification. BioSci 67 (4):386-391. https://doi.org/10.1093/biosci/bix010
7. Bajželj B, Richards KS, Allwood JM, Smith P, Dennis JS, Curmi E et al (2014) Importance of food-demand management for climate mitigation. Nat Clim Chang 4:924-929. https://doi.org/10.1038/nclimate2353
8. Bryngelsson D, Wirsenius S, Hedenus F, Sonesson U (2016) How can the EU climate targets be met? A combined analysis of technological and demand-side changes in food and agriculture. Food Policy 59:152-164. https://doi.org/10.1016/j.foodpol.2015.12.012
9. Springmann M, Clark M, Mason-D'Croz D, Wiebe K, Bodirsky BL, Lassaletta L et al (2018) Options for keeping the food system within environmental limits. Nature. https://doi.org/10.1038/s41586-018-0594-0
10. Röös E, Bajželj B, Smith P, Patel M, Little D, Garnett T (2017) Greedy or needy? Land use and climate impacts of food in 2050 under different livestock futures. Global Environ Chang 47:1-12. https://doi.org/10.1016/j.gloenvcha.2017.09.001
11. Hallström E, Carlsson-Kanyama A, Börjesson P (2015) Environmental impact of dietary change: a systematic review. J Clean Prod 91:1-11. https://doi.org/10.1016/j.jclepro.2014.12.008
12. Aleksandrowicz L, Green R, Joy EJM, Smith P, Haines A (2016) The impacts of dietary change on greenhouse gas emissions, land use, water use, and health: A systematic review. PLOS ONE 11 (11):e0165797. https://doi.org/10.1371/journal.pone.0165797
13. Perignon M, Vieux F, Soler L-G, Masset G, Darmon N (2017) Improving diet sustainability through evolution of food choices: review of epidemiological studies on the environmental impact of diets. Nutr Rev 75 (1):2-17. https://doi.org/10.1093/nutrit/nuw043
14. Nelson ME, Hamm MW, Hu FB, Abrams SA, Griffin TS (2016) Alignment of healthy dietary patterns and environmental sustainability: A systematic review. Adv Nutr 7 (6):1005-1025. https://doi.org/10.3945/an.116.012567
15. van Dooren C, Marinussen M, Blonk H, Aiking H, Vellinga P (2014) Exploring dietary guidelines based on ecological and nutritional values: A comparison of six dietary patterns. Food Policy 44:36-46. https://doi.org/10.1016/j.foodpol.2013.11.002
16. Springmann M, Wiebe K, Mason-D'Croz D, Sulser TB, Rayner M, Scarborough P (2018) Health and nutritional aspects of sustainable diet strategies and their association with environmental impacts: a global modelling analysis with country-level detail. Lancet Planet Health 2 (10):e451-e461. https://doi.org/10.1016/S2542-5196(18)30206-7

17. Masset G, Vieux F, Verger EO, Soler L-G, Touazi D, Darmon N (2014) Reducing energy intake and energy density for a sustainable diet: a study based on self-selected diets in French adults. Am J Clin Nutr 99 (6):1460-1469. https://doi.org/10.3945/ajcn.113.077958
18. van Dooren C, Keuchenius C, de Vries JHM, de Boer J, Aiking H (2018) Unsustainable dietary habits of specific subgroups require dedicated transition strategies: Evidence from the Netherlands. Food Policy 79:44-57. https://doi.org/10.1016/j.foodpol.2018.05.002
19. Behrens P, Kiefte-de Jong JC, Bosker T, Rodrigues JFD, de Koning A, Tukker A (2017) Evaluating the environmental impacts of dietary recommendations. Proc Natl Acad Sci USA 114 (51):13412. https://doi.org/10.1073/pnas.1711889114
20. Huseinovic E, Ohlin M, Winkvist A, Bertz F, Sonesson U, Brekke HK (2017) Does diet intervention in line with nutrition recommendations affect dietary carbon footprint? Results from a weight loss trial among lactating women. Eur J Clin Nutr 71 (10):1241-1245. https://doi.org/10.1038/ejcn.2017.63
21. Roca M, Kohls E, Gili M, Watkins E, Owens M, Hegerl U et al (2016) Prevention of depression through nutritional strategies in high-risk persons: rationale and design of the MooDFOOD prevention trial. BMC Psychiatry 16 (1):192. https://doi.org/10.1186/s12888-016-0900-z
22. Dernini S, Berry EM (2015) Mediterranean diet: From a healthy diet to a sustainable dietary pattern. Front Nutr 2 (15). https://doi.org/10.3389/fnut.2015.00015
23. Bot M, Brouwer IA, Roca M, Kohls E, Penninx BWJH, Watkins E et al (2019) Effect of multinutrient supplementation and food-related behavioral activation therapy on prevention of major depressive disorder among overweight or obese adults with subsyndromal depressive symptoms: The MooDFOOD Randomized Clinical Trial. JAMA 321 (9):858-868. https://doi.org/10.1001/jama.2019.0556
24. Kroenke K, Spitzer RL, Williams JBW (2001) The PHQ-9. J Gen Intern Med 16 (9):606-613. https://doi.org/10.1046/j.1525-1497.2001.016009606.x
25. Cuijpers P, van Straten A, Warmerdam L (2007) Behavioral activation treatments of depression: A meta-analysis. Clin Psychol Rev 27 (3):318-326. https://doi.org/10.1016/j.cpr.2006.11.001
26. Jacka FN, Pasco JA, Mykletun A, Williams LJ, Hodge AM, O'Reilly SL et al (2010) Association of Western and traditional diets with depression and anxiety in women. Am J Psychiatry 167 (3):305-311. https://doi.org/10.1176/appi.ajp.2009.09060881
27. Akbaraly TN, Brunner EJ, Ferrie JE, Marmot MG, Kivimaki M, Singh-Manoux A (2009) Dietary pattern and depressive symptoms in middle age. Br J Psychiatry 195 (5):408-413. https://doi.org/10.1192/bjp.bp.108.058925
28. Rienks J, Dobson AJ, Mishra GD (2013) Mediterranean dietary pattern and prevalence and incidence of depressive symptoms in mid-aged women: Results from a large community-based prospective study. Eur J Clin Nutr 67 (1):75-82. https://doi.org/10.1038/ejcn.2012.193
29. Skarupski KA, Tangney CC, Li H, Evans DA, Morris MC (2013) Mediterranean diet and depressive symptoms among older adults over time. J Nutr Health Aging 17 (5):441-445. https://doi.org/10.1007/s12603-012-0437-x
30. Mamplekou E, Bountziouka V, Psaltopoulou T, Zeimbekis A, Tsakoundakis N, Papaerakleous N et al (2010) Urban environment, physical inactivity and unhealthy dietary habits correlate to depression among elderly living in eastern Mediterranean islands: The MEDIS (MEDiterranean ISlands Elderly) study. J Nutr Health Aging 14 (6):449-455. https://doi.org/10.1007/s12603-010-0091-0
31. Nicolaou M, Colpo M, Vermeulen E, Elstgeest LEM, Cabout M, Gibson-Smith D et al (2019) Association of a priori dietary patterns with depressive symptoms: A harmonised meta-analysis of observational studies. Psychol Med:1-12. https://doi.org/10.1017/S0033291719001958

32. Health Council (2006) Guidelines for Good Nutrition 2006 (in Dutch). Gezondheidsraad, The Hague, Netherlands.
33. German Nutrition Society (2004) The Nutrition Report 2004. Deutsche Gesellschaft für Ernährung e.V., Bonn, Germany.
34. Sociedad Española de Nutrición Comunitaria (SENC) (2004) Guía de la alimentación saludable SENC, Madrid, Spain.
35. Food Standards Agency (FSA) (2007) FSA nutrient and food based guidelines for UK institutions. Food Standards Agency UK.
36. World Health Organization (WHO) (2003) Food based dietary guidelines in the WHO European Region. WHO, Copenhagen, Denmark.
37. Garcia-Larsen V, Luczynska M, Kowalski ML, Voutilainen H, Ahlström M, Haahtela T et al (2011) Use of a common food frequency questionnaire (FFQ) to assess dietary patterns and their relation to allergy and asthma in Europe: pilot study of the GA2LEN FFQ. Eur J Clin Nutr 65:750. https://doi.org/10.1038/ejcn.2011.15
38. Food Standard Agency (2006) Food Portion Sizes Guidelines. 3rd edn edn., London
39. Roe M, Pinchen H, Church S, Finglas P (2015) McCance and Widdowson's The Composition of Foods Seventh Summary Edition and updated Composition of Foods Integrated Dataset. Nutr Bull 40 (1):36-39. https://doi.org/10.1111/nbu.12124
40. Tyszler M, Kramer G, Blonk H (2016) Just eating healthier is not enough: studying the environmental impact of different diet scenarios for Dutch women (31–50 years old) by linear programming. Int J LCA 21 (5):701-709. https://doi.org/10.1007/s11367-015-0981-9
41. van Dooren C, Aiking H, Vellinga P (2018) In search of indicators to assess the environmental impact of diets. Int J LCA 23 (6):1297-1314. https://doi.org/10.1007/s11367-017-1371-2
42. Huijbregts MAJ, Steinmann ZJN, Elshout PMF, Stam G, Verones F, Vieira MDM et al (2016) ReCiPe 2016: A harmonized life cycle impact assessment method at midpoint and endpoint level Report I: Characterization. National Institute for Public Health and the Environment, Bilthoven, The Netherlands.
43. Joint Research Centre (JRC) (2010) ILCD Handbook: General Guide for Life Cycle Assessment—Detailed Guidance. European Commission, Joint Research Centre, Institute for Environment and Sustainability, Ispra, Italy.
44. European Food Safety Authority (2011) Use of the EFSA Comprehensive European Food Consumption Database in exposure assessment. EFSA J 9 (3):2097. https://doi.org/10.2903/j.efsa.2011.2097
45. Van Rossum CTM, Fransen HP, Verkaik-Kloosterman J, Buurma-Rethans EJM, Ocké MC (2011) Dutch National Food Consumption Survey 2007-2010. Diet of children and adults aged 7 to 69 years. National Institute for Public Health and the Environment, Bilthoven, The Netherlands.
46. Goedkoop M, Heijungs R, Huijbregts M, De Schryver A, Struijs J, Van Zelm R (2009) ReCiPe 2008: A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level; Report 1: Characterisation.
47. Sevenster MN, Blonk H, Van der Flier S (2010) Milieuanalyses Voedsel en Voedselverliezen (Environmental analysis of food and food losses). CE Delft, Blonk Milieu Advies, Delft, The Netherlands.
48. Twisk J, Bosman L, Hoekstra T, Rijnhart J, Welten M, Heymans M (2018) Different ways to estimate treatment effects in randomised controlled trials. Contemp Clin Trials Commun 10:80-85. https://doi.org/10.1016/j.conctc.2018.03.008
49. Twisk J (2013) Applied Longitudinal Data Analysis for Epidemiology: A Practical Guide. Second Edition edn. Cambridge University Press, Cambridge, UK
50. Holm S (1979) A simple sequentially rejective multiple test procedure. Scand J Stat 6 (2):65-70. http://www.jstor.org/stable/4615733

51. Abdi H (2010) Holm's sequential bonferroni procedure. In: Salkind N (ed) Encyclopedia of Research Design. SAGE Publications, Inc., Thousand Oaks, CA, pp 574-577. http://dx.doi.org/10.4135/9781412961288.n178
52. The British Dietetic Association (BDA) (2016) Food fact sheet. https://www.bda.uk.com/foodfacts/portionsizesfoodfactsheet.pdf. Accessed 4 December 2018
53. Rellinger D (2013) How to convert grams of sugars into teaspoons. https://www.canr.msu.edu/news/how_to_convert_grams_of_sugars_into_teaspoons. Accessed 4 December 2018
54. Staffell I (2011) The energy and fuel data sheet. University of Birgmingham, UK.
55. van de Kamp ME, van Dooren C, Hollander A, Geurts M, Brink EJ, van Rossum C et al (2018) Healthy diets with reduced environmental impact? – The greenhouse gas emissions of various diets adhering to the Dutch food based dietary guidelines. Food Res Int 104:14-24. https://doi.org/10.1016/j.foodres.2017.06.006
56. Vieux F, Darmon N, Touazi D, Soler LG (2012) Greenhouse gas emissions of self-selected individual diets in France: Changing the diet structure or consuming less? Ecol Econ 75:91-101. https://doi.org/10.1016/j.ecolecon.2012.01.003
57. Birney CI, Franklin KF, Davidson FT, Webber ME (2017) An assessment of individual foodprints attributed to diets and food waste in the United States. Environ Res Lett 12 (10):105008. https://doi.org/10.1088/1748-9326/aa8494
58. Tom MS, Fischbeck PS, Hendrickson CT (2016) Energy use, blue water footprint, and greenhouse gas emissions for current food consumption patterns and dietary recommendations in the US. Environ Sys Decis 36 (1):92-103. https://doi.org/10.1007/s10669-015-9577-y
59. Hartmann C, Siegrist M (2017) Consumer perception and behaviour regarding sustainable protein consumption: A systematic review. Trends Food Sci Tech 61:11-25. https://doi.org/10.1016/j.tifs.2016.12.006
60. Macdiarmid JI, Douglas F, Campbell J (2016) Eating like there's no tomorrow: Public awareness of the environmental impact of food and reluctance to eat less meat as part of a sustainable diet. Appetite 96:487-493. https://doi.org/10.1016/j.appet.2015.10.011
61. de Bakker E, Dagevos H (2012) Reducing meat consumption in today's consumer society: Questioning the citizen-consumer gap. J Agric Environ Ethics 25 (6):877-894. https://doi.org/10.1007/s10806-011-9345-z
62. Parker RWR, Blanchard JL, Gardner C, Green BS, Hartmann K, Tyedmers PH et al (2018) Fuel use and greenhouse gas emissions of world fisheries. Nat Clim Chang 8 (4):333-337. https://doi.org/10.1038/s41558-018-0117-x
63. Pelletier N, Audsley E, Brodt S, Garnett T, Henriksson P, Kendall A et al (2011) Energy intensity of agriculture and food systems. Annu Rev Environ Resour 36 (1):223-246. https://doi.org/10.1146/annurev-environ-081710-161014
64. Araghi Y, Dijkema GPJ Alternative energy sources and energy infrastructure for Dutch greenhouses: Investigating growers' preferences. In: International Symposium for Next Generation Infrastructure Conference Proceedings: 30 September - 1 October 2014 International Institute of Applied Systems Analysis (IIASA), Schloss Laxenburg, Vienna, Austria, UCL STEaPP London, 2015. pp 199-203
65. Blackstone NT, El-Abbadi NH, McCabe MS, Griffin TS, Nelson ME (2018) Linking sustainability to the healthy eating patterns of the Dietary Guidelines for Americans: a modelling study. Lancet Planet Health 2 (8):e344-e352. https://doi.org/10.1016/S2542-5196(18)30167-0
66. Naska A, Lagiou A, Lagiou P (2017) Dietary assessment methods in epidemiological research: current state of the art and future prospects. F1000Research 6:926. https://doi.org/10.12688/f1000research.10703.1

67. Natarajan L, Pu M, Fan J, Levine RA, Patterson RE, Thomson CA et al (2010) Measurement error of dietary self-report in intervention trials. Am J Epidemiol 172 (7):819-827. https://doi.org/10.1093/aje/kwq216
68. Vanham D, Leip A, Galli A, Kastner T, Bruckner M, Uwizeye A et al (2019) Environmental footprint family to address local to planetary sustainability and deliver on the SDGs. Sci Total Environ 693:133642. https://doi.org/10.1016/j.scitotenv.2019.133642
69. Huseinovic E, Winkvist A, Bertz F, Brekke HK (2014) Changes in food choice during a successful weight loss trial in overweight and obese postpartum women. Obesity 22 (12):2517-2523. https://doi.org/10.1002/oby.20895

Supplementary material

Online Resource Table 1 Adapted GA2LEN FFQ food sections & items used in MooDFOOD prevention trial with food group classification

Food section/item	Food group classification
1. Bread and rolls	
a) Any type of bread	-
b) Wholemeal or brown bread (with or without seeds)	Whole grains
c) White bread (e.g. baguette, rolls, sliced)	Refined grains
d) Rye bread (any)	Whole grains
e) Naan bread	Refined grains
f) Chapatti	Refined grains
g) Yeast based bread	Refined grains
2. Breakfast cereals	
a) Any breakfast cereals	-
b) Wheat germ	Whole grains
c) Quaker (or other oat cereal)	Whole grains
d) Corn-flakes	Refined grains
e) All-bran cereals	Whole grains
3. Semolina	
a) Couscous	Whole grains
4. Pasta (and wheat-derived foods)	
a) Any pasta	-
b) Plain (refined) pasta (e.g. spaghetti)	Refined grains
c) Plain wholemeal (unrefined) pasta	Whole grains
d) Filled pasta (with meat/cheese/vegetables)	Refined grains
e) Noodles (excluding rice noodles)	Refined grains
5. Bakery products/desserts	
a) Any cakes or pastries	-
b) Cakes (e.g. sponge, chocolate)	Sweets/extras
c) Pastries (e.g. croissants)	Sweets/extras
d) Rolls (with/without filling)	Sweets/extras
e) Muffins	Sweets/extras
f) Doughnuts, buns (plain or filled)	Sweets/extras
g) Rice pudding	Sweets/extras
h) Cheesecake	Sweets/extras
i) Pancakes	Sweets/extras
j) Plain biscuits (with no fillings or cream)	Sweets/extras
6. Rice	
a) Any rice	-
b) White rice	Refined grains
c) Brown/wholemeal (unrefined) rice	Whole grains
d) Rice noodles	Refined grains
7. Sugar & jam	
a) Table sugar (white)	Sweets/extras
b) Jam	Sweets/extras
c) Marmalade	Sweets/extras
d) Honey	Sweets/extras
8. Sugar products excluding chocolate	
a) Any sweets or bonbons	-
b) Boiled sweets, toffees, caramels	Sweets/extras
c) Mixed candies	Sweets/extras
d) Cereal bars, flapjacks/fruit bar	Sweets/extras
e) Ice lolly	Sweets/extras
9. Chocolate	
a) Any chocolates	-
b) Chocolate snack bars (e.g. Mars bar)	Sweets/extras
c) Dark chocolate	Sweets/extras
d) Milk chocolate	Sweets/extras
10. Vegetable oils	
a) Any vegetable oil (blended)	-
b) Sunflower oil	Other fats/oils
c) Olive oil	Olive oil
d) Extra virgin olive oil	Olive oil
e) Palm oil	Other fats/oils

Food section/item	Food group classification
11. Margarine and fats of mixed origin	
a) Any margarine or spread (excluding soya spread)	-
b) Low-fat margarine	Other fats/oils
c) Normal margarine	Other fats/oils
d) Blended spreads	Other fats/oils
e) Soya-based margarine or spreads	Other fats/oils
f) Any margarines or vegetable spreads fortified with omega-3	Other fats/oils
12. Butter and animal fats	
a) Any butter	-
b) Low/reduced fat butter	Other fats/oils
c) Normal butter	Other fats/oils
d) Lard	Other fats/oils
13. Nuts	
a) Any nuts	-
b) Peanuts	Pulses/legumes
c) Cashew nuts	Nuts
d) Almonds	Nuts
e) Walnuts	Nuts
14. Legumes	
a) Any legumes	-
b) Kidney (red), black beans	Pulses/legumes
c) Lentils	Pulses/legumes
d) Chickpeas (also hummus)	Pulses/legumes
e) Cluster beans (guar)	Pulses/legumes
f) French beans (string beans)	Pulses/legumes
g) Fava beans	Pulses/legumes
h) Soya beans	Pulses/legumes
15. Vegetables excluding potatoes	
a) Any vegetables (excluding potatoes)	-
b) Lettuce	Vegetables
c) Spinach (including lamb's quarters)	Vegetables
d) Chard	Vegetables
e) Fenugreek	Vegetables
f) Wild greens (e.g. watercress)	Vegetables
g) Okra	Vegetables
h) Tomato	Vegetables
i) Aubergine	Vegetables
j) Courgette	Vegetables
k) Sweet peppers (e.g. red, green, yellow)	Vegetables
l) Cucumber	Vegetables
m) Bitter melon (Karela)	Vegetables
n) Carrots	Vegetables
o) Parsnip	Vegetables
p) Turnip or Swede	Vegetables
q) Artichoke	Vegetables
r) Radish	Vegetables
s) Beetroot	Vegetables
t) Celery	Vegetables
u) Coleslaw	Vegetables
v) Sweetcorn	Vegetables
w) Asparagus	Vegetables
x) Herbs (e.g. mint, fennel, chive, basil, dill, coriander, parsley)	Vegetables
y) Leek	Vegetables
z) White/other mushrooms	Vegetables
aa) Onions	Vegetables
bb) Garlic	Vegetables
cc) Cauliflower	Vegetables
dd) Pumpkin	Vegetables
ee) Brussels sprouts	Vegetables
ff) Peas (green)	Pulses/legumes
gg) Broccoli	Vegetables
hh) Cabbage (e.g. white, green red, Savoy)	Vegetables
ii) Stuffed vegetables (e.g. vine/green leaves with rice or meat)	Vegetables
jj) Pickled vegetables (e.g. cucumber, radish, cabbage)	Vegetables

Food section/item	Food group classification
kk) Ginger (e.g. in savoury and sweet dishes, in infusion)	Vegetables
16. Starchy roots or potatoes	
a) Any potatoes	-
b) Mashed potatoes	Potatoes
c) Baked/roasted/casserole	Potatoes
d) Chips/French fries	Sweets/extras
e) In salads	Potatoes
f) Potato dumpling, bread dumpling, gnocchi	Potatoes
g) Potato tortilla (omelette)	Potatoes
h) Sweet potato	Potatoes
17. Fruits	
a) Any fresh fruits	-
b) Apple	Fruit
c) Pear	Fruit
d) Avocado	Fruit
e) Mango	Fruit
f) Apricot	Fruit
g) Nectarine	Fruit
h) Peach	Fruit
i) Plum	Fruit
j) Cherries	Fruit
k) Rhubarb	Fruit
l) Berries (e.g. blueberry, strawberry, blackcurrants, blackberry, raspberry)	Fruit
m) Banana	Fruit
n) Melon/ Watermelon	Fruit
o) Grapes	Fruit
p) Squeezed fresh fruit	Soft drinks
q) Pineapple	Fruit
r) Kiwi	Fruit
s) Lemon	Fruit
t) Orange	Fruit
u) Mandarin/tangerine	Fruit
v) Grapefruit	Fruit
w) Tinned fruits	Fruit
x) Raisins, sultana	Fruit
y) Figs	Fruit
z) Prunes	Fruit
aa) Olives (e.g. black, green)	Fruit
bb) Dates	Fruit
18. Fruit juices (1 glass 200 ml)	
a) Concentrated juice, with sugar	Soft drinks
b) Concentrated juice, without sugar (with sweetener)	Soft drinks
19. Non-alcoholic beverages (1 glass 200 ml)	
a) Carbonated/soft drinks with sugar	Soft drinks
b) Carbonated/soft drinks with artificial sweetener	Soft drinks
c) Tap water	Water/coffee/tea
d) Mineral water (e.g. still or sparkling)	Water/coffee/tea
20. Tea/coffee	
a) Black tea (any)	Water/coffee/tea
b) Coffee (instant or ground)	Water/coffee/tea
c) Greek (Turkish) Coffee	Water/coffee/tea
d) Green tea	Water/coffee/tea
e) Peppermint tea	Water/coffee/tea
f) Other herbal infusions	Water/coffee/tea
21. Beer (1/2 pint or 1 glass 200 ml)	
a) Beer (any)	Alcoholic beverages
22. Wine (1 glass 125 ml)	
a) Any wine	-
b) Red wine	Alcoholic beverages
c) White wine	Alcoholic beverages
d) Rose wine	Alcoholic beverages
23. Other alcoholic beverages (1 glass 50 ml)	
a) Fortified wines (Liqueurs) (e.g. Sherry, port, Madeira)	Alcoholic beverages
b) Spirits (e.g. whisky, vodka, rum, gin)	Alcoholic beverages

Food section/item	Food group classification
24. Red meat and meat products	
a) Any red meat (e.g. beef, veal, lamb, pork, game)	-
b) Hot/cold roast beef, boiled beef, beef steak, fillet, loin	Meat
c) Beef burger (hamburger)	Meat
d) Minced beef meat (e.g chilli con carne, Bolognese sauce, meatballs)	Meat
e) Beef meat in stew, casserole, in curry	Meat
f) Pork cutlet, chop, steak, fillet, loin, pork ribs, minced	Meat
g) Meat pies	Meat
h) Sausages	Meat
i) Veal	Meat
j) Small game (e.g. rabbit, goat, pheasant, duck)	Meat
k) Other game (e.g. deer, moose)	Meat
l) Lamb (e.g. in stews, kebabs)	Meat
Smoked/cured meat (3 slices)	
m) Cured pork (cold or hot-cooked)	Meat
n) Gammon, ham (e.g. Serrano, prosciutto)	Meat
o) Dried cured sausages (chorizo, salchichon, salami)	Meat
p) Frankfurter	Meat
q) Bacon, bacon cubes	Meat
r) Smoked lamb	Meat
s) Smoked game (any)	Meat
25. Poultry	
a) Any poultry with skin	-
b) Any poultry without skin	-
Fresh (unsmoked)	
c) Chicken (e.g. boiled, roasted, chicken burgers)	Meat
d) Chicken (e.g. stews or casserole)	Meat
e) Turkey (e.g. roasted, boiled, strips)	Meat
Smoked or cured poultry	
f) Any smoked/cured poultry	Meat
26. Offal	
a) Liver (e.g. panita), pâtés, potted meat	Meat
b) Other offal (e.g. tongue, brain, heart, kidney, tripe)	Meat
27. Fish and seafood	
a) Any fish or seafood (fresh, tinned, smoked, etc)	-
b) Fresh oily fish (e.g. salmon, tuna, trout, anchovy, herring, mackerel, sardine, gravalax, eel)	Fish
c) Fresh white fish (e.g. hake/turbot, cod, haddock, plaice, whiting)	Fish
d) Other fresh fish/seafood products (e.g. taramasalata)	Fish
e) Fresh crustaceans and molluscs (e.g. mussel, crab, calamari, octopus, cuttlefish, shrimp, clam)	Fish
f) Cured or smoked oily fish (e.g. sardines, tuna, salmon, kipper)	Fish
g) Cured or smoked white fish (e.g. cod, bacalao, salt cod)	Fish
h) Tinned fish (sardine, tuna or salmon)	Fish
i) Tinned crustaceans and molluscs (e.g. mussel, crab, calamari, octopus, cuttlefish, shrimp, clam)	Fish
28. Eggs (from hen)	
a) Any eggs	-
b) Eggs (fried/poached/boiled/hard boiled/in sandwiches)	Egg/soy
c) Egg-based savoury dishes	Egg/soy
d) Egg-based desserts (e.g. egg cakes, tarts, egg and nut sweets)	Egg/soy
29. Milk, dairy and soya	
a) Any milk (excluding soy)	-
Cow milk	
b) Full-fat milk	High-fat dairy
c) Semi-skimmed milk	Low-fat dairy
d) Skimmed milk	Low-fat dairy
e) Milk fortified with omega 3 fatty acids	High-fat dairy
f) Yogurt (any type including fromage)	High-fat dairy
Soy	
g) Soy milk	Egg/soy
h) Yogurt from soy	Egg/soy
i) Tofu	Egg/soy

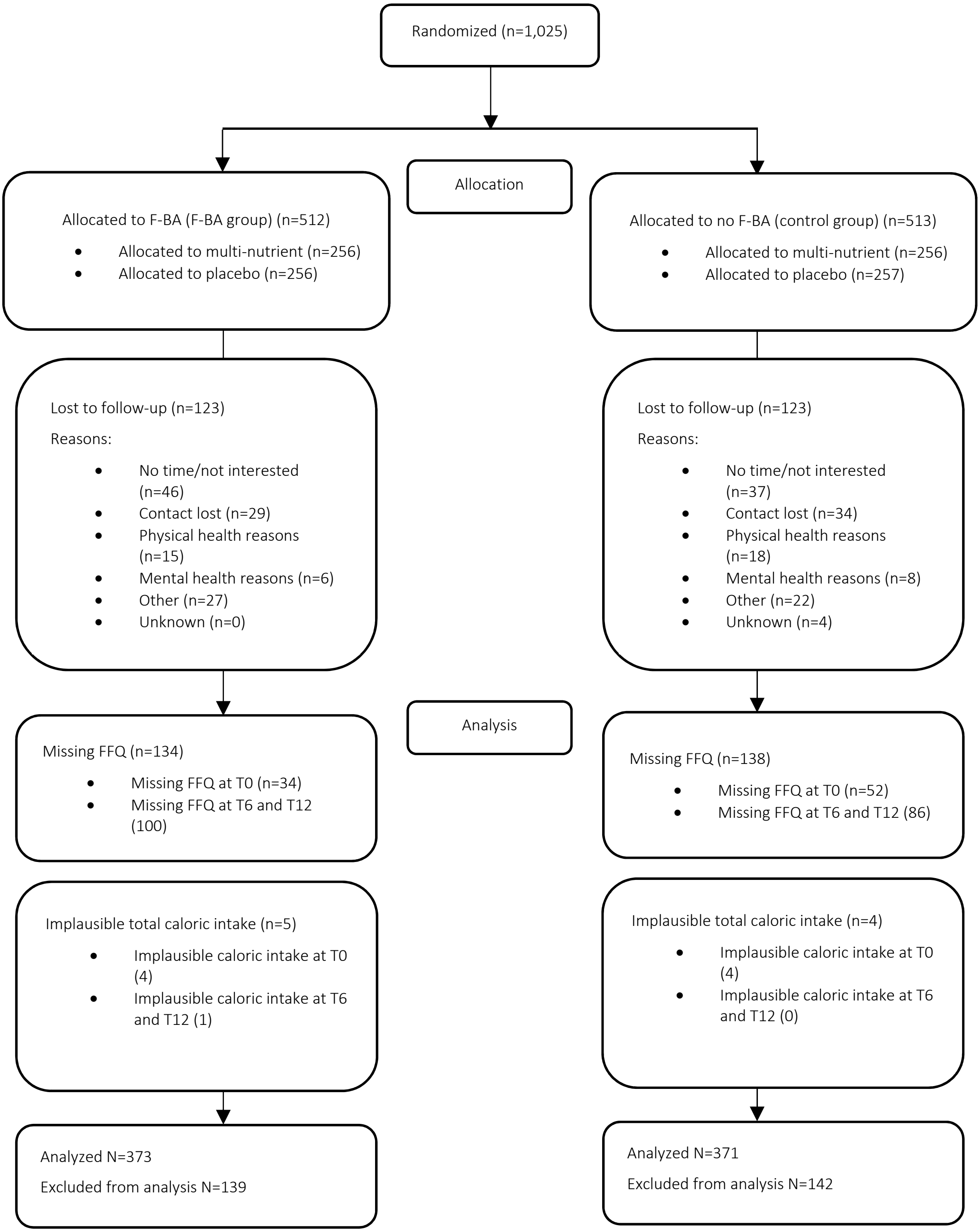
Food section/item	Food group classification
30. Cheese	
a) Any cheese	High-fat dairy
b) Hard cheeses (e.g. Cheddar, parmesan)	High-fat dairy
c) Soft cheeses (e.g. Brie, camembert, Philadelphia, tomini, boursault, brinza, chaource, coulommiers, Humboldt fog, kochkase)	High-fat dairy
d) Semi-hard cheeses (e.g. Gouda, Emmental/Edam)	High-fat dairy
e) Cottage cheese (cheese curd natural/with flavouring)	Low-fat dairy
f) Hard and semi-hard Greek cheeses (e.g. Kaseri, kefalotiri, Grafiera, Kefalograviera, Ladotiri)	High-fat dairy
g) Fresh cheeses (e.g. Feta, mozzarella)	Low-fat dairy
31. Other milk-derived products	
a) Ice cream	Sweets/extras
b) Single cream	High-fat dairy
c) Crème fraîche	High-fat dairy
d) Sour cream	High-fat dairy
e) Double or clotted cream	High-fat dairy
32. Miscellaneous food	
a) Dressing sauces (e.g. French, Cesar, thousand island)	Other fats/oils
b) Mayonnaise	Other fats/oils
c) White sauce	Sweets/extras
d) Ketchup	Sweets/extras
e) Instant soup	Sweets/extras
f) Pizza (any)	Sweets/extras
g) Brown sauce	Sweets/extras

Online Resource Table 2 Baseline characteristics of participants of the MooDFOOD prevention trial included in the mixed model analysis and excluded from analysis due to missing dietary data or implausible reported total caloric intake at T0 or at both T6 and T12

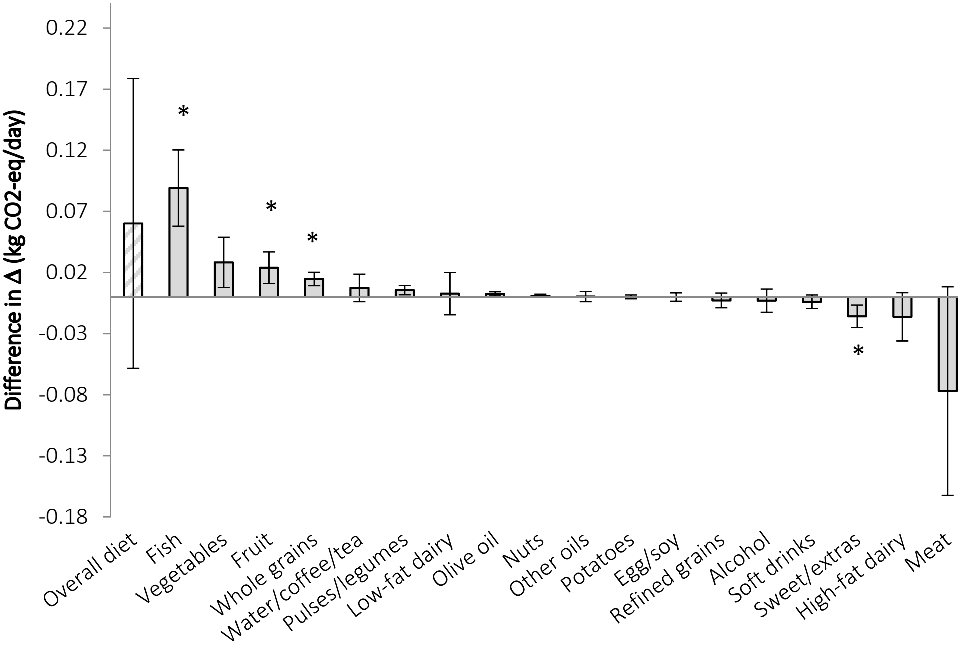
Characteristic	Included n=744	Excluded n=281
Sex[a]		
Female	75.4 (561)	75.1 (211)
Male	24.6 (183)	24.9 (70)
Age (years)[b]	47.6 ± 13.1	43.8 ± 12.6
Education[a]		
Low	9.7 (72)	11.0 (31)
Middle	47.2 (351)	52.3 (147)
High	43.1 (321)	36.7 (103)
Site[a]		
Germany	30.4 (226)	18.1 (51)
United Kingdom	24.7 (184)	24.9 (70)
Spain	21.4 (159)	33.1 (93)
The Netherlands	23.5 (175)	23.8 (67)
History of depression[a]		
Yes	32.3 (240)	36.7 (103)
No	67.7 (504)	63.3 (178)
Pills[a]		
Multi-nutrient	48.3 (359)	54.4 (153)
Placebo	51.7 (385)	45.6 (128)
BMI (kg/m^2)[b]	31.2 ± 4.0	31.8 ± 4.0
Total energy intake (kcal/day)[c]	2078.4 (1636.0; 2554.6)	2218.6 (1761.1; 2848.9)[d]

[a] Values displayed as percentage (frequency); [b] Values displayed as mean ± sd; [c] Values displayed as median with interquartile range (25; 75th percentile); [d] Total caloric intake of those who over-reported energy intake only (n=9)

Online resource Fig 1 Flow diagram of MooDFOOD depression trial participants included in the ITT analysis

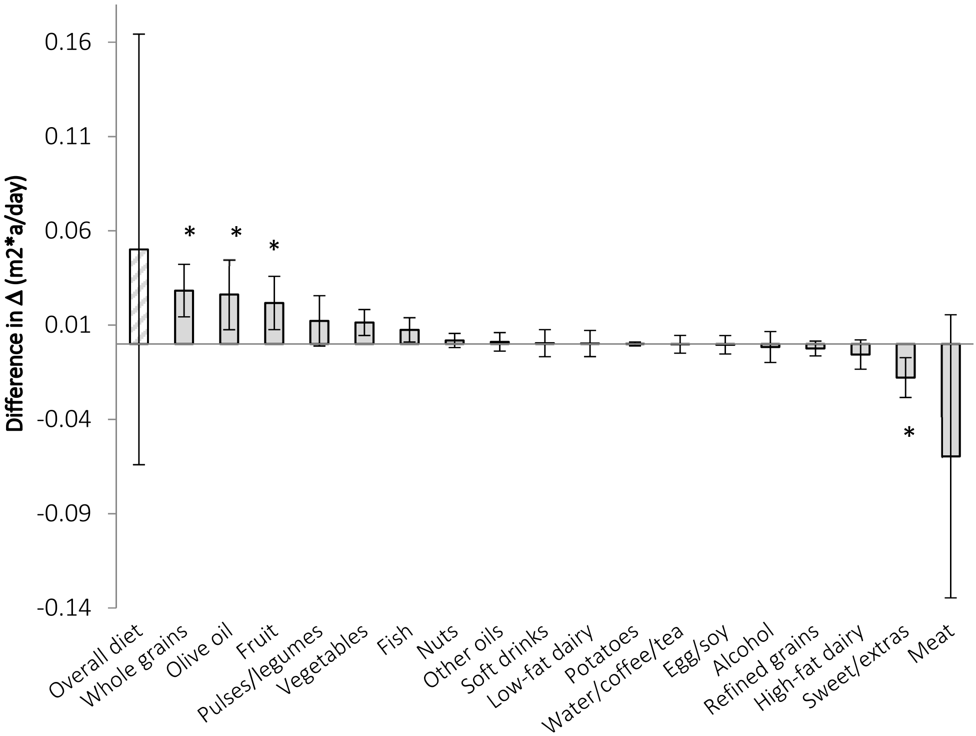


Online Resource Fig 2 Effect of the food-related behavioral activation therapy (F-BA) intervention on diet-associated greenhouse gas emissions in overweight adults with subsyndromal symptoms for depression during the 12-month MooDFOOD depression prevention trial (N=744)



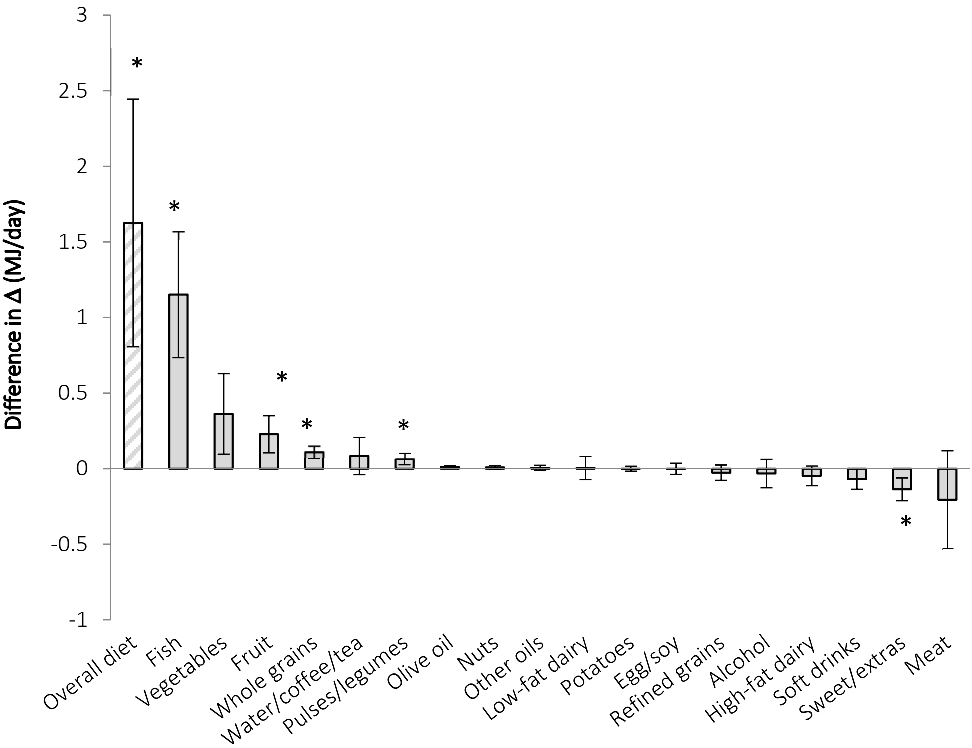
The bars represent the difference in change in greenhouse gas emissions (GHGE; kg CO_2-eq/day) from baseline to 12 months between participants who received the F-BA intervention (F-BA group) and participants who did not receive the F-BA intervention (control group) when controlling for baseline value of outcome, age, sex and site. The lines represent 95% confidence intervals. *Significant at Holm-Bonferroni-corrected *P*-value

Online Resource Fig 3 Effect of the food-related behavioral activation therapy (F-BA) intervention on diet-associated land use (LU) in overweight adults with subsyndromal symptoms for depression during the 12-month MooDFOOD depression prevention trial (N=744)



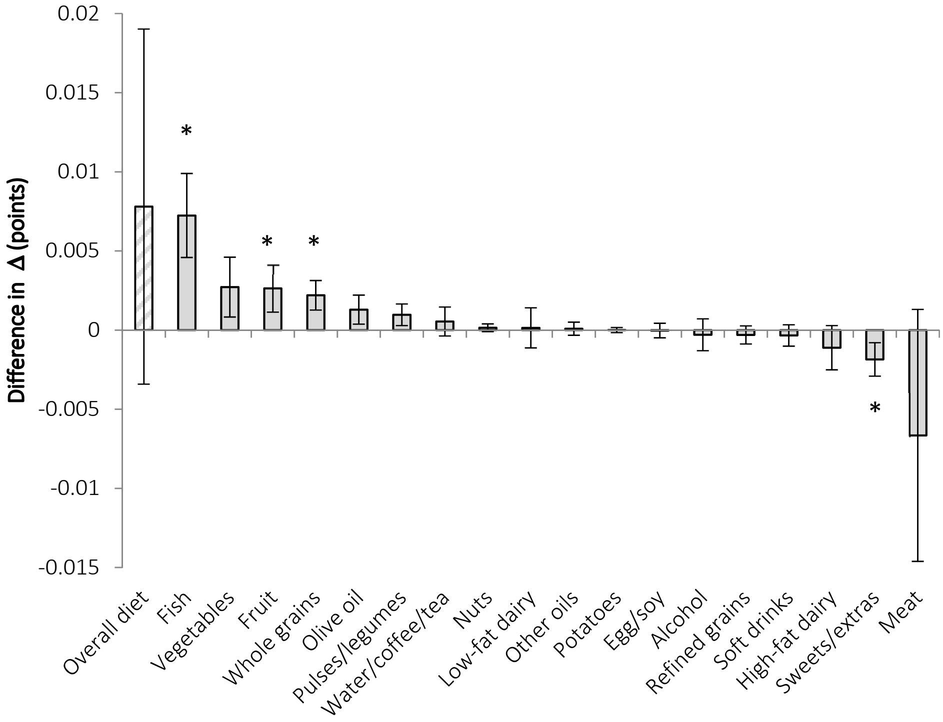
The bars represent the difference in change in land use (LU; m^2*a/day) from baseline to 12 months between participants who the F-BA intervention (F-BA group) and participants who did not receive the F-BA intervention (control group) when controlling for baseline value of outcome, age, sex and site. The lines represent 95% confidence intervals. *Significant at Holm-Bonferroni-corrected *P*-value

Online Resource Fig 4 Effect of the food-related behavioral activation therapy (F-BA) intervention on diet-associated fossil energy use (FEU) in overweight adults with subsyndromal symptoms for depression during the 12-month MooDFOOD depression prevention trial (N=744)



The bars represent the difference in change in fossil energy use (FEU; MJ/day) from baseline to 12 months between participants who received the F-BA intervention (F-BA group) and participants who did not receive the F-BA intervention (control group) when controlling for baseline value of outcome, age, sex and site. The lines represent 95% confidence intervals. *Significant at Holm-Bonferroni-corrected *P*-value

Online Resource Fig 5 Effect of the food-related behavioral activation therapy (F-BA) intervention on *p*ReCiPe score in overweight adults with subsyndromal symptoms for depression during the 12-month MooDFOOD depression prevention trial (N=744)



The bars represent the difference in change in *p*ReCiPe score (points) of diet from baseline to 12 months between participants who received the F-BA intervention (F-BA group) and participants who did not receive the F-BA intervention (control group) when controlling for baseline value of outcome, age, sex and site. The lines represent 95% confidence intervals. *Significant at Holm-Bonferroni-corrected *P*-value

CHAPTER 7

Effect of personalized dietary advice to increase protein intake on food consumption and the environmental impact of the diet in community-dwelling older adults: results from the PROMISS trial

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Abstract

Purpose Diet modelling studies suggest that increasing protein intake with no consideration for sustainability results in a higher environmental impact of the diet. To better understand the impact in real life, the aim of this study was to assess the effect of dietary advice to increase protein intake on food consumption and the environmental impact of the diet in community-dwelling older adults.

Methods Food consumption and environmental impact were analyzed among 124 Dutch older adults with lower habitual protein intake (<1.0 g/kg aBW/d) participating in the six-month PROMISS trial. Dietary intake data from a combination of three food diaries and three 24-hour dietary recalls and results from life cycle assessments were used to examine the differences in changes in food consumption and environmental impact between those who received dietary advice to isocalorically increase protein intake to ≥1.2 g/kg aBW/d (Protein+; n=84) and those who did not receive dietary advice (Control; n=40).

Results Compared to the Control, Protein+ increased protein intake from animal-based food products (11.0 g protein/d, 95% CI 6.6–15.4), plant-based food products (2.1 g protein/d, 95% CI 0.2–4.0) and protein-enriched food products provided during the trial (18 g protein/d, 95% CI 14.5–21.6) at the 6-month follow-up. Diet-associated greenhouse gas emissions increased by 16%, land use by 13%, terrestrial acidification by 20%, and marine eutrophication by 26% in Protein+ compared to the Control.

Conclusion This study found that the dietary advice increased protein intake, favoring animal-based protein, and increased the environmental impact of the diet in older adults.

1. Introduction

While protein is a key component of the diet for optimal physical function throughout all life stages, it is of particular importance among older adults as they frequently experience a reduction in muscle mass and function [1]. As people age, physiological, psychological and environmental changes associated with reduced food consumption increase the risk of suboptimal protein intake [1-3]. Lower protein intake has been shown to be associated with sarcopenia [4,5], which is characterized by a decline in muscle mass, strength, and physical function [6], increased risk of mortality and comorbidities [7,8]. While several short-term metabolic and observational studies suggest that older adults aged 65 years and older need to consume more protein compared to younger adults to maintain adequate muscle mass and strength [9-13], evidence from randomized controlled trials is not conclusive [14]. Nevertheless, several expert groups propose an increase of the recommended daily allowance (RDA) of protein from 0.8 g/kg body weight (BW)/d to 1.0-1.2 g/kg BW/d for older adults [15-17].

It has been previously argued that increasing protein intake based on current food consumption patterns is likely to have unfavorable consequences for the natural environment [18-20]. Globally, current food production and consumption are dominant drivers of climate change, eutrophication, acidification, and biodiversity loss and are a considerable drain on resources such as land, water, energy, and nutrients [21,22]. Notwithstanding the various components of the human diet, all of which have some impact on the environment, animal-based protein sources have been identified as having the largest impact on the environment than other dietary components [23,24]. In the Netherlands, animal-based protein constitutes 60% of total protein consumed by young and older adults alike [25,26]. A theoretical high-protein diet, modelled based on actual food intake data of Dutch community-dwelling older adults, showed that increasing protein intake from 1.0 to 1.2 g/kg BW/d, with isocaloric replacement and no consideration of environmental sustainability, increased the contribution of animal-based protein to 65% of total protein and increased diet-associated greenhouse gas emissions (GHGE) by 12-14%, land use (LU) by 10-12%, and fossil energy use by 9-10% [20]. This study used diet optimization, which is a powerful tool to model realistic diets as it simultaneously combines a given set of nutritional and environmental constraints while staying as close to the habitual diet as possible. However, given the diversity and complexity of food consumption behavior, understanding the effect of increasing protein intake on diet composition and diet sustainability in real life remains warranted.

Therefore, this study aimed to assess the change in consumption of protein-rich foods achieved by the PRevention Of Malnutrition In Senior Subjects in the EU (PROMISS) trial and to examine the effect of these changes over six months on the environmental impact of the diet. The PROMISS trial provides a unique opportunity to investigate the effect of the personalized dietary advice aiming at isocalorically increasing protein intake on food consumption and diet sustainability in community-dwelling older adults with low protein intake under real-life circumstances [27].

2. Methods

2.1. Study design and subjects

The PROMISS trial was a 6-month randomized controlled trial that investigated the effect of personalized dietary advice aiming at increasing protein intake with or without advice regarding timing of protein intake to close proximity of any usual physical activity, on change in physical functioning among community-dwelling older adults with a habitual protein intake of < 1.0 g/kg adjusted (a)BW/d. The design, methods, and primary outcomes of the trial are described in detail elsewhere [27,28] and are summarized below. A sample of 276 community-dwelling older adults (≥65 years) were recruited from the Netherlands and Finland and randomized to one of three groups: (1) intervention group 1 received personalized dietary advice aiming at increasing protein intake to at least 1.2 g/kg aBW/d (n=96); (2) intervention group 2 received personalized dietary advice aiming at increasing protein intake to at least 1.2 g/kg aBW/d *and* advice to optimize the timing of protein intake in close proximity of usual physical activity (n=89); and (3) control group did not receive any intervention (n=91). In addition to being ≥65 years and having a habitual protein intake <1.0 g/kg aBW/d, eligibility criteria included having normal cognition or mild dementia as determined by a Mini-Mental State Examination (MMSE) score >20, ability to walk 400 m within 15 minutes, and body mass index (BMI) ≥18.5 kg/m^2 and ≤32.0 kg/m^2. The eligibility criteria described above were assessed during a clinic visit, where body weight and height were measured. Participants also completed a baseline questionnaire, which included demographics like education. Randomization was stratified according to participants' baseline habitual intake (<0.9 or 0.9-1.0 g/kg aBW/d) and sex across the two countries. For the purposes of this study, only participants from the Netherlands (n=132) are included because the environmental data used is specific for food products consumed in the Netherlands. Further, to assess the effect of the dietary advice aiming at increasing protein intake, the two intervention groups were condensed into one to make comparisons between participants who received dietary advice to increase protein intake (Protein+ group, n=84) and those who did not (Control group, n=40). The advice on timing of protein intake had no effect on food consumption; this was checked by adding both intervention groups as dummy variables to the statistical models and it did not affect results.

2.2. Intervention: Personalized dietary advice to increase protein intake

Trained nutritionists provided participants in the intervention groups with personalized dietary advice to increase protein intake to ≥1.2 g/kg aBW/d with isocaloric replacement based on personal habitual dietary characteristics, protein intake and BW of participants as assessed at baseline. Advice was personalized based on food preferences and practices, taking into account whether the participants usually prepared their own meal, where and with whom they ate (e.g. family, friends' or community home), and whether they typically ate ready-to-eat meals or used a meal service. Participants received both written dietary advice and a verbal explanation from the nutritionist. Advice included the use of habitually consumed protein-rich food products and protein-enriched food products that were not habitually eaten prior to the trial. The protein-enriched food products, which included protein bars, cereals, puddings, coconut whey water and whey powder, were provided for free by the research team and sent to participants' home. Guidelines on how to incorporate the protein-enriched food products within their diet were provided. It was also advised to consume at least one daily meal consisting of $\geq$35g protein to stimulate muscle protein synthesis [29,30].

The nutritionists consulted with the participants from the Protein+ group several times throughout the intervention period to ensure that they have understood and are able to adhere to the advice. Changes in the dietary advice were made if necessary. For example, participants were requested to contact the nutritionists when a BW change of >2 kg occurred, so the dietary advice could be adapted accordingly. Participants allocated to the Control group were also contacted at similar time points as the intervention groups to ask how they are doing. To stimulate commitment to the trial, two lectures on non-health-related themes were organized and participants received incentives after three months.

2.3. Dietary data

Food consumption was assessed by a combination of three food diaries and three 24-hour dietary recalls one week prior to baseline and one week prior to the 3-month and 6-month follow-up clinic visit. The participants were asked to keep track of their dietary intake by filling out a food diary for three consecutive days (three weekdays or two weekdays and one weekend day). They received a diary and booklet with pictures of portion sizes to help them accurately fill out the diary. Nutritionists called the participants to go through their food diary of the day before (24-hour dietary recall). In case one of the three days was reported by the participant as not representative, mean intake was based on two instead of three days (n=5).

Food intake data were entered into the program 'Eetmeter' of the Netherlands Nutrition Center using an extended version of the Dutch Food Composition Table [31,32]. Food consumption data were categorized into 20 main food groups, modified from the GloboDiet food group classification, which were used to determine protein-rich food groups for the analysis [33]. Protein-enriched food products provided during the trial were a separate food group, making a total of 21 main food groups (Supplementary Table 1). The energy value provided by protein for each food item was calculated in energy percent (E% protein) [(g protein x (4 kcal / 1 g protein)) / total kcal of the food)] and were averaged across the food items in each food group. Food groups with at least an average 12 E% protein were considered protein-rich, as the European Commission recognizes food with at least 12 E% protein as a source of protein [34]. The 'Meat and meat products' food group was further stratified into subcategories due to their different impacts on health and the environment. Further, food groups were classified by protein source category: animal-based, plant-based and miscellaneous. Miscellaneous sources contain both animal and plant-based sources of protein (e.g. meat and dairy substitutes, soups and mixed dishes).

2.4. Environmental data

Various environmental impact indicators were investigated to assess diet sustainability, namely GHGE expressed in kilograms of carbon dioxide equivalents (kg CO_2-eq), LU in square meter-year ($m^{2}*y$), terrestrial acidification in kg sulfur dioxide equivalents (kg SO_2-eq), freshwater eutrophication in kg phosphorous equivalents (kg P-eq), marine eutrophication in kg nitrogen equivalents (kg N-eq), and blue water use, representing irrigated water from ground and surface water, in cubic meter (m^3). The life cycle assessment (LCA) approach was applied to calculate the environmental impact of foods and beverages throughout the entire life cycle, including farming, processing, distribution, through to waste. Primary LCA data was available for 242 foods representative of the Dutch situation and were calculated by Blonk Consultants (Gouda, the Netherlands) [35]. An extended dataset including extrapolated data for foods and beverages for which primary data were not available was used [36]. The extended dataset covered 84% of all foods consumed by the trial participants. Additional extrapolations from the primary data were made for foods and beverages for which data were not available, including protein-enriched food products provided during the trial. Extrapolations were made based on similarities in types of food, production systems and ingredient composition by expert judgement. For composite dishes, standardized recipes were used where available, and if not available, recipes were based on label information.

2.5. Statistical analysis

Descriptive statistics were produced to describe the baseline characteristics of the study participants stratified by study group. Education was categorized into three groups, namely lower education (includes elementary education or less), middle education (includes lower vocational education and general intermediate) and higher education (includes intermediate vocational education, general secondary, higher vocational, college or university). Mean daily consumption of protein-rich foods groups and protein source categories (i.e. animal, plant, miscellaneous), GHGEs, LU, blue water use, terrestrial acidification, freshwater eutrophication, and marine eutrophication were calculated for each participant over three days and at each time point (baseline, 3-month, 6-month follow up).

Longitudinal analysis of covariance was carried out using mixed effects models to assess the effect of the dietary advice on food consumption and the environmental impact of the diet. To assess the trial effect on food consumption, protein intake (in grams protein per day) by protein source (i.e. animal-based, plant-based, and miscellaneous) and consumption of the protein-rich food groups (in grams food per day) were analyzed. To assess the trial effect on the environmental impact of the diet, GHGE, LU, terrestrial acidification, freshwater and marine eutrophication, and blue water use were analyzed. A random intercept was added to the models to take into account the dependency of the repeated observations within the participants. Participants with missing dietary data at only one of the follow-up measurements were included in the analyses and no imputations were conducted, as mixed model analysis estimated with the maximum likelihood estimator accounts for missing data [37,38]. Drop-outs, i.e. participants with missing dietary data at the 3-month follow-up and the 6-month follow-up, were excluded in the analyses (n=8), and therefore the analytical sample included 124 participants.

Adjustment was made for the baseline value of the outcomes to increase precision [37,38]. Further adjustment was made for sex and baseline energy intake due to group differences at baseline (see Table 1). To explore the effect of only the compositional changes on the environmental impact of the diet, secondary analyses were conducted to adjust for energy intake at each time point. Regression coefficients and 95% CI along with p values are presented. For all statistical tests the 2-sided significance threshold was set to a p-value of 0.05. The analyses were performed on an intention-to-treat basis. Statistical analyses were conducted with Stata 16 (StataCorp. 2019. *Stata Statistical Software: Release 16*. College Station, TX: StataCorp LLC).

3. Results

3.1. Study participants and baseline characteristics

Baseline characteristics of the two study groups are presented in Table 1. The participants had an average age of 74 years and an average body mass index of 26 kg/m^2. The Protein+ group had a slightly higher proportion of males and a higher proportion of participants who completed higher education compared to the Control group at baseline. The baseline mean ± sd protein intake of the study participants was 62.9 ± 11.5 g/d or 0.84 ± 0.13 g/kg aBW/d.

Table 1. Baseline characteristics of participants who did not receive personalized dietary advice to increase protein intake (Control group) and participants who received personalized dietary advice to increase protein intake (Protein+ group) (N= 124)

Characteristic	Control group (n=40)	Protein+ group (n=84)
Age (y)	74 ± 5	74 ± 4
Sex, n (%)		
Male	20 (50%)	45 (54%)
Female	20 (50%)	39 (46%)
Education[a], n(%)		
Lower	-	2 (2%)
Middle	13 (32%)	8 (10%)
Higher	27 (68%)	74 (88%)
BMI [b] (kg/m^2)	26.7 ± 3	26.2 ± 3
Energy intake (kcal/d)	1678.9 ± 289.3	1759.5 ± 409.6
Protein intake (g/d)	63.2 ± 10.1	62.8 ± 12.2
Protein intake (g/kg aBW/d)	0.83 ± 0.12	0.84 ± 0.14
Greenhouse gas emissions (kg CO_2-eq/d)	4.1 ± 1.0	4.2 ± 1.3
Land use (m^2*y/d)	2.5 ± 0.5	2.5 ± 0.7
Terrestrial acidification (kg SO_2-eq/d)	0.04 ± 0.01	0.04 ± 0.01
Freshwater eutrophication (kg P-eq/d)	$3.1x10^{-4}$ ± $7.6x10^{-5}$	$3.3x10^{-4}$ ± $1.3x10^{-4}$
Marine eutrophication (kg N-eq/d)	$7.4x10^{-3}$ ± $5.0x10^{-3}$	$6.5x10^{-3}$ ± $3.1x10^{-3}$
Blue water use (m^3/d)	0.2 ± 0.1	0.2 ± 0.1

Results presented in mean ± standard deviation unless reported otherwise. [a] Lower education includes elementary education or less; Middle education includes lower vocational education and general intermediate; Higher education includes intermediate vocational education, general secondary, higher vocational, college or university. [b] Body mass index.

3.2. Intervention effect on consumption of protein and protein-rich food groups

The dietary advice aiming at increasing protein intake among community-dwelling older adults led to an increase in protein intake by 46% (95% CI 38% to 55%) [29.2 g /d (95% CI 23.9 to 34.5 g/d, $p<0.001$) or 0.4 g /kg aBW/d (95% CI 0.3 to 0.5 g/kg aBW/d, $p<0.001$)] relative to the Control group. The intervention resulted in more participants reaching or exceeding the recommended protein intake of 1.2 g/kg aBW/d at 6 months: 58% of older adults in the Protein+ group compared to 10% in the Control group. Although advice aimed for an isocaloric increase in protein intake, the Protein+ group increased their energy intake by 115.3 kcal/d (95% CI 6.9 to 223.6 kcal/d, $p=0.037$) from baseline to the 6-month follow-up compared to the Control group. Nevertheless, no difference in mean body weight change was found between the Protein+ and Control group ($p=0.371$). When energy intake at the different time points was taken into account, protein intake increased by 24.7 g/d (95% 19.8 to 29.7 g/d, $p<0.001$) in the Protein+ group relative to the Control group.

A statistically significant change in protein intake from plant-based and animal-based sources resulted from the dietary advice relative to the control, but no change in protein intake from miscellaneous sources (Figure 1). The Protein+ group increased their consumption of plant-based protein by 2.1 g /d (95% CI 0.2 to 4.0 g/d, $p=0.031$) and animal-based protein by 11.0 g /d (95% CI 6.6 to 15.4 g/d, $p<0.001$) from baseline to the 6-month follow-up compared to the Control group. Further, the Protein+ group increased their consumption of protein from the PROMISS protein-enriched food products by 18 g of protein (95% CI 14.5 to 21.6 g/d, $p<0.001$), which were derived from a daily average consumption of 160 g of these products (Table 2). Among the 84 participants in the Protein+ group, 84% consumed at least one of the PROMISS protein-enriched food products during the trial. Those who ate the products consumed a daily average 36.3 g of protein bar (8.4 g protein/d, n=26), 39.1 g of cereal crunch (6.5 g protein/d, n=27), 10.8 g protein powder (9.4 g protein/d, n=51), 269.0 g coconut whey water (16.4 g protein/d, n=43), 138.9 g chocolate pudding (14.6 g protein/d, n=9) and 154.2 g vanilla pudding (16.2 g protein/d, n=6). When looking at the relative changes in consumption of the other protein-rich food groups during the trial, only an increase in consumption of milk and milk products was found in the Protein+ group compared to the Control group (Table 2).

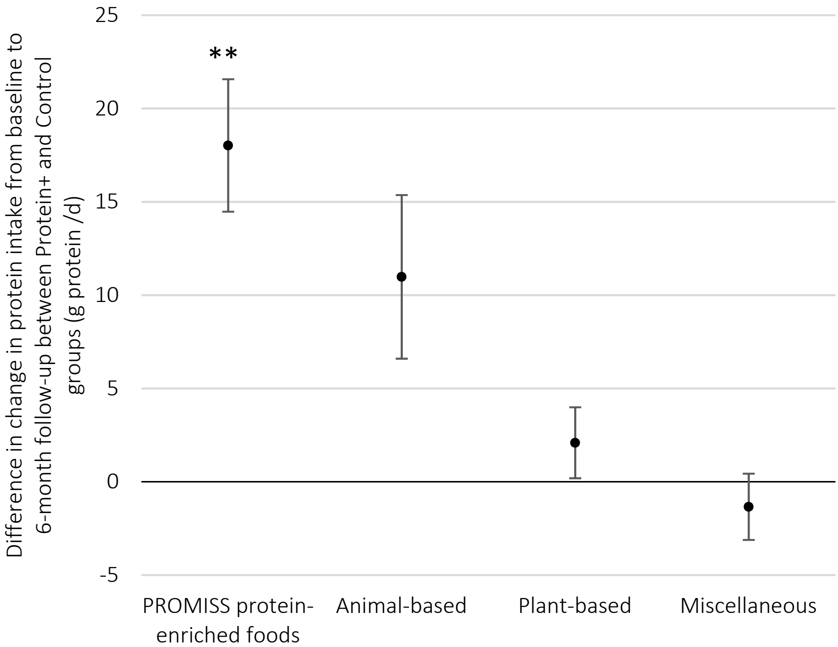


Figure 1 Six-month change in protein intake (in g/d) by protein source among those who received dietary advice aiming at increasing protein intake (Protein+ group) compared to those who did not receive dietary advice (Control group) during the PROMISS trial (N=124), adjusted for sex, baseline energy intake and baseline value of outcome. The dots represent the effect size estimates and lines represent 95% confidence intervals. * $p<0.05$ ** $p<0.001$

Table 2 Consumption of protein-rich food groups (in g food/d) at baseline and 6-month follow-up of those who did not receive dietary advice (Control group) and those who received dietary advice aiming at increasing protein intake (Protein+ group) during the PROMISS trial

	Control group		**Protein+ group**		**Difference in change between Protein+ and Control group (95% CI)[a]**
	Baseline (n=40)	**6-month follow-up (n=39)**	**Baseline (n=84)**	**6-month follow-up (n=82)**	
PROMISS protein-enriched foods[b]	-	-	-	160.0 ± 159.3	157.0* (116.6 – 198.4)
Animal-based					
Fish	19.2 ± 26.8	17.6 ± 31.5	22.4 ± 30.5	23.2 ± 34.0	5.2 (-6.5 – 17.0)
Meat and meat products	51.2 ± 40.3	71.4 ± 50.5	47.0 ± 41.7	72.3 ± 60.8	8.5 (-7.0 – 24.0)
Beef, veal, lamb and goat	20.7 ± 25.9	21.5 ± 25.6	16.5 ± 22.8	25.8 ± 31.1	7.2 (-1.4 – 15.8)
Pork	20.2 ± 20.8	33.0 ± 40.1	22.3 ± 29.6	23.6 ± 28.8	0.4 (-4.9 – 5.7)
Poultry	10.3 ± 16.8	16.8 ± 33.4	8.3 ± 18.5	21.6 ± 36.8	1.9 (-6.1 – 9.9)
Processed meat	13.6 ± 21.2	13.3 ± 21.4	17.4 ± 24.1	16.3 ± 22.8	-2.8 (-9.3 – 3.5)
Eggs	21.1 ± 26.7	21.9 ± 24.4	19.5 ± 20.0	21.3 ± 24.3	2.3 (-4.4 – 8.9)
Milk and milk products	275.0 ± 171.5	269.7 ± 166.6	205.8 ± 157.9	287.5 ± 165.4	72.7* (31.9 – 113.6)
Cheese	29.0 ± 21.0	28.7 ± 21.7	28.2 ± 20.0	34.7 ± 26.5	6.7 (-0.6 – 14.2)
Plant-based					
Vegetables	170.2 ± 103.9	196.0 ± 113.3	184.4 ± 103.6	160.5 ± 88.1	-14.0 (-42.0 – 14.0)
Legumes	5.9 ± 15.0	6.2 ± 15.2	9.5 ± 22.5	10.5 ± 20.1	3.1 (-2.0 – 8.1)
Cereal and cereal products	116.4 ± 65.3	119.6 ± 59.3	129.6 ± 67.5	130.8 ± 56.4	8.2 (-7.0 – 23.4)
Nuts and seeds	16.4 ± 16.7	14.0 ± 17.1	16.6 ± 21.4	16.5 ± 16.6	2.9 (-1.4 – 7.1)
Miscellaneous					
Meat and dairy substitutes	2.9 ± 7.8	5.5 ± 14.3	14.6 ± 41.9	16.3 ± 48.6	4.3 (-8.9 – 17.5)
Soups	54.1 ± 78.5	59.0 ± 80.7	79.1 ± 99.9	59.6 ± 95.2	-24.1 (-52.5 – 4.3)
Mixed dishes	50.4 ± 117.7	37.7 ± 68.5	41.3 ± 68.3	32.5 ± 58.1	-20.2 (-41.3 – 1.0)

Values displayed as mean ± standard deviation. [a] Unstandardized regression coefficients and 95% confidence intervals of difference in change from baseline to 6-month follow up between Protein+ group and Control group, controlling for sex, baseline energy intake and baseline value of outcome. [b] PROMISS protein-enriched food products included protein bars, cereals, puddings, coconut whey water and whey powder. * Statistically significant at $p<0.05$.

3.3. Intervention effect on environmental impact of diet

The dietary advice aiming at increasing protein intake among community-dwelling older adults led to an increase in GHGE by 0.66 kg CO_2-eq/d (95% CI 0.29 to 1.02 kg CO_2-eq/d), LU by 0.46 m^{2}*y/d (95% CI 0.28 to 0.67 m^{2}*y/d), terrestrial acidification by 0.01 kg SO_2-eq/d (95% CI 0.002 to 0.01 kg SO_2-eq/d), and marine eutrophication by 1.04×10^{-3} kg N-eq/d (95% CI 7.27×10^{-5} to 2.01×10^{-3} kg N-eq/d) (Table 3). The dietary advice had no effect on freshwater eutrophication or blue water consumption. Adjustment for energy intake over time attenuated the effect on GHGE (0.40 kg CO_2-eq/d, 95% CI 0.09 to 0.71 kg CO_2-eq/d), LU (0.30 m^{2}*y/d, 95% CI 0.13 to 0.47 m^{2}*y/d) and terrestrial acidification (0.005 kg SO2-eq/d, 95% CI 8.69×10^{-6} to 0.01 kg SO2-eq/d) and no longer had a statistically significant effect on marine eutrophication (1.3×10^{-3} kg N-eq/d, 95% CI -3.1×10^{-6} to 1.1×10^{-2} kg N-eq/d).

Table 3 Effect of dietary advice aiming at increasing protein intake on the environmental impact of the diet in Dutch community-dwelling older adults during the PROMISS trial (N=124)

Environmental outcomes	Difference in change from baseline to 6 months[a]	95% CI	P value
Greenhouse gas emissions (kg CO_2-eq/d)			
Model 1[b]	0.69	0.33 – 1.06	<0.001
Model 2[c]	0.66	0.29 – 1.02	<0.001
Land use (m^{2}*y/d)			
Model 1	0.50	0.28 – 0.71	<0.001
Model 2	0.46	0.24 – 0.67	<0.001
Terrestrial acidification (kg SO_2-eq/d)			
Model 1	0.01	0.003 – 0.01	0.004
Model 2	0.01	0.002 – 0.01	0.010
Eutrophication - Freshwater (kg P-eq/d)			
Model 1	4.14×10^{-5}	3.8×10^{-7} – 8.24×10^{-5}	0.048
Model 2	3.57×10^{-5}	-3.37×10^{-6} – 7.47×10^{-6}	0.073
Eutrophication - Marine (kg N-eq/d)			
Model 1	1.24×10^{-3}	2.50×10^{-4} – 2.24×10^{-3}	0.014
Model 2	1.04×10^{-3}	7.27×10^{-5} – 2.01×10^{-3}	0.035
Blue water use (m^3/d)			
Model 1	-0.01	-0.02 – 0.01	0.304
Model 2	-0.01	-0.03 – 0.01	0.329

[a] Unstandardized beta coefficient of the difference in change from baseline to 6-month follow-up between participants who received dietary advice (Protein+ group) and participants who did not receive dietary advice (Control group). [b] Model 1 controls for sex, baseline energy intake and baseline value of outcome. [c] Model 2 controls for sex, energy intake over time, and baseline value of outcome.

3.4. Contribution of food groups to total protein intake and environmental impacts

At baseline, the top three food groups contributing most to total protein intake across the total study population were cereal products (18% of total protein intake), meat products (16%), and milk products (15%). At the 6-month follow-up, the dominant protein sources in the Protein+ group were the PROMISS protein-enriched food products (19% of total protein intake) followed by meat products (17%) and milk products (14%), whereas meat products (23%), cereal products (16%), and milk products (13%) were dominant sources in the Control group (Supplementary Figure 1 and 2).

For GHGE, LU, terrestrial acidification and marine eutrophication, meat and meat products were the largest contributors at baseline and 6-month follow-up for both groups (Supplementary Figure 1). Milk and milk products were second largest contributor to total GHGE, terrestrial acidification, and marine eutrophication at baseline and 6-month follow-up for both groups. The second largest contributor to LU was drinks for both groups except for the Protein+ group at the 6-month follow-up, for which the PROMISS protein-enriched food products contributed the most. Drinks contributed most to freshwater eutrophication at baseline, followed by meat and meat products, but the order switched at the 6-month follow-up for both groups. For blue water use, fruits, drinks, and nuts and seeds were the main contributors at baseline and 6-month follow-up for both groups. Among the protein-rich food products, meat and milk products hold most weight in the diet's environmental impact across all indicators, except blue water use, for which nuts and seeds hold most weight.

4. Discussion

Dietary advice aiming at increasing protein intake among community-dwelling older adults with lower habitual protein intake (<1.0 g/kg aBW/d) led to a change in food consumption and an increase in four out of six environmental impact indicators. Older adults who received dietary advice increased their protein intake by 46% compared to older adults who did not receive advice. This result was explained by a small but significant increase in protein intake from plant-based foods, a large significant increase in protein intake from animal-based foods, and an introduction of protein-enriched food products in the diet. These changes made to the diet yielded a significant increase in GHGE by 16%, LU by 13%, terrestrial acidification by 20%, and marine eutrophication by 26% compared to the control group. Once energy intake over time was accounted for, the environmental impacts were attenuated and the trial no longer had an effect on marine eutrophication.

Our findings are consistent with previous studies that modelled theoretical dietary changes from current diets to high-protein diets, which expose a tendency to value animal-based protein, leading to higher environmental impacts. In Switzerland, a hypothetical protein-oriented diet consisted of greater amounts of animal-based foods compared to the current Swiss diet, resulting in a 50% increase in GHGE and a 20% increase in land, nitrogen and phosphorus footprint [18]. Similarly, the diet optimization study among Dutch older adults found that an increase in protein intake from the average intake of 1.0 to 1.2 g/kg BW/d, with no consideration of diet sustainability, led to increases in animal-based protein and an increase GHGE, LU and fossil energy use [20]. The present study shows that in real life, dietary advice aiming at increasing protein intake resulted in increased protein intake mainly from animal-based protein sources, and especially from milk and milk products, and protein-enriched food products. This in turn led to increases in GHGE, LU, terrestrial acidification and marine eutrophication, but no change in freshwater eutrophication and blue water use.

What is unique about this study compared to the aforementioned modelling studies is the inclusion of protein-enriched food products. Protein-enriched food products contributed to approximately one fifth of total protein intake, but to only 5% GHGE, 13% LU, 3% terrestrial acidification, 4% freshwater eutrophication, 3% marine eutrophication, and 2% blue water use in the diet of the Protein+ group at the 6-month follow-up. Protein-enriched foods, which are protein-dense given its volume, are thus efficient in delivering protein with relatively low environmental impact. Although consumer studies have shown that older adults tend to be skeptical towards protein-enriched foods [39,40], this study supports findings from previous trials that show protein-enriched foods are acceptable and can be successfully implemented in the menu of older adults [41-43]. The protein-enriched food product consumed by the most participants was the whey protein powder, which has a relatively high environmental impact being derived from milk. An LCA study shows that 14 kg CO_2-eq can be avoided by replacing 1 kg whey with 1 kg soy protein [44]. However, whey is a waste product created from cheese making, and therefore its production is inevitable given the high demand for cheese [45]. This creates an opportunity for the dairy industry to channel an environmentally burdensome waste product into protein-enriched foods and beverages for older consumers, although technological innovation is needed to bring down the environmental impact of whey processing and transportation [46].

Evidence is clear that a protein transition is needed to achieve more environmentally-friendly diets [19,22,47]. To increase protein intake in an environmentally friendly way in older adults, the diet optimization study showed that a shift towards a more plant-based diet was needed, one in which the animal- to plant-protein ratio shifts from 60:40 to 50:50 [20]. This is in line with the Health Council of the Netherlands' advice to shift towards a more plant-based diet (i.e. a diet in which 50% of total protein consumed is derived from animal sources and 50% from plant sources) to reconcile the environmental pressures of the current diet, as well as to reduce the risk of chronic diseases associated with high consumption of red and processed meat [48,49]. When it comes to the transition to plant-based diets, protein quality remains a concern. In general, animal-based proteins are superior to plant-based protein in terms of their higher digestibility and better composition of essential amino acids, but it has been shown that consuming sufficient amounts and a diverse assortment of plant-based foods can provide adequate protein [47]. When it comes to preserving muscle mass among older adults, a higher amount of protein consumed, regardless of protein type, was found to be beneficial, and there was no added value of having a higher animal- to plant-protein ratio [50]. Because a serving of plant-based food contains on average less protein compared to an equivalent portion of animal-based food, more plant-based foods would need to be consumed to obtain sufficient protein intake [51]. This might be problematic for older adults who have physical problems with eating or low appetite who are at higher risk of low protein intake [51,52]. In this case, protein-enrichment of habitually consumed foods and beverages, in addition to consuming more plant protein in place of animal protein, might support the shift towards environmentally-friendly high-protein diets. Nevertheless, exclusion of food groups like meat is not necessary to improve the sustainability of diets [20].

This study provides insight into the effect of increasing the current RDA for protein on changes in food consumption and diet sustainability among older adults. Although energy intake and body weight were carefully monitored during the trial, which would not happen if the RDA were to change, the Protein+ group increased their energy intake by 115 kcal compared to those in the Control group. However, there was no difference in body weight change between the Protein+ and control group [28]. Higher total energy intake, regardless of source, has also been associated with higher environmental impact of the diet [53,54], explaining the attenuation of the trial effects on GHGE, LU and terrestrial acidification when energy intake over time was accounted for. Nevertheless, even if energy intake remained constant, the observed increases in GHGE, LU, terrestrial acidification and marine eutrophication serve as a warning. If we are to meet the 2030 GHGE targets of the Intergovernmental Panel on Climate Change (IPCC) report, designed to limit the global average temperature rise to 1.5^{o}C, the GHGE of the average Dutch diet should be 2.04 kg CO2-eq/d, half of the baseline GHGE estimate [55]. In light of a growing older population and the impending climate crisis, it is necessary to consider environmental sustainability in addition to the nutritional adequacy of the diet in older adults.

The present study has a number of strengths and limitations. A strength of this study was the provision of personalized dietary advice tailored to each participant's preferences and practices, which is a more effective strategy to change food consumption compared to generalized dietary advice [56]. This allowed us to examine the environmental impact of dietary change within a relatively short period of time (6 months). Further, trained nutritionists performed three 24-hour dietary recalls at baseline and two follow-up moments to capture usual protein intake at the population level [57]. The use of the food diary, which served as a memory aid for participants, might have yielded more accurate recalls since some older adults may have a poorer short-term memory. A drawback to this is that respondents may have unintentionally changed their dietary habits through self-reflection, or intentionally to make their responses socially desirable [58]. A disadvantage to 24-hour dietary recalls is their susceptibility to error including misreporting and day-to-day variation, which we did not take into account to establish the distribution of usual dietary intake [59]. It is possible, for instance, that differential response bias due intervention exposure may have led to over-reporting of protein-rich foods among those in the Protein+ group [60]. Day-to-day variation, however, is a random error and is not expected to influence mean intake of the population, because on average random errors cancel out. Another strength is the use of five environmental impact indicators, which give a more nuanced insight into diet sustainability compared to the majority of studies that focus on GHGE [36]. The environmental impact indicators in our study do not include other metrics like biodiversity loss and antibiotic use in poultry production, due to a lack of robust data. Nevertheless, LCA data have a high level of uncertainty due to various factors such as limited data and variations in local environments [61]. More than 20% of the foods in this study are based on extrapolated data, adding more uncertainty to the environmental estimates [36]. However, the ranking of food groups is unlikely to be affected, and besides, our LCA data is complete [36].

The need for considering environmental sustainability in dietary guidance is clear [62]. Evidence consistently indicates that the impacts of animal-based foods exceed those of plant-based alternatives across multiple environmental indicators including GHGE, LU, acidification, eutrophication, and water use [63,64]. Nevertheless, there is great variability in impacts between different food products among animal- and plant-based sources. For instance, compared to non-ruminant meat (e.g. poultry, pork), ruminant meat (e.g. beef, goat, lamb) has a much larger environmental impact because ruminants do not efficiently convert feed into body weight and they emit methane, a potent greenhouse gas, as a by-product of enteric fermentation during their digestive process [24,63]. Dietary advice aiming at increasing protein intake among older adults should therefore address the proportion of animal- to plant-protein in the diet and recommend low-impact alternatives (e.g. poultry vs. beef). More research is warranted to assess the effect of increasing protein intake mainly from plant-based sources like legumes, nuts, and whole grains with isocaloric replacement on (long-term) functional outcomes in older adults. In addition, further research is needed to evaluate the environmental impact of dietary change due to dietary advice aiming at increasing protein intake that also considers environmental sustainability.

5. Conclusion

Personalized dietary advice aiming at increasing protein intake led to a small increase in protein intake from plant-based sources, a larger increase in protein intake from animal-based sources, and an increase in protein intake from protein-enriched food products. These dietary changes together yielded an increase in GHGE, LU, terrestrial acidification and marine eutrophication, but no change in freshwater eutrophication and blue water use. Once energy intake over time accounted for, the intervention no longer had an effect on marine eutrophication. To meet the protein needs of a growing older population, dietary guidance must incorporate environmental sustainability aspects, in particular reducing the animal- to plant-protein ratio and replacing high-impact protein sources with lower-impact protein sources within each protein source category (e.g. poultry to replace beef). Consumers would benefit from receiving clear guidance on how much and what type of foods can sustainably deliver their daily protein needs.

References

1. Deer RR, Volpi E (2015) Protein intake and muscle function in older adults. Curr Opin Clin Nutr Metab Care 18 (3):248-253. https://doi.org/10.1097/MCO.0000000000000162
2. Volkert D, Kiesswetter E, Cederholm T, Donini LM, Eglseer D, Norman K et al (2019) Development of a model on determinants of malnutrition in aged persons: A MaNuEL Project. Gerontol Geriatr Med 5:2333721419858438. https://doi.org/10.1177/2333721419858438
3. de Boer A, Ter Horst GJ, Lorist MM (2013) Physiological and psychosocial age-related changes associated with reduced food intake in older persons. Ageing Res Rev 12 (1):316-328. https://doi.org/10.1016/j.arr.2012.08.002
4. Buford TW, Anton SD, Judge AR, Marzetti E, Wohlgemuth SE, Carter CS et al (2010) Models of accelerated sarcopenia: Critical pieces for solving the puzzle of age-related muscle atrophy. Ageing Res Rev 9 (4):369-383. https://doi.org/10.1016/j.arr.2010.04.004
5. Kiesswetter E, Sieber CC, Volkert D (2020) Protein intake in older people. Zeitschrift für Gerontologie und Geriatrie 53 (4):285-289. https://doi.org/10.1007/s00391-020-01723-4
6. Cruz-Jentoft AJ, Bahat G, Bauer J, Boirie Y, Bruyère O, Cederholm T et al (2019) Sarcopenia: revised European consensus on definition and diagnosis. Age and Ageing 48 (1):16-31. https://doi.org/10.1093/ageing/afy169
7. Xia L, Zhao R, Wan Q, Wu Y, Zhou Y, Wang Y et al (2020) Sarcopenia and adverse health-related outcomes: An umbrella review of meta-analyses of observational studies. Cancer Medicine 9 (21):7964-7978. https://doi.org/10.1002/cam4.3428
8. Mendonça N, Kingston A, Granic A, Jagger C (2019) Protein intake and transitions between frailty states and to death in very old adults: the Newcastle 85+ study. Age and Ageing 49 (1):32-38. https://doi.org/10.1093/ageing/afz142
9. Moore DR, Churchward-Venne TA, Witard O, Breen L, Burd NA, Tipton KD et al (2015) Protein ingestion to stimulate myofibrillar protein synthesis requires greater relative protein intakes in healthy older versus younger men. J Gerontol A 70 (1):57-62. https://doi.org/10.1093/gerona/glu103
10. Katsanos CS, Kobayashi H, Sheffield-Moore M, Aarsland A, Wolfe RR (2005) Aging is associated with diminished accretion of muscle proteins after the ingestion of a small bolus of essential amino acids. Am J Clin Nutr 82 (5):1065-1073. https://doi.org/10.1093/ajcn/82.5.1065
11. Isanejad M, Mursu J, Sirola J, Kröger H, Rikkonen T, Tuppurainen M et al (2016) Dietary protein intake is associated with better physical function and muscle strength among elderly women. Br J Nutr 115 (7):1281-1291. https://doi.org/10.1017/S000711451600012X
12. Lemieux FC, Filion ME, Barbat-Artigas S, Karelis AD, Aubertin-Leheudre M (2014) Relationship between different protein intake recommendations with muscle mass and muscle strength. Climacteric 17 (3):294-300. https://doi.org/10.3109/13697137.2013.829440
13. Mendonça N, Hengeveld LM, Visser M, Presse N, Canhão H, Simonsick EM et al (2021) Low protein intake, physical activity, and physical function in European and North American community-dwelling older adults: a pooled analysis of four longitudinal aging cohorts. Am J Clin Nutr 114 (1):29-41. 10.1093/ajcn/nqab051
14. Health Council of the Netherlands (2021) Evaluation of dietary reference values for protein. Background document to: Dietary reference values for protein 2021/10. Health Council of the Netherlands, The Hague.
15. Bauer J, Biolo G, Cederholm T, Cesari M, Cruz-Jentoft AJ, Morley JE et al (2013) Evidence-based recommendations for optimal dietary protein intake in older people: A position paper

from the PROT-AGE study group. J Am Med Dir Assoc 14 (8):542-559. https://doi.org/10.1016/j.jamda.2013.05.021
16. Deutz NEP, Bauer JM, Barazzoni R, Biolo G, Boirie Y, Bosy-Westphal A et al (2014) Protein intake and exercise for optimal muscle function with aging: Recommendations from the ESPEN Expert Group. Clin Nutr 33 (6):929-936. https://doi.org/10.1016/j.clnu.2014.04.007
17. Richter M, Baerlocher K, Bauer JM, Elmadfa I, Heseker H, Leschik-Bonnet E et al (2019) Revised reference values for the intake of protein. Ann Nutr Metab 74 (3):242-250. https://doi.org/10.1159/000499374
18. Chen C, Chaudhary A, Mathys A (2019) Dietary change scenarios and implications for environmental, nutrition, human health and economic dimensions of food sustainability. Nutrients 11 (4):856. https://doi.org/10.3390/nu11040856
19. de Gavelle E, Leroy P, Perrimon M, Huneau J-F, Sirot V, Orset C et al (2019) Modeled gradual changes in protein intake to increase nutrient adequacy lead to greater sustainability when systematically targeting an increase in the share of plant protein. Clim Change. https://doi.org/10.1007/s10584-019-02592-6
20. Grasso AC, Olthof MR, van Dooren C, Broekema R, Visser M, Brouwer IA (2020) Protein for a healthy future: How to increase protein intake in an environmentally sustainable way in older adults in the Netherlands. J Nutr 151 (1):109-119. https://doi.org/10.1093/jn/nxaa322
21. IPCC (2019) Climate Change and Land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Intergovernmental Panel on Climate Change (IPCC), Geneva, Switzerland.
22. Willett W, Rockstrom J, Loken B, Springmann M, Lang T, Vermeulen S et al (2019) Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems. Lancet 393 (10170):447-492. https://doi.org/10.1016/s0140-6736(18)31788-4
23. Notarnicola B, Tassielli G, Renzulli PA, Castellani V, Sala S (2017) Environmental impacts of food consumption in Europe. J Clean Prod 140:753-765. https://doi.org/10.1016/j.jclepro.2016.06.080
24. Garnett T, Godde C, Muller A, Röös E, Smith P, de Boer I et al (2017) Grazed and confused? Ruminanting on cattle, grazing systems, methane, nitrous oxide, the soil carbon sequestration question - and what it all means for greenhouse gas emissions. Food Climate Research Network, Oxford Martin Programme on the Future of Food, Environmental Change Institute, University of Oxford, Oxford.
25. Ocké M, Buurma-Rethans E, EJ Bd, C W-vdH, Z E-G, JJMM D et al (2013) Diet of community-dwelling older adults: Dutch National Food Consumption Survey Older Adults 2010-2012. National Institute for Public Health and the Environment, Bilthoven, The Netherlands.
26. Ocké MC, Toxopeus IB, Geurts M, Mengelers MJB, Temme EHM, Hoeymans N (2017) What is on our plate? Safe, healthy and sustainable diets in the Netherlands. RIVM Report 2017-0024. Rijksinstituut voor Volksgezondheid en Milieu, Bilthoven.
27. Reinders I, Wijnhoven HAH, Jyväkorpi SK, Suominen MH, Niskanen R, Bosmans JE et al (2020) Effectiveness and cost-effectiveness of personalised dietary advice aiming at increasing protein intake on physical functioning in community-dwelling older adults with lower habitual protein intake: rationale and design of the PROMISS randomised controlled trial. BMJ Open 10 (11):e040637. https://doi.org/10.1136/bmjopen-2020-040637
28. Reinders I, Visser M, Jyväkorpi SK, Niskanen RT, Bosmans JE, Ben ÂJ et al (in press) The (cost-)effectiveness of personalized dietary advice to increase protein intake on change in physical functioning in older adults with lower habitual protein intake: A randomized controlled trial. Eur J Nutr
29. Paddon-Jones D, Rasmussen BB (2009) Dietary protein recommendations and the prevention of sarcopenia. Curr Opin Clin Nutr Metab Care 12 (1):86-90. https://doi.org/10.1097/MCO.0b013e32831cef8b

30. Deutz NE, Wolfe RR (2013) Is there a maximal anabolic response to protein intake with a meal? Clin Nutr 32 (2):309-313. https://doi.org/10.1016/j.clnu.2012.11.018
31. The Netherlands Nutrition Center (Voedingscentrum) Eetmeter. https://mijn.voedingscentrum.nl/nl/eetmeter/.
32. National Institute for Public Health and the Environment (RIVM) (2016) Nederlands Voedingsstoffenbestand 2016 (Dutch Food Composition Table 2016). https://nevo-online.rivm.nl/.
33. Slimani N, Ferrari P, Ocké M, Welch A, Boeing H, van Liere M et al (2000) Standardization of the 24-hour diet recall calibration method used in the European Prospective Investigation into Cancer and Nutrition (EPIC): general concepts and preliminary results. Eur J Clin Nutr 54 (12):900-917. https://doi.org/10.1038/sj.ejcn.1601107
34. Commission. E (2014) Regulation (EC) No 1924/2006 of the European Parliament and of the Council of 20 December 2006 on nutrition and health claims made on foods. http://data.europa.eu/eli/reg/2006/1924/2014-12-13.
35. Database environmental impact of foods (2021) https://www.rivm.nl/voedsel-en-voeding/duurzaam-voedsel/database-milieubelasting-voedingsmiddelen.
36. Vellinga RE, van de Kamp M, Toxopeus IB, van Rossum CTM, de Valk E, Biesbroek S et al (2019) Greenhouse gas emissions and blue water use of Dutch diets and its association with health. Sustainability 11 (21):6027. https://doi.org/10.3390/su11216027
37. Twisk J (2013) Applied Longitudinal Data Analysis for Epidemiology: A Practical Guide. Second Edition edn. Cambridge University Press, Cambridge, UK
38. Twisk J, Bosman L, Hoekstra T, Rijnhart J, Welten M, Heymans M (2018) Different ways to estimate treatment effects in randomised controlled trials. Contemp Clin Trials Commun 10:80-85. https://doi.org/10.1016/j.conctc.2018.03.008
39. Banovic M, Arvola A, Pennanen K, Duta DE, Brückner-Gühmann M, Lähteenmäki L et al (2018) Foods with increased protein content: A qualitative study on European consumer preferences and perceptions. Appetite 125:233-243. https://doi.org/10.1016/j.appet.2018.01.034
40. van der Zanden LDT, van Kleef E, de Wijk RA, van Trijp HCM (2014) Knowledge, perceptions and preferences of elderly regarding protein-enriched functional food. Appetite 80:16-22. https://doi.org/10.1016/j.appet.2014.04.025
41. Beelen J, de Roos NM, de Groot LCPGM (2017) A 12-week intervention with protein-enriched foods and drinks improved protein intake but not physical performance of older patients during the first 6 months after hospital release: a randomised controlled trial. Br J Nutr 117 (11):1541-1549. https://doi.org/10.1017/S0007114517001477
42. Ziylan C, Haveman-Nies A, Kremer S, de Groot LCPGM (2017) Protein-enriched bread and readymade meals increase community-dwelling older adults' protein intake in a double-blind randomized controlled trial. J Am Med Dir Assoc 18 (2):145-151. https://doi.org/10.1016/j.jamda.2016.08.018
43. Beelen J, de Roos NM, de Groot LCPGM (2017) Protein enrichment of familiar foods as an innovative strategy to increase protein intake in institutionalized elderly. J Nutr Health Aging 21 (2):173-179. https://doi.rog/10.1007/s12603-016-0733-y
44. Braun M, Muñoz I, Schmidt JH, Thrane M (2016) Sustainability of soy protein from life cycle assessment. FASEB J 30 (S1):894.895-894.895. https://doi.org/10.1096/fasebj.30.1_supplement.894.5
45. Papademas P, Kotsaki P (2019) Technological utilization of whey towards sustainable exploitation. Adv Dairy Res 7:1-10. https://doi.org/10.35248/2329-888X.7.4.231
46. Bacenetti J, Bava L, Schievano A, Zucali M (2018) Whey protein concentrate (WPC) production: Environmental impact assessment. J Food Eng 224:139-147. https://doi.org/10.1016/j.jfoodeng.2017.12.018

47. Lonnie M, Johnstone AM (2020) The public health rationale for promoting plant protein as an important part of a sustainable and healthy diet. Nutr Bull 45 (3):281-293. https://doi.org/10.1111/nbu.12453
48. Kromhout D, Spaaij CJK, de Goede J, Weggemans RM (2016) The 2015 Dutch food-based dietary guidelines. Eur J Clin Nutr 70 (8):869-878. https://doi.org/10.1038/ejcn.2016.52
49. The Netherlands Nutrition Center (Voedingscentrum) (2018) Source document: Towards a more plant-based diet (in Dutch). Voedingscentrum, The Hague.
50. Lim MT, Pan BJ, Toh DWK, Sutanto CN, Kim JE (2021) Animal protein versus plant protein in supporting lean mass and muscle strength: A systematic review and meta-analysis of randomized controlled trials. Nutrients 13 (2):661. https://doi.org/10.3390/nu13020661
51. Berrazaga I, Micard V, Gueugneau M, Walrand S (2019) The role of the anabolic properties of plant- versus animal-based protein sources in supporting muscle mass maintenance: A critical review. Nutrients 11 (8):1825. https://doi.org/10.3390/nu11081825
52. van der Pols-Vijlbrief R, Wijnhoven HA, Schaap LA, Terwee CB, Visser M (2014) Determinants of protein-energy malnutrition in community-dwelling older adults: a systematic review of observational studies. Ageing Res Rev 18:112-131. https://doi.org/10.1016/j.arr.2014.09.001
53. Masset G, Vieux F, Verger EO, Soler L-G, Touazi D, Darmon N (2014) Reducing energy intake and energy density for a sustainable diet: a study based on self-selected diets in French adults. Am J Clin Nutr 99 (6):1460-1469. https://doi.org/10.3945/ajcn.113.077958
54. Mertens E, Kuijsten A, van Zanten HHE, Kaptijn G, Dofková M, Mistura L et al (2019) Dietary choices and environmental impact in four European countries. J Clean Prod 237:117827. https://doi.org/10.1016/j.jclepro.2019.117827
55. Broekema R, Tyszler M, van 't Veer P, Kok FJ, Martin A, Lluch A et al (2020) Future-proof and sustainable healthy diets based on current eating patterns in the Netherlands. Am J Clin Nutr 112 (5):1338-1347. https://doi.org/10.1093/ajcn/nqaa217
56. Celis-Morales C, Lara J, Mathers JC (2015) Personalising nutritional guidance for more effective behaviour change. Proc Nutr Soc 74 (2):130-138. https://doi.org/10.1017/S0029665114001633
57. Freedman LS, Guenther PM, Dodd KW, Krebs-Smith SM, Midthune D (2009) The population distribution of ratios of usual intakes of dietary components that are consumed every day can be estimated from repeated 24-hour recalls. J Nutr 140 (1):111-116. https://doi.org/10.3945/jn.109.110254
58. Shim J-S, Oh K, Kim HC (2014) Dietary assessment methods in epidemiologic studies. Epidemiol Health 36:e2014009-e2014009. https://doi.org/10.4178/epih/e2014009
59. Naska A, Lagiou A, Lagiou P (2017) Dietary assessment methods in epidemiological research: current state of the art and future prospects. F1000Research 6:926-926. https://doi.org/10.12688/f1000research.10703.1
60. Natarajan L, Pu M, Fan J, Levine RA, Patterson RE, Thomson CA et al (2010) Measurement error of dietary self-report in intervention trials. Am J Epidemiol 172 (7):819-827. https://doi.org/10.1093/aje/kwq216
61. Reap J, Roman F, Duncan S, Bras B (2008) A survey of unresolved problems in life cycle assessment. Int J LCA 13 (5):374. https://doi.org/10.1007/s11367-008-0009-9
62. Rose D, Heller MC, Roberto CA (2019) Position of the Society for Nutrition Education and Behavior: The importance of including environmental sustainability in dietary guidance. J Nutr Educ Behav 51 (1):3-15.e11. https://doi.org/10.1016/j.jneb.2018.07.006
63. Poore J, Nemecek T (2018) Reducing food's environmental impacts through producers and consumers. Science 360 (6392):987-992. https://doi.org/10.1126/science.aaq0216
64. Sabaté J, Sranacharoenpong K, Harwatt H, Wien M, Soret S (2014) The environmental cost of protein food choices. Public Health Nutr 18 (11):2067-2073. https://doi.org/10.1017/S1368980014002377

Supplementary Material

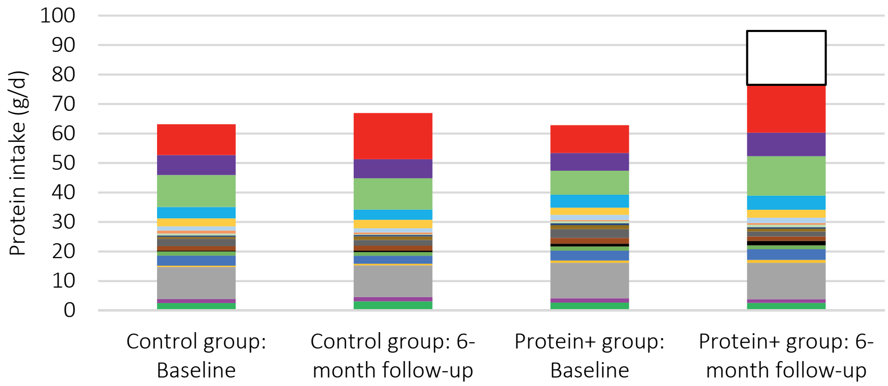
Supplementary Table 1 Mean energy content, energy value provided by protein and greenhouse gas emissions (GHGE), land use (LU), terrestrial acidification, freshwater and marine eutrophication, and blue water use per 100g of food groups, based on actual consumption by the Dutch participants of the PROMISS trial[a]

Main food groups	Energy (kcal)	Protein (E%)	GHGE (kg CO_2-eq)	LU (m^2*y/d)	Terrestrial acidification (kg SO_2-eq/d)	Freshwater eutrophication (kg P-eq/d)	Marine eutrophication (kg N-eq/d)	Blue water use (m^3/d)
PROMISS products[b]	*253*	*70*	*0.36*	*0.31*	*0.003*	*2.0x10-5*	*5.9x10-4*	*0.004*
Animal-based								
Fish and shellfish	*183*	*50*	*0.68*	*0.09*	*0.002*	*8.7x10-5*	*2.6x10-4*	*0.004*
Meat and meat products[c]	*227*	*43*	*1.58*	*0.94*	*0.022*	*9.6x10-5*	*3.5x10-3*	*0.015*
Beef, veal, lamb and goat	*204*	*55*	*2.93*	*1.46*	*0.052*	*1.3x10-4*	*8.7x10-3*	*0.025*
Pork	*201*	*44*	*1.39*	*0.99*	*0.017*	*1.0x10-4*	*2.4x10-3*	*0.013*
Poultry	*144*	*68*	*1.00*	*0.68*	*0.008*	*8.2x10-5*	*7.5x10-4*	*0.013*
Processed meat	*254*	*35*	*1.39*	*0.89*	*0.019*	*9.2x10-5*	*2.9x10-4*	*0.013*
Eggs	*148*	*36*	*0.43*	*0.39*	*0.006*	*4.0x10-5*	*4.8x10-4*	*0.011*
Milk and milk products	*89*	*30*	*0.27*	*0.10*	*0.003*	*7.9x10-6*	*4.5x10-4*	*0.002*
Cheese	*344*	*28*	*1.15*	*0.50*	*0.016*	*3.8x10-5*	*2.3x10-3*	*0.010*
Plant-based								
Vegetables[d]	*28*	*24*	*0.16*	*0.05*	*5.9x10-4*	*1.4x10-5*	*1.4x10-4*	*0.007*
Legumes	*185*	*22*	*0.37*	*0.05*	*8.6x10-4*	*3.1x10-5*	*3.1x10-4*	*0.007*
Cereal and cereal products	*296*	*14*	*0.14*	*0.17*	*0.001*	*1.7x10-5*	*2.9x10-4*	*0.004*
Nuts and seeds[e]	*622*	*14*	*0.48*	*0.82*	*0.003*	*7.6x10-5*	*9.2x10-4*	*0.145*
Potatoes and other tubers	113	8	0.17	0.07	0.001	1.8x10-5	1.8x10-4	0.002
Fruits	89	5	0.26	0.09	0.001	1.9x10-5	1.5x10-4	0.036
Miscellaneous								
Meat and dairy substitutes	*208*	*26*	*0.29*	*0.25*	*9.9x10-4*	*1.9x10-5*	*2.2x10-4*	*0.004*
Soups	*31*	*18*	*0.14*	*0.06*	*0.001*	*1.0x10-5*	*2.1x10-3*	*0.003*
Mixed dishes	*164*	*16*	*0.43*	*0.31*	*0.005*	*3.2x10-5*	*1.0x10-3*	*0.016*
Condiments and sauces	287	8	0.36	0.33	0.002	3.5x10-5	4.7x10-4	0.011
Miscellaneous[f]	198	7	0.23	0.14	0.002	2.3x10-5	3.4x10-4	0.004
Cakes	413	5	0.32	0.24	0.002	3.2x10-5	5.2x10-4	0.012
Sugar and confectionary	392	2	0.26	0.28	0.002	6.7x10-5	4.7x10-4	0.007
Drinks	18	1	0.05	0.03	0.003	5.8x10-6	5.8x10-5	0.004
Fats	641	0	0.68	0.92	0.007	5.6x10-5	1.3x10-3	0.056

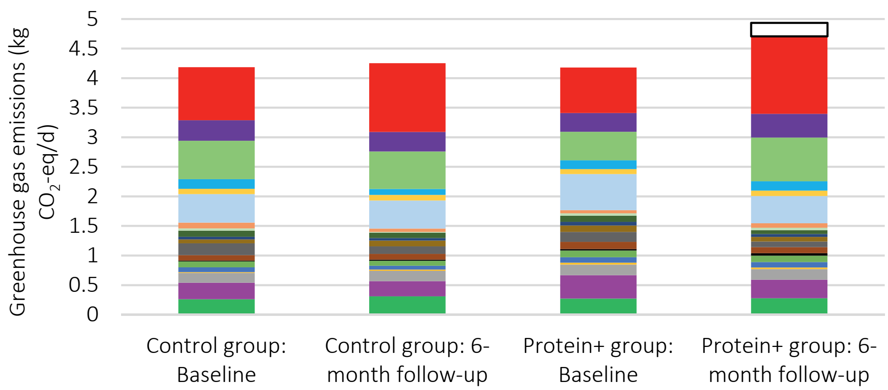
[a] Protein-rich food groups, italicized, have at least 12 energy percent (E%) of protein. [b] PROMISS protein-enriched food products included protein bars, cereals, puddings, cocowhey water and whey powder. [c] Meat and meat products includes the subcategories listed in the table (3.1-3.4) plus offal. [d] Vegetables include pod vegetables such as peas, broad beans, string beans and green beans. [e] Nuts and seeds include peanuts and peanut butter. [e] Miscellaneous food items include unclassified food products and snacks.

Supplementary Figure 1 Average (a) protein intake in grams protein per day, (b) greenhouse gas emissions in kg CO_2-eq per day, (c) land use in m^2*y per day, (d) terrestrial acidification in kg SO_2-eq per day, (e) freshwater eutrophication in kg P-eq per day, (f) marine eutrophication in kg N-eq per day, (g) blue water use in m^3 per day by those who received dietary advice aiming at increasing protein intake (Protein+ group) and those who did not (Control group) at baseline and at the 6-month follow-up of the PROMISS trial

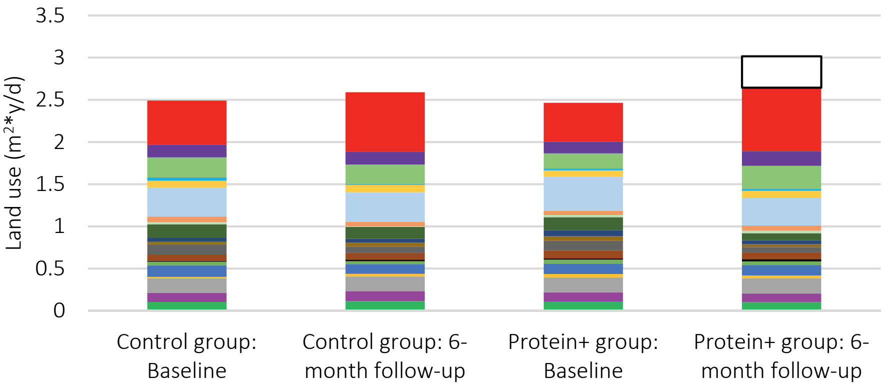
a)



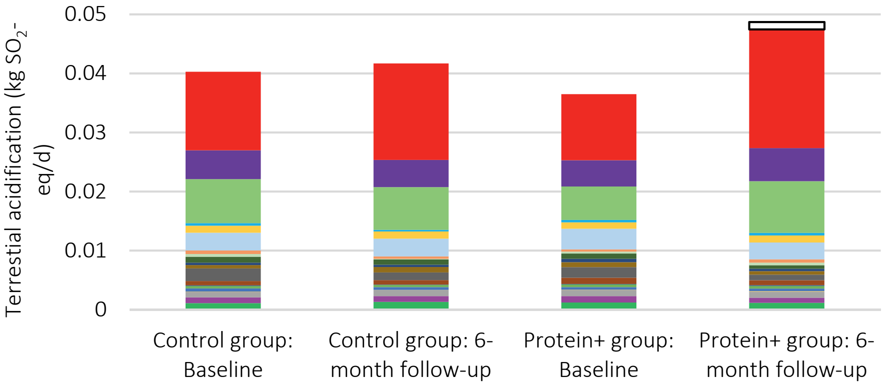
b)



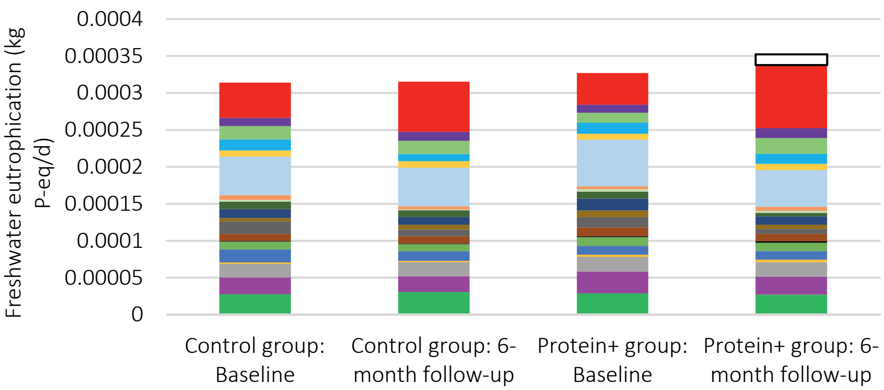
c)


3.5
3
2.5
2
1.5
1
0.5
0
Land use (m²*y/d)
Control group: Baseline
Control group: 6-month follow-up
Protein+ group: Baseline
Protein+ group: 6-month follow-up

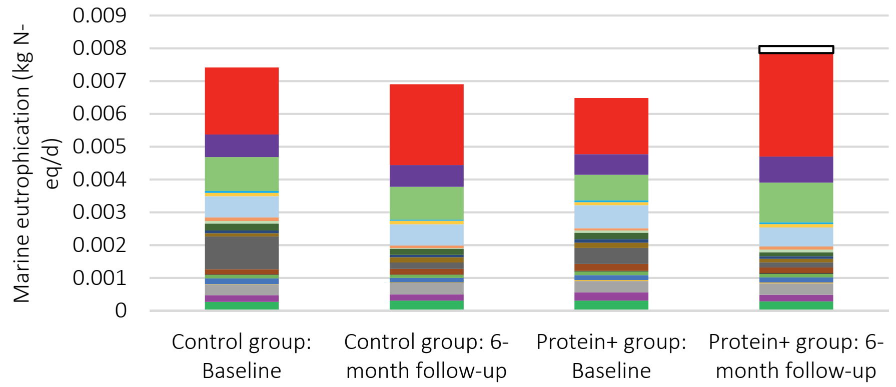
d)


0.05
0.04
0.03
0.02
0.01
0
Terrestial acidification (kg SO2-eq/d)
Control group: Baseline
Control group: 6-month follow-up
Protein+ group: Baseline
Protein+ group: 6-month follow-up

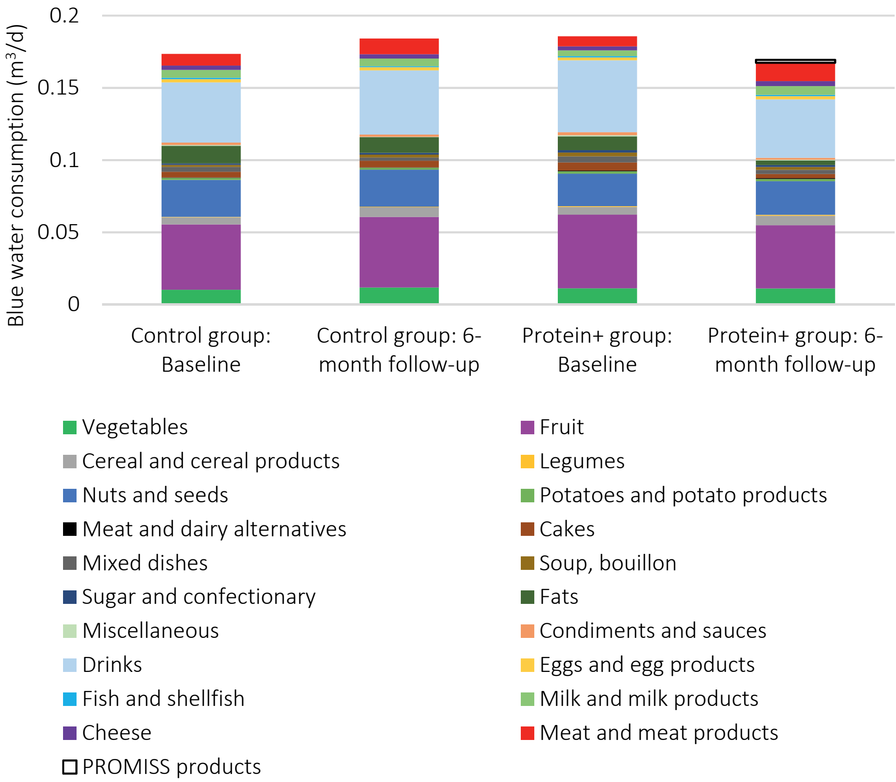
e)


0.0004
0.00035
0.0003
0.00025
0.0002
0.00015
0.0001
0.00005
0
Freshwater eutrophication (kg P-eq/d)
Control group: Baseline
Control group: 6-month follow-up
Protein+ group: Baseline
Protein+ group: 6-month follow-up

f)

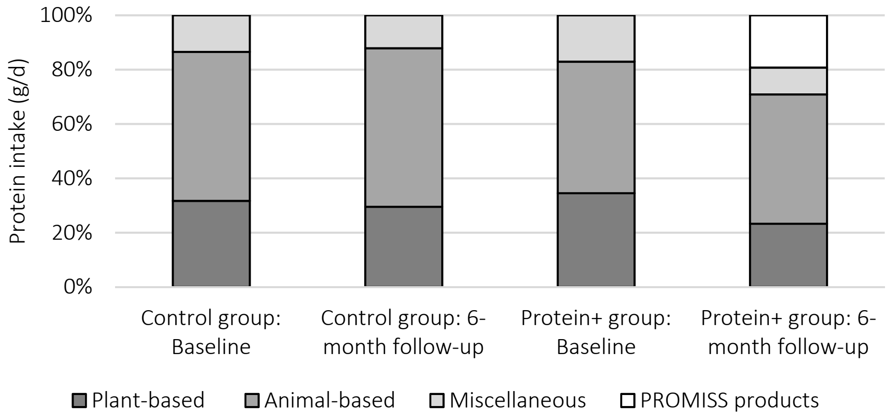

Marine eutrophication (kg N-eq/d)
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
Control group: Baseline
Control group: 6-month follow-up
Protein+ group: Baseline
Protein+ group: 6-month follow-up

g)

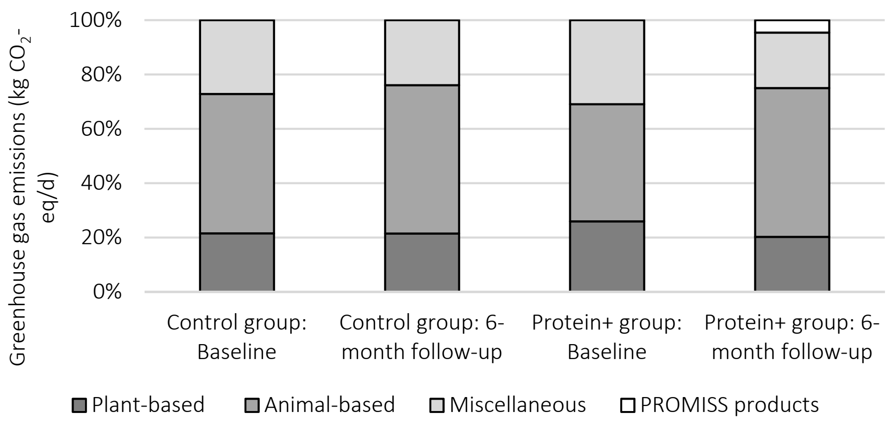

Blue water consumption (m³/d)
0.2
0.15
0.1
0.05
0
Control group: Baseline
Control group: 6-month follow-up
Protein+ group: Baseline
Protein+ group: 6-month follow-up
Vegetables
Fruit
Cereal and cereal products
Legumes
Nuts and seeds
Potatoes and potato products
Meat and dairy alternatives
Cakes
Mixed dishes
Soup, bouillon
Sugar and confectionary
Fats
Miscellaneous
Condiments and sauces
Drinks
Eggs and egg products
Fish and shellfish
Milk and milk products
Cheese
Meat and meat products
PROMISS products

Supplementary Figure 2 Percent contribution of protein source to (a) protein intake in grams protein per day, (b) greenhouse gas emissions in kg CO_2-eq per day, (c) land use in $m^{2*}y$ per day, (d) terrestrial acidification in kg SO_2-eq per day, (e) freshwater eutrophication in kg P-eq per day, (f) marine eutrophication in kg N-eq per day, (g) blue water use in m^3 per day by those who received dietary advice aiming at increasing protein intake (Protein+ group) and those who did not (Control group) at baseline and at the 6-month follow-up of the PROMISS trial

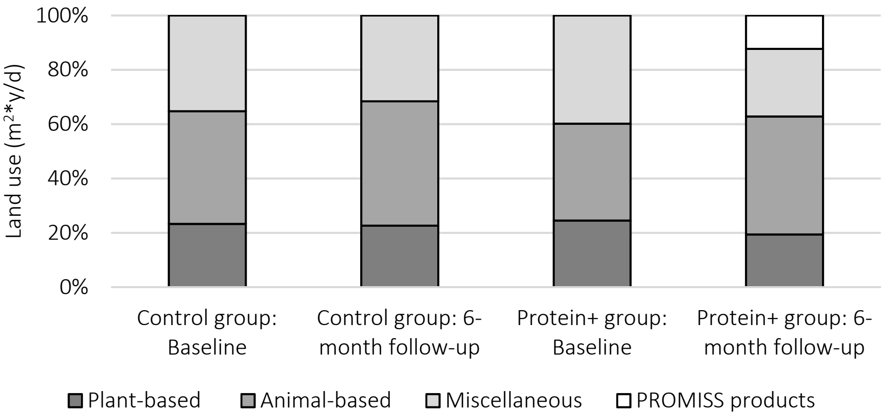
a)



b)

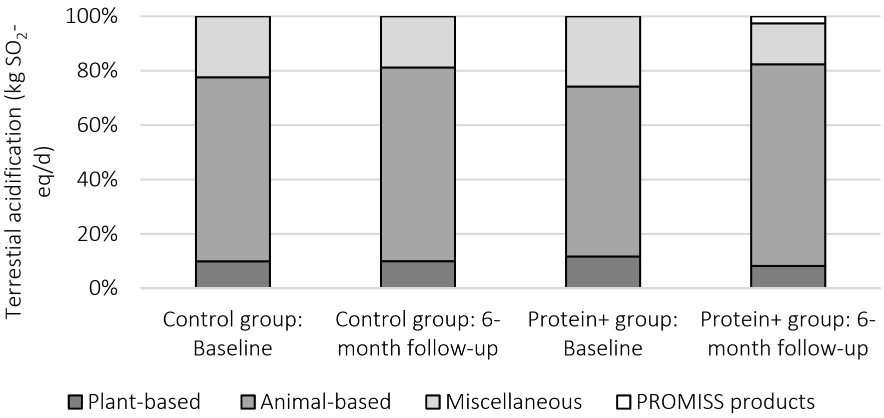


c)



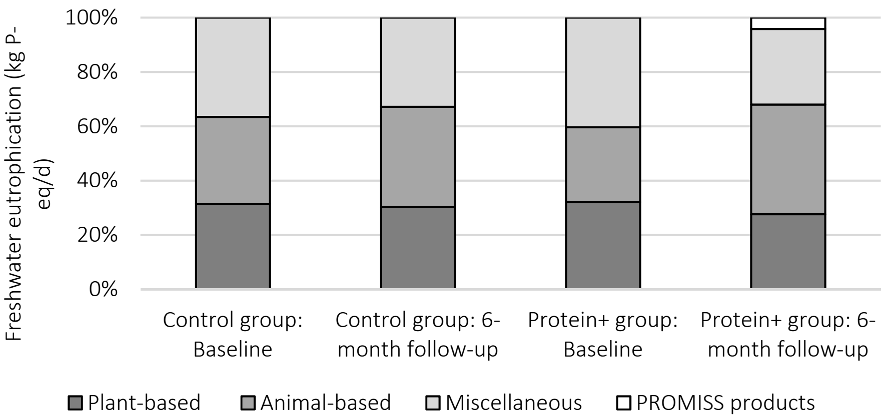
100%
80%
60%
40%
20%
0%
Land use (m²*y/d)
Control group: Baseline
Control group: 6-month follow-up
Protein+ group: Baseline
Protein+ group: 6-month follow-up
Plant-based
Animal-based
Miscellaneous
PROMISS products

d)



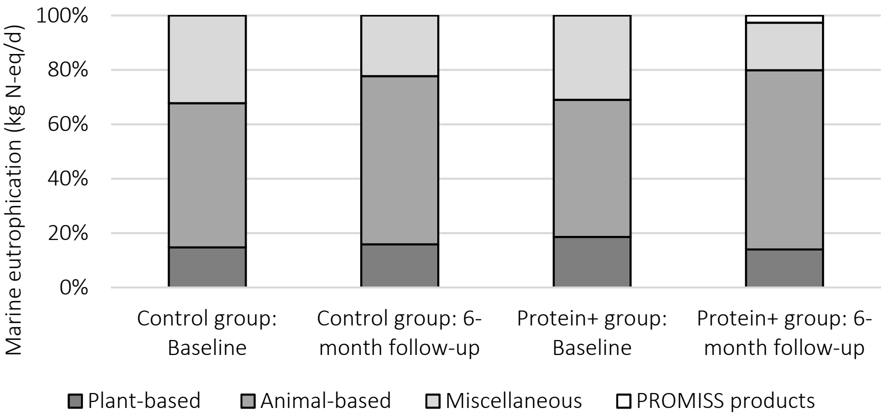
100%
80%
60%
40%
20%
0%
Terrestial acidification (kg SO2-eq/d)
Control group: Baseline
Control group: 6-month follow-up
Protein+ group: Baseline
Protein+ group: 6-month follow-up
Plant-based
Animal-based
Miscellaneous
PROMISS products

e)

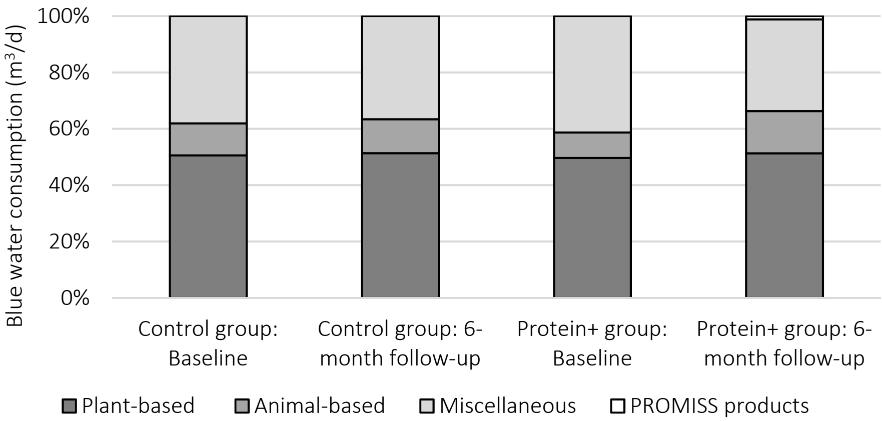


100%
80%
60%
40%
20%
0%
Freshwater eutrophication (kg P-eq/d)
Control group: Baseline
Control group: 6-month follow-up
Protein+ group: Baseline
Protein+ group: 6-month follow-up
Plant-based
Animal-based
Miscellaneous
PROMISS products

f)


Marine eutrophication (kg N-eq/d)
100%
80%
60%
40%
20%
0%
Control group: Baseline
Control group: 6-month follow-up
Protein+ group: Baseline
Protein+ group: 6-month follow-up
Plant-based
Animal-based
Miscellaneous
PROMISS products

g)


Blue water consumption (m3/d)
100%
80%
60%
40%
20%
0%
Control group: Baseline
Control group: 6-month follow-up
Protein+ group: Baseline
Protein+ group: 6-month follow-up
Plant-based
Animal-based
Miscellaneous
PROMISS products

CHAPTER 8
General Discussion

1. Introduction

This thesis examines individual- and diet-level factors related to sustainable nutrition among two subpopulations in Europe, namely overweight adults with subsyndromal depressive symptoms and older adults. The overall aim of this thesis was to evaluate the environmental impact of health-oriented dietary guidance and provide insight into how to make such guidance more environmentally sustainable for these two specific subpopulations. To this end, we employed diverse quantitative methods and used personal, cognitive, behavioral and dietary data collected within two European-wide projects, MooDFOOD and PROMISS, and linked it with nutritional and life cycle assessment (LCA) data to assess the environmental sustainability of diets.

This final chapter starts with a summary and reflection of the main findings for the two objectives addressed in this thesis. It then continues with a discussion on methodological considerations, directions for future research, and implications for practice.

2. Main findings and interpretations

2.1. Objective 1: To identify individual-level factors that pose as facilitators and barriers to environmentally sustainable food-related behavior

Various individual-level factors were investigated in relation to two consumer behaviors critical to change for more environmentally sustainable food-related behavior, namely food waste behavior and meat/alternative protein consumption. The individual-level factors studied in this thesis included socio-demographic characteristics (e.g., sex, education, etc.), psychographic characteristics (e.g., acceptability, food choice motives, attitudes, etc.), and life situation (e.g., health status). Facilitators and barriers to environmentally sustainable food-related behavior were identified by having a strong or consistent positive or negative association with one of the studied behaviors (summarized in Figure 1).

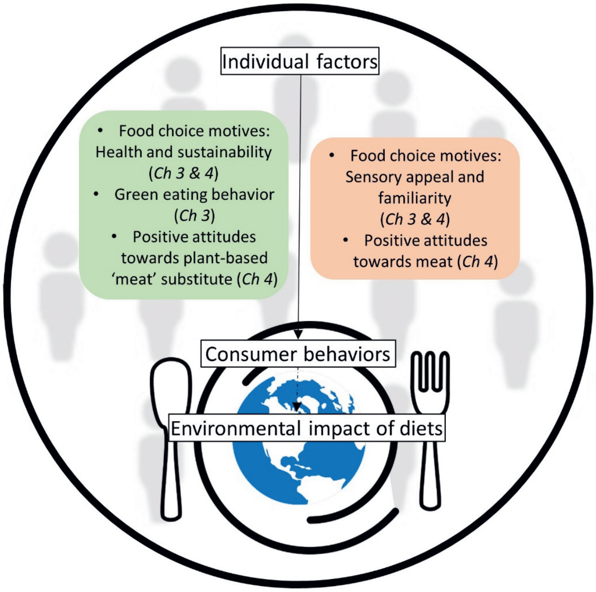


Figure 1. Schematic overview of findings for objective 1 of this thesis: to identify individual-level factors that pose as facilitators and barriers to environmentally sustainable food-related behavior. The green box represents factors positively associated with environmentally sustainable consumer behavior (facilitators) and the orange box represents factors negatively associated with environmentally sustainable consumer behavior (barriers). Factors with mixed results are not shown in image, but include socio-demographics (Chapters 2, 3, 4), food fussiness (Chapters 3 & 4) and life situation (Chapter 4).

2.1.1. Individual-level factors that pose as facilitators to environmentally sustainable food-related behavior

In general, community-dwelling older adults ($\geq$65 y) living in Europe are meat eaters, with less than 2% reporting to follow a vegetarian or vegan diet (Chapter 3 and Chapter 4). While older adults are less willing to accept to consume alternative protein sources compared to conventional sources like dairy, meat, and fish, their relatively high acceptability of plant-based protein sources poses as an opportunity to increase protein in an environmentally sustainable way (Chapter 3). To illustrate, approximately 62% respondents reported (high) acceptability to consume meat while 58% of the respondents reported (high) acceptability to consume plant-based protein, which is promising compared to 20% who reported to accept single-cell protein, 9% to accept insect-based protein, and 6% to accept in vitro meat-based protein. When older adults were segmented into groups based on their meat consumption and meat liking, we found that three consumer groups prevailed, namely heavy meat consumers (i.e. high meat consumption and moderate meat liking score, 27% of study sample), medium meat consumers (medium meat consumption and high meat liking score, 52%), and light meat consumers (low meat consumption and low meat liking score, 21%) (Chapter 4). A summary of the attitudes and motivations of the different consumer segments are summarized in Figure 2.

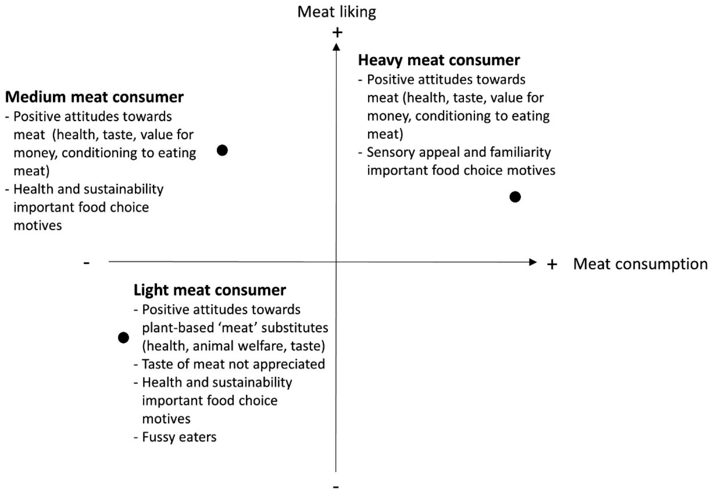


Figure 2. Summary of attitudes and motivations of the three older consumer segments based on meat consumption and meat liking among older adults living in the United Kingdom, the Netherlands, Poland, Spain and Finland (Chapter 4). The axes represent average values of consumption (x-axis) and meat liking (y-axis) and the black dots represent average values for the consumer segments.

Individual-level factors that serve as facilitators to the acceptability of alternative, more sustainable protein sources and low meat consumption include health and sustainability food choices motives, 'green' eating behavior, and positive attitudes towards plant-based 'meat' substitutes. Placing more importance on health when making food choices was associated with a higher acceptance to eat plant-based protein sources (Chapter 3) and for being classified as a medium and light meat consumer as compared to a heavy meat consumer (Chapter 4). A positive association was found between sustainability food choice motive and the likelihood for being classified as a medium and light meat consumer as compared to a heavy meat consumer (Chapter 4). Although sustainability food choice motive was not associated with acceptability of alternative protein sources, older adults who reported practicing more 'green' eating behaviors like purchasing local or organic food were more accepting of eating alternative, more sustainable protein sources (Chapter 3). Medium meat consumers, who on average consumed less meat but reported to like meat more than heavy meat consumers, had a slightly more positive attitude towards animal welfare compared to heavy meat consumers, although not statistically significant (Chapter 4). Light meat consumers agreed more strongly with meat not being good for health nor the environment, that they do not like the taste of meat and did not grow up with it, and that they value animal welfare, while they agreed more strongly with plant-based 'meat' substitutes tasting good and being good for health and better for animal welfare.

Further, we found that the life situation of older adults also differed between meat consumer segments (Chapter 4). Older adults who live alone, do their own grocery shopping, and decide what to eat for themselves were more likely to be classified as a light meat consumer compared to a medium or heavy meat consumer. Light meat consumers had on average a lower appetite and had a higher probability of having low protein intake compared to the medium and heavy meat consumers.

2.1.2. *Individual-level factors that pose as barriers to environmentally sustainable food-related behavior*

Placing more importance on sensory appeal and familiarity when making food choices and having positive attitudes towards meat were found to be barriers to environmentally sustainable food-related behavior among older adults in Europe. Valuing sensory appeal was found to be negatively associated with acceptance to consume insect- and single-cell-based protein sources (Chapter 3), as well as with being classified as a light meat consumer compared to a heavy meat consumer (Chapter 4). Also placing importance on familiarity when making food choices was found to be negatively associated with being classified as a light meat consumer compared to a heavy meat consumer (Chapter 4). Heavy and medium meat consumers reported more positive attitudes towards meat compared to light meat consumers, agreeing more strongly that meat is important for health, tastes good, is good value for money, they grew up eating meat, and because the people they live with want to eat meat (Chapter 4).

2.1.3. *Individual-level factors with mixed results or no association*

The role of socio-demographic factors in predicting food waste behavior (FWB) and explaining meat/alternative protein consumption is varied. Our study showed that age, employment status, sex, and household size were associated with FWB, and that the number of socio-demographic predictors of FWB differed by country (Chapter 2). Younger adults and individuals with a full-time job were found to practice more FWB compared to older adults and those not working full time in both Denmark and Spain. Men and individuals in four-person households were associated with more FWB compared to women and individuals living single-person households in Denmark but not in Spain. Nevertheless, the socio-demographic characteristics studied provided modest predictive power for FWB. With regards to meat/alternative protein consumption among older adults in Europe, females were less likely to accept to eat insect-, single-cell-, and in vitro meat-based protein sources compared to males (Chapter 3) but were more likely to be classified as a light meat consumer as compared to a medium or heavy meat consumer (Chapter 4). While higher educated individuals were more likely to accept alternative protein sources (Chapter 3), they were equally distributed among the different meat consumer segments (i.e., heavy, medium, and light meat consumer segments) (Chapter 4). The country of residence influenced both alternative protein acceptability and meat consumption behavior. Older adults living in Poland were more likely to eat plant-based protein sources and less likely to eat in vitro meat-based protein sources compared to those living in the UK (Chapter 3). Those living in the Netherlands, Finland and Spain were also more likely to eat insect-based protein sources compared to those living in the UK. Further, medium meat eaters more commonly lived in Poland and less in the Netherlands compared to the heavy and light meat consumers (Chapter 4).

Food fussiness was examined among older adults living in five European countries as it has been previously found to influence older consumers' meal experience [1] and therefore likely to influence food choice. A higher score on the food fussiness scale was associated with being less likely to accept to consume alternative, more sustainable protein sources (Chapter 3) but more likely to be classified as a light meat consumer as compared to a heavy meat consumer (Chapter 4).

Further, convenience and price food choice motives were not significant determinants in our study with the exception of price consciousness being positively associated with the acceptance to consume in vitro meat-based protein sources (Chapter 3). Food sustainability knowledge, assessed using an ad hoc scale, was not found to be related to meat consumption behavior (Chapter 4).

2.2. Objective 2: To assess the environmental impact of dietary change due to health-oriented dietary guidance

Health-oriented dietary strategies increased the environmental impact of the diet in the modelling study and in both trial studies (Figure 3).

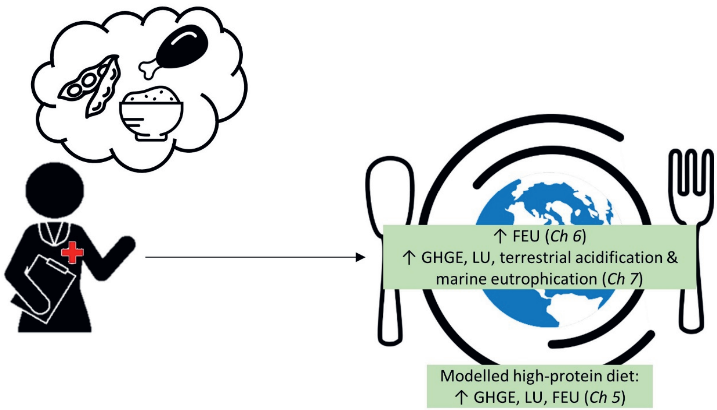


Figure 3. Schematic overview of findings for objective 2 of this thesis: to assess the environmental impact of dietary change due to health-oriented dietary guidance. Abbreviations: GHGE (greenhouse gas emissions), LU (land use), FEU (fossil energy use).

We performed a modelling study to identify dietary changes needed to increase protein intake in an environmentally sustainable way among 1,354 older adults (56-101y) from the Longitudinal Aging Study Amsterdam cohort (Chapter 5). Using diet optimization techniques, we modelled several high-protein diets with minimal deviation from habitual food consumption (as large changes may not be considered culturally acceptable) and applied stepwise constraints to see the gradual effect of reducing diet-associated greenhouse gas emissions (GHGE). Starting from an average habitual diet with a protein content of 1.0 g protein/kg body weight (BW)/d, we found that achieving a high-protein diet containing 1.2 g protein/kg BW/d, without considering GHGE, resulted in an increased contribution of animal-based protein to total protein intake from 60 to 65%. This in turn led to a 12-14% increase in GHGE, 10-12% increase in land use (LU), and 9-10% increase in fossil energy use (FEU). Based on these findings, we hypothesized that dietary advice aiming at increasing protein intake would favor animal-based protein and increase the environmental impact of the diet in real life, which was confirmed in Chapter 7. During the 6-month PROMISS randomized controlled trial, 120 Dutch community-dwelling older adults aged 65 years and older with low protein intake (<1.0 g/kg adjusted body weight (aBW)/day) received personalized dietary advice to increase protein intake to 1.2 g/kg aBW/day [2]. The advice did not consider environmental sustainability. Compared to older adults who did not receive dietary advice, older adults who received dietary advice aiming at increasing protein intake increased protein intake from animal-based foods (11 g protein/d, 95% CI 7-15) and PROMISS protein-enriched food products (18 g protein/d, 95% CI 15-22), and marginally from plant-based foods (2 g protein/d, 95% CI 0.2-4). These changes were found to increase diet-associated GHGE by 16%, LU by 13%, terrestrial acidification by 20%, and marine eutrophication by 26%. To increase protein intake in an environmentally sustainable way among older adults, we found that a change in meat type, an increase in diverse plant-based protein sources including whole grains, legumes, nuts and meat/dairy alternatives, and a reduction in discretionary food were needed (Chapter 5). A (partial) replacement of beef/lamb and processed meat with poultry and pork was required to reduce the environmental impact of meat, which remained at the maximum healthy limit (500 grams meat per week as recommended by the Dutch food-based dietary guidelines) with moderate GHGE reductions. GHGE reductions greater than 50% resulted in a shift in the animal- to plant-based protein ratio to one favoring plant protein and to larger changes in quantities of food groups and food items from the habitual diet, compromising the cultural acceptability of the diet.

When it comes to overweight adults (18-75y) with subsyndromal depression symptoms, dietary changes towards a Mediterranean-style dietary pattern were hypothesized to reduce the environmental impact of the diet, as previous studies investigating a theoretical Mediterranean diet showed that it produced lower environmental impacts compared to current diets [3]. During the 12-month MooDFOOD depression prevention randomized controlled trial, 744 overweight adults with subsyndromal depression symptoms from the UK, Germany, Spain, and the Netherlands either received food-related behavioral activation (F-BA) therapy applying Mediterranean-style dietary guidelines (n=373) or no therapy (n=371). Our findings showed that adults who received F-BA therapy increased consumption of vegetables, fruit, fish, pulses/legumes, and whole grains and decreased consumption of sweets/extras relative to the control group. These changes were found to have no impact on GHGE, LU, and pReCiPe score (i.e., a weighted average of GHGE, LU, and FEU), but led to a 4% increase in FEU.

3. Discussion of the main findings

3.1. Individual-level factors influencing food choice and food-related behavior

In order to support the transition to more environmentally sustainable diets, more knowledge on determinants of consumer food choice and food-related behavior is needed. In light of the complex nature of consumer behavior, the evidence on drivers of food choice and food-related behavior, and barriers and facilitators to change food choice and behavior, remains scattered. The individual-level factors studied in this thesis proved to have a limited role in explaining FWB and meat/alternative protein consumption. Nevertheless, as food choices and food-related behavior vary between subgroups differing on individual-level factors [4,5], information on these differences can contribute to targeted nutritional messages and interventions for improving health and diet sustainability.

Taking an individualistic perspective of food waste, one framework to identify factors that contribute to food waste include motivation (i.e. awareness and attitudes), opportunities (i.e. aspects from the environment), and abilities (i.e. skills and knowledge sets) [6,7]. This framework expands on insights gained from the theory of planned behavior [8], which propose that attitudes, subjective norms, and perceived behavioral control shape an individual's intention to reduce food waste [9-13]. Studies in this line of research suggest that factors other than motivation are of influence as well, including emotion and habit [14]. Socio-demographic factors may influence individuals' motivation, opportunity, or ability to behave in certain ways and thus may be important drivers of FWB. Most research, including our study, however, reveals that socio-demographic factors are often insufficient or poor predictors of FWB [13,15-17]. Our findings are in line with previous studies which have demonstrated that being younger [11,13,18], male respondents [18,19], being employed [19], and having a larger household size [20] resulted in more food waste compared to being older, female respondents, being unemployed or retired, and having a smaller household size (Chapter 2). Yet some studies show opposite results, or show that socio-demographic characteristics have no influence on food waste [16].

In respect to socio-demographic characteristics influencing meat consumption behavior, evidence from younger samples suggests that females are more willing than males to reduce meat consumption [21-24]. We found a similar pattern among older European consumers, in which older women were more likely to be classified as a light meat consumer as to a medium or a heavy meat consumer than older men (Chapter 4). But when looking at acceptance of alternative protein sources, we see that older women were less likely to accept insect-, single-cell-, and in vitro meat-based protein sources than older men (Chapter 3). However, other studies have found that plant-based protein sources are more accepted by females [25,26]. This was elucidated in Chapter 4, which showed that the light meat consumer segment, dominated by older females, consumed greater amounts of and had more positive attitudes towards plant-based 'meat' substitutes compared to medium and heavy meat consumer segments. Further, we found that education played a role in acceptability of alternative protein sources

(Chapter 3) but not in meat consumption behavior (Chapter 4) among older adults. Previous studies have also found that higher educated individuals are more willing to accept alternative protein sources [27] while no clear association between education and willingness to reduce meat consumption has been found [28]. Furthermore, culture and ethnicity are also important drivers of meat/alternative protein consumption [23,29]. Country differences in both survey studies were found between the UK, the Netherlands, Poland, Spain and Finland (Chapter 3 and 4), which are likely due to differences in food cultures and penetration of alternative protein sources in the market [29,30].

Apart from socio-demographics, individual-level factors like psychographic attributes may alter with age, as age-related changes like lower appetite, declining (oral) health, and being alone influence eating habits and motivations among older adults [31,32]. Previous studies focusing on older consumers found that taste, price, sensory appeal, and convenience mainly influence older adults' meal decisions [33,34]. While previous studies did not find that health was an important motivation for food selection among older adults, except among higher educated individuals [34], we found that older individuals who value health when making food choices were more likely to accept to consume plant-based protein sources (Chapter 3) and were more likely to be classified as a medium or light meat consumer than a heavy meat consumer (Chapter 4). Despite a perceived match between health and sustainability when it comes to plant-based foods [35], we did not find sustainability food choice to influence acceptance of plant-based protein sources (Chapter 3). Nevertheless, older adults practicing more 'green' eating behaviors were more likely to accept to consume alternative protein sources, suggesting that there is willingness among those already practicing more sustainable behaviors to make their food consumption more sustainable [36]. Still, sustainable food choice motive was found to be more important for light and medium meat consumers compared to heavy meat consumers (Chapter 4). Although medium meat consumers had a higher meat liking score compared to heavy meat consumers, they reported significantly less meat consumption which may be due to their higher motivation for health and sustainability when making food choices and more positive attitudes towards animal welfare. Previous studies found that animal welfare attitudes influence diet choice, with more positive attitudes being associated with less meat consumption [37,38]. Appealing to animal welfare and health and sustainability motivations may therefore encourage the reduction of meat consumption and following more plant-based diets among older adults [39,40].

Yet, in light of previous literature and the results of our studies, placing importance on sensory appeal and familiarity when making food choices may present challenges in changing meat/alternative protein consumption among older adults. Heavy meat consumers placed more importance on sensory appeal and familiarity as compared to light meat consumers and reported more positive attitudes towards meat with regards to health, taste, value for money and reported to have grown up with meat (Chapter 4). In addition, food fussiness may be a barrier to acceptance of alternative protein sources as it was consistently negatively associated with acceptance of alternative protein sources (Chapter 3). Given its overlap with food neophobia [41], it is coherent that fussy eaters would be less likely to accept alternative protein sources which are not so familiar. However, fussy eaters were more likely to be classified as a light meat consumer than a heavy meat consumer, suggesting that other factors may be underlying food fussiness in older adults, such as low appetite (Chapter 4) [42]. Addressing motivations for sensory appeal and familiarity may involve increasing awareness and acceptance of hybrid meats (i.e. meat products in which a proportion of meat is partially replaced by plant-based functional ingredients [43]) and meat analogues (i.e. meat products that mimic meat in taste, texture, etc. [44]) as they may provide similar sensory experiences and enable them to maintain their familiar meal patterns and dishes.

3.2. Environmental sustainability of health-oriented dietary strategies for specific subpopulations

The health-oriented dietary strategies studied in this thesis were shown to improve health outcomes of the target populations, but consistently led to a higher environmental impact of the diet. The findings from our studies are in line with previous studies which have shown that shifts towards healthier diets do not always result in lower environmental impacts [45-49].

3.2.1. Mediterranean-style dietary pattern for prevention of depression

In the MooDFOOD trial, overweight adults with subsyndromal depressive symptoms who received F-BA therapy sessions focused on changing food-related behaviors (e.g. snacking) and shifting habitual dietary patterns towards a Mediterranean-like diet had significantly lower anxiety symptoms compared to the control group [50]. Our findings show that the F-BA therapy led to significant increases in consumption of several promoted foods (i.e. vegetables, fruit, fish, pulses/legumes, and whole grains) and a significant decrease in consumption of one discouraged food (i.e. sweets/extras) (Chapter 6). To have a neutral or reduced environmental impact, reductions in environmental impacts of discouraged foods, like red and processed meat and discretionary foods, need to counterbalance or exceed increases in environmental impacts of recommended foods like vegetables, fruits, whole grains, legumes, etc. [46]. Despite having higher amounts of vegetables, fruits, grains, fish, and legumes compared to current diets, theoretical Mediterranean diets perform better in terms of environmental impact because they contain significantly less meat, milk, cheese and discretionary products [51,52]. In this thesis, an offset in environmental impact was partly observed among those who received F-BA therapy promoting a Mediterranean-like diet during the MooDFOOD trial, as the dietary changes observed led to no change in GHGE, LU, and the pReCiPe score. In a modeling study, reducing discretionary food intake was also shown to allow for a small increase in emissions from core foods, particularly vegetables, dairy, and grains, thereby providing a nutritional benefit at little environmental expense [53]. At the same time, we found that the F-BA therapy led to an increase in FEU, which is likely attributable to the relative increase of FEU from fish, due to high energy inputs to operate fishing fleets [54], and from vegetables, due to fossil-energy heated greenhouses in the Netherlands [55]. Dietary scenarios that found higher environmental impacts when shifting towards healthier dietary patterns reveal that there is greater need for increasing consumption of vegetable, fruits, legumes, and fish than reducing consumption of meat and dairy [48,56]. Nevertheless, it is widely acknowledged that meat consumption needs to be considerably reduced in high-income countries [57]. The F-BA group had a baseline intake of about 860 g meat per week, which is substantially higher than the 300 grams per week recommended by the MooDFOOD dietary guidelines. The MooDFOOD dietary guidelines promoted consumption of white, lean meat like chicken and turkey in place of red and processed meat, which is in line with the planetary health diet [58]. The guidelines also named protein-rich alternatives to meat, including eggs, nuts, soy products like tofu, and fish. Despite the recommendations for reduced meat consumption, meat consumption did not change in the F-BA group relative to the control group.

3.2.2. High-protein diet for healthy aging

During the PROMISS trial, personalized dietary advice to increase protein intake was found to improve the physical function of community-dwelling older adults with low habitual protein intake, measured by 400-m walk time and leg strength [59]. Our findings show that personalized dietary advice to increase protein intake led to significant increases in protein intake, deriving mainly from animal sources and protein-enriched food products, and marginally from plant-based sources (Chapter 7). Such dietary changes led to increases in GHGE, LU, terrestrial acidification, and marine eutrophication, and no change in freshwater eutrophication and blue water use. The dietary advice did not take environmental sustainability into account, but food preferences and practices. The environmental outcomes were expected, based on our modelling study (Chapter 5) and previous studies showing that a high-protein diet favors animal protein and has a high environmental impact [60]. While a reduction in total meat intake in older adults with low protein intake may not be desirable as meat is suggested to be more effective in stimulating muscle protein synthesis compared to plant-based protein sources [61], a change in meat type could be beneficial in reducing the environmental impact of meat consumption. Our diet modelling study showed that a change in meat type, in which poultry partially replaced beef/lamb and processed meat, could reduce the environmental impact of total meat intake consumed by older adults (Chapter 5). This reduction in environmental impact of total meat intake gives room for increases in environmental impact of plant-based protein food sources, like whole grains, legumes, nuts, and meat/dairy alternatives. The reduction in environmental impact of meat consumption by changes in meat type have been demonstrated in previous studies [62].

On the contrary, the habitual meat intake among community-dwelling older adults who participated in the Longitudinal Aging Study Amsterdam Nutrition and Food-Related Behavior ancillary study was on average above the healthy limit of 500 grams per week recommended by the Dutch food-based dietary guidelines (FBDG) (Chapter 5). We found that especially to be the case for men, as they had to reduce their meat intake by 29% to adhere to the FBDG. In this case, reductions in meat to the maximum advised amount are needed, and increases in protein intake should come from a diverse array of plant-based sources, including whole grains, legumes, nuts, and plant-based meat/dairy alternatives. We showed that high-protein diets with GHGE reductions up to 50% resulted in a higher protein quality, which was determined by higher quantities of nine essential amino acids compared to the habitual diet of older adults. At a 50% GHGE reduction, when the contribution of animal- and plant-based protein to total protein was equal, only lysine fell below habitual levels. High-protein diets with >50% GHGE reduction had compromised protein quality (seven of the nine essential amino acids fell below habitual levels), but were also at risk of being unacceptable due to the substantially higher departures from food quantities in the habitual diet. A shift to equal contribution of animal- and plant-based sources to total protein intake, which in our study led to a 50% GHGE reduction, is in line with the Netherlands Nutrition Center's recommendation for a sustainable, plant-based diet [63].

3.2.3. *Note about energy intake*

The health-oriented dietary strategies in this thesis focused on changing diet composition and did not intervene in total caloric intake. It has been suggested, however, that consuming no more food than needed to maintain a healthy body weight can lead up to a 10% reduction in the climate impact of the diet, depending on assumed energy requirements, and has co-benefits for health [62,64,65]. When energy intake over time was accounted for when studying the trial effects on the environmental impact of the diet, we saw that effect sizes were attenuated but in general remained statistically significant.

3.3. Dietary strategies that could benefit both the health of the population and the environment

Most research points to the need for a shift towards healthy plant-based diets, but paints a slightly different picture depending on baseline dietary intake and nutritional needs. The studies in this thesis substantiate this general consensus and add nuance for specific population groups in Europe, namely overweight adults with subsyndromal depressive symptoms and older adults. In light of our findings and previous literature, four strategies are recommended that could have win-wins for population and planetary health: 1) reduce total meat intake to a healthy limit by targeting values and attitudes around meat, 2) moderate fish consumption, 3) replace high impact foods with lower impact foods and 4) achieve energy-balanced diets.

3.3.1. Reduce meat consumption

Reconciling overconsumption of meat, i.e., consumption of meat that is more than the recommended daily intake, is needed to combat the negative impact of diets on environmental and human health [66]. Individuals in developed countries are on average consuming 50% more meat than the quantity recommended for a healthy and sustainable diet [67]. While removal of meat and other animal-based foods from the diet results in the lowest environmental impact, reducing meat consumption, and in particular red and processed meat, to a healthy limit defined by national guidelines can also have substantial reductions in environmental impact and also benefits for health [67,68].

Overweight adults with subsyndromal depressive symptoms consumed close to triple the amount of meat recommended by the MooDFOOD dietary guidelines (Chapter 6). While we saw changes in consumption of several foods towards the recommended amounts during the 12 month trial, we saw no change in meat consumption among the F-BA group. There can be many reasons for not observing a reduction in meat consumption, including the positive entrenched attitudes and beliefs with regard to meat consumption, low willingness and awareness to reduce meat consumption, and lack of cooking skills to prepare non-meat dishes [69]. When it comes to overweight adults with subsyndromal depressive symptoms, targeting the reduction of meat consumption, and red and processed meat in particular, is likely to not only lead to reduced environmental impact of the diet, but to have benefits for depression prevention [70].

When it comes to community-dwelling older adults in Europe, targeting the replacement of meat with more sustainable protein sources is important to reduce the environmental impact of diets while maintaining or increasing their total protein intake. Replacing meat with dairy, fish, and eggs may be beneficial for maintaining intake of high-quality protein and essential nutrients, but would elicit more adverse effects for the environment compared to promoting intake of plant-based protein sources like legumes, whole grains, and nuts. One study showed that small, realistic changes that increase the share of plant protein increase the overall nutritional adequacy and the environmental sustainability of the diet in French young adults [71]. We found that a reduction in meat consumption to the advised maximum of 500 g/week and increases in whole grains, nuts, vegetables, legumes, and meat and dairy alternatives led to increased protein content and essential amino acid quantities and moderate GHGE reductions of the diet (Chapter 5).

However, previous studies have indicated that older adults with low protein intake generally have a lower intake of meat [72,73]. This was also found in our study that showed that among the light meat consumer segment, 61% of the older adults had a high probability of low protein intake (Chapter 4). Because meat is an efficient source of protein and other nutrients like vitamin B12, iron, and zinc, targeting meat reduction among older adults with low protein intake and already low consumption of meat is discouraged [74]. However, gains in protein intake should be made by diverse, sustainable protein sources like legumes, whole grains, vegetables, and nuts (Chapter 5).

3.3.2. Moderate fish consumption

One well-acknowledged trade-off between healthy and sustainable diets is fish consumption. In Chapter 5, the sensitivity analysis showed the important role of fish in increasing protein intake with reduced GHGE of the diet in older adults. In Chapter 6, fish consumption was promoted for the prevention of depression, with the MooDFOOD dietary guidelines recommending three portions of fish a week. While fish is prized for its high content of protein, omega-3 fatty acids, and other important nutrients, approximately 94% of the world's marine fish stocks are fully exploited or overfished [75]. When applying commonly used environmental impact indicators like GHGE and LU, fish performs relatively well compared to its animal counterparts. Some exceptions exist, for example with fish and seafood caught by nets dragged across the ocean floor (i.e.

trawling), which have higher emissions than seafood caught by non-trawling [46]. Choosing fatty wild caught fish types like sardines and herring are favored because of their high content of omega-3 fatty acids and low impact on GHGEs [54]. Nevertheless, there are other environmental issues that are not accounted for in traditional LCAs, such as overfishing and aquatic biodiversity loss. In the Netherlands, the food-based dietary guidelines changed from recommending two portions of fish a week to one portion, as more than one portion does not add reduction of disease risk but poses a risk to biodiversity [76,77]. When we applied the Dutch FBDGs to the optimization of high-protein diets, we saw that fish consumption needed to be reduced by 33-36% to one serving of fish per week among older adults (Chapter 5). The modelled diets with one serving of fish per week were compromised in omega-3 fatty acids. To consume fish with limited negative environmental effects, consumption of fish by-catch and discards can be solution (by-catch being unwanted fish caught with the primary target species of a fishery and discards being unwanted fish caught with the primary target species of a fishery, but are usually discarded due to having little economic value) [78]. Development of a supply chain for fish by-catch and discards, as well as more sustainable methods of aquaculture, are needed to provide fish in an environmentally sustainable way.

3.3.3. Replace high impact foods with lower impact foods

There are many different ways to follow food-based dietary guidance. Considering the great variability in the environmental impacts of different food products, the actual change in the environmental impact of diets is highly sensitive to the change in food choice [62,79]. Previous studies simulating replacements of high impact foods with lower impact foods within and between food groups have shown such changes to be very effective in lowering the environmental impact of the diet [80,81]. When it comes to meat, replacing beef, veal, lamb, and sheep with poultry and pork has shown to reduce the GHGE impact of total meat intake [58,62]. This was also shown in Chapter 5, when meat content of the diet remained the same but the environmental impact of meat reduced due to partial substitution of beef/lamb and processed meat with pork and poultry. Animal-based foods often have a higher environmental impact than plant-based food because of the inefficiency with which animals convert feed into human-edible food. Ruminant animals (e.g. cattle, sheep, goats) have an additional impact because of the methane released by their digestive symbionts. When it comes to vegetables and fruits, choosing seasonal products that are grown in the field rather than in greenhouses, and are not airfreighted, can lead to more environmentally friendly consumption of vegetables and fruits [82].

3.3.4. Achieve energy-balanced diets

While the dietary interventions included in this thesis focused on changing dietary composition and not on improving possible energy imbalances, this is another component that can result in co-benefits for both health and environmental sustainability. Eating beyond one's needs contributes to avoidable environmental impacts and promoting energy-balanced diets has benefits for obesity prevention [83]. Reducing overall caloric intake without changing the composition of the diet has been shown to result in lower environmental impact of the diet [48,53,56]. However, from an environmental standpoint, it is important to consider the source as well as the amount of calories we consume. The environmental impact of the reduction in overall caloric intake with compositional changes will depend on the types of food in the diet. For instance, if an energy-restricted, high protein, low carbohydrate diet were adopted, it would be unlikely to reduce GHGE if the diet is high in meat and dairy products [45]. Over-eating has also been considered as food loss, having as big as an impact on the environment as food wasted by consumers [83]. Springmann et al. showed that limiting excessive energy intake could lead to a 19-30% lower prevalence of being overweight and obese around the world [84]. Lowering consumption to be closer to nutritional requirements is therefore a strategy to improve the health and sustainability of diets [65].

3.4. Role of alternative, more sustainable protein sources in sustainable diets

In the quest to feed an ever-growing population within environmental limits, researchers are quantifying the nutritional and environmental benefits and trade-offs of alternative protein sources that can act as meat substitutes, such as plant-based sources, insects, and in vitro meat (also known as lab-grown, cultured or clean meat) [85]. In this thesis, we found that the acceptability to consume alternative, more sustainable protein sources is generally low among European older adults with the exception of plant-based protein sources (Chapter 3). When it comes to plant-based sources, there is a broad variety of more sustainable protein sources that can replace meat, including traditional plant-based sources (e.g. legumes, nuts, seeds, whole grains), soy-based protein foods (e.g. tofu, seitan, tempeh), novel protein foods like mycoprotein (quorn) or microalgae, and ultra-processed plant-based meat substitutes which are designed to imitate meat (e.g. the Impossible Burger). Meat and dairy alternatives, such as soy milk and vegetarian burgers, contributed to <1% of total habitual protein intake among Dutch older adults (Chapter 5). However, in the high-protein diet aligned with the Dutch food-based dietary guidelines with a 50% GHGE reduction, meat and dairy alternatives contributed to approximately 5% of total protein. The quantities of meat and dairy alternatives in the high-protein diets increased incrementally with a stepwise reduction in GHGE, suggesting their role in providing protein in an environmentally sustainable way. While such alternative protein sources have been found to have environmental benefits and be comparable to animal-based protein sources in terms of protein content [86,87], there are nutritional concerns regarding the ultra-processed plant-based substitutes [88-90]. Until recently, plant-based meat and dairy substitutes were a niche market targeting vegetarian and vegan consumers, but are now consumed by a wider range of consumers who for various reasons want to reduce their meat intake [91]. Recently, researchers found that consuming ultra-processed plant-based substitutes in place of meat and dairy could potentially lead to higher calorie, fat, salt, and sugars intakes, and risk adequate intake of calcium, potassium, magnesium, phosphorous, zinc, iron, and vitamin B12 [90].

To have maximum co-benefits for health and sustainability, it is better to promote whole plant-based protein sources like legumes and nuts and soy-based sources like tofu than ultra-processed alternatives where less desirable nutrients are hidden [89]. The concern now, however, is protein quality. Plant-based foods do not contain all essential amino acids as do animal-based foods, having a lower anabolic effect [92,93]. Nevertheless, a plant-based diet can achieve optimal protein quality by combining different plant-based sources so that the amino acids of one protein source may compensate for the limitations of the other [94]. In the context of diverse diets consumed in Europe, the quality of protein and other key nutrients may not be affected when animal products are reduced in the diet [95].

4. Methodological considerations

Compared to previous research on sustainable diets, strengths of the studies in this thesis include the use of individual-level dietary intake data and multiple environmental impact indicators to evaluate the environmental impact of dietary change in real-life as well in a theoretical setting using diet optimization techniques. Further, this thesis uses large population-based surveys to describe consumer behavior and identify individual-level factors influencing behavior. There are, however, some methodological considerations that need to be addressed.

4.1. Dietary assessment

4.1.1. Dietary assessment methods for individual-level dietary intake

The dietary assessment methods most commonly used in research evaluating the health and environmental sustainability of diets, and used in this thesis, are diet records (Chapter 7), repeated 24-hour dietary recalls (Chapter 7) and food frequency questionnaires (FFQs) (Chapter 5 and Chapter 6) [96]. Diet records (or food diaries) and 24-hour dietary recalls are open-ended surveys and collect detailed information regarding intake of an unlimited number of food items consumed by an individual over a specific time period, with portion sizes and preparation practices [97]. Because of high day-to-day variation and seasonal changes of food intake, a single diet record or 24-hour dietary recall represents the current diet and not the habitual diet. However, using multiple, repeated diet records and 24-hour recalls, one can estimate habitual intake at the population level [97-99]. In Chapter 7, a combination of three diet records and 24-hour dietary recalls were used to assess dietary intake of community-dwelling older adults participating in the PROMISS trial to assess habitual food intake at multiple time-points, i.e. baseline, 3-month follow up, and 6-month follow up. A diet record was used as a memory aid, as participants record intake at the time the foods are eaten, which helped inform the 24-hour dietary recall. The benefit of this was to minimize recall bias. However, is it possible that by conducting repeated measurements, respondents may have unintentionally changed their dietary habits through self-reflection, or intentionally to make their responses socially desirable [97].

In contrast to diet records and 24-hour dietary recalls, FFQs capture intake of food items over a designated time period from a finite list. Given their ability to assess long-term dietary intakes in a relatively simple, inexpensive and time-efficient manner, FFQs are widely used to assess habitual dietary intake of large populations [97]. FFQs are suitable for ranking individuals according to their usual food intake in order to examine relationship between dietary intake and health/disease outcomes [100]. Because FFQs are used in a closed format, it is critical to have an appropriate selection of foods for the target population, as differences exist in culturally specific food intake patterns. Its validity is highly dependent on the correct selection of the foods in the questionnaire, the choice on the correct portion size, and nutrient content assumption for each foods [101]. Two validated FFQs were used in this thesis. The GA2LEN FFQ was used in the MooDFOOD trial (Chapter 6) to assess dietary intake of participants across four European countries, i.e. Germany, United Kingdom, Spain, and the Netherlands. The GA2LEN was developed to estimate food intake across Europe regardless of cultural and linguistic differences [102]. The Healthy Life in an Urban Setting (HELIUS) FFQ was used to assessed dietary intake of Dutch older adults participating in the Longitudinal Aging Study Amsterdam (Chapter 5) [103,104]. While FFQs are subject to low accuracy (recall bias) [97], the use of the FFQs enabled the assessment of habitual food intake among larger samples compared to the use of the 24-hour dietary recall.

4.1.2. Assessment of food and nutrient intake

Measurement error from the dietary assessment methods used may have led to over- or underestimations of food and nutrient intakes. Systematic errors like intake-specific and person-specific bias are inherent to dietary assessment methods described above. An example of systematic error is the tendency of obese individuals to underreport total food consumption compared to lean individuals [105]. There are also intervention-associated biases that could influence dietary intake, including differential response bias due to exposure to intervention [106]. For instance, those who received dietary counselling are likely to overreport promoted foods and underreport discouraged foods targeted in the intervention [106]. This might have resulted in a stronger trial effects especially in Chapter 7, as meat and other animal-based foods are commonly regarded as superior sources of protein compared to plant-based foods [93]. Yet, because the RCTs were not focused on sustainability, it is not expected that participants misreported due to sustainability reasons (e.g. reporting less meat).

The other type of measurement error that dietary assessments are prone to are random errors like within-subject variation, seasonality, and weekdays vs. weekend consumption differences that often result in attenuation of associations [107]. When accounting for random error in a 24-hour dietary recall, correlations with GHGE and pReCiPe were stronger compared to when random error was not taken into account [108]. While methods exist to statistically correct for random error attributable to within-person variation in food intake [109], they were not used in this thesis as we were interested in estimating and comparing mean habitual intake of intervention and control groups and not assessing the distribution of habitual intake.

4.1.3. Assessment of diet-related environmental impact

The availability of life cycle assessment (LCA) data on single food products allows for researchers to study environmental impact of diets using dietary intake data collected at the individual level. Measurement error due to the dietary assessment methods discussed above may have led to less accurate estimates of environmental impact of diets. FFQs may be inferior to 24-hour dietary recalls when evaluating the environmental impact of diets as they aggregate and incorporate food items that differentiate diets with respect to dietary quality rather than environmental impact [108]. An evaluation study found that the FFQ slightly underestimated environmental impact when compared to the 24-hour dietary recall [108]. The dietary assessment methods in this thesis did not include information on production method, country of origin of foods, cooking methods, and food waste. Therefore, we could only include the mean environmental impact of food items. To assess the environmental impact of relative dietary composition rather than absolute intake levels of foods, one should adjust for energy intake. Isocaloric replacement was conducted in Chapter 5, and therefore changes in environmental impacts were due to changes in diet composition. The primary environmental outcomes of the trial studies, however, did not take into account energy intake over time, as we were primarily interested in the environmental impact of all changes made to the diet.

4.2. Estimating diet-related environmental impacts

4.2.1. Life cycle assessments

Environmental impact of foods are commonly assessed using attributional LCAs that describe the environmental impact of a food product throughout its entire life cycle at one specific moment in time. There is high level of uncertainty in LCA data due to lack of data, unrepresentative process data, differences in geographical or temporal scopes of data collected, etc. [110]. Because many emissions cannot be directly measured, they have to be estimated with models given their diffuse nature [111]. Emissions strongly depend on climate, soil, topography and can vary considerably even in the same region. Further, because the LCAs are a measurement at one specific point in time, they do not take into account the changing climatic conditions, food waste, trade patterns, and GHGE- and water-intensity of production. Over time, these factors will change in ways that are difficult to anticipate, e.g., due to changing diets, climate, etc. [81]. Most LCAs are static and therefore do not represent system feedbacks that incorporate changes in demand because of production efficiency enhancements, or marginal changes in environmental effects involved in large-scale dietary shifts [112].

The geographical scope of the LCA data used in this thesis is the Netherlands. While we applied this data to Dutch food consumption data in Chapter 5 and Chapter 7, we also applied it to food consumption data from Germany, Spain, and the UK in Chapter 6. However, LCAs for foods are particularly sensitive to geographical system boundaries. Differences between these countries and the Netherlands in terms of geography, climate and production, processing, and distribution systems may influence the actual diet-related environmental impact in each country. However, in the absence of country-specific data, our LCA data served as a proxy to provide a rough estimation on diet-level impacts. This uncertainty is expected to have minor influence when determining the differences in the environmental impact between the control and intervention groups, as the rankings of the environmental impact of foods are likely to be similar despite country of consumption [113].

4.2.2. Environmental impact indicators

This thesis makes use of several environmental impact indicators, namely GHGE, LU, FEU, blue water use, terrestrial acidification, freshwater eutrophication, and marine eutrophication. Previous studies commonly use GHGE as a proxy for the total environmental impact due the high correlation between GHGE and other environmental impacts [80]. However trade-offs have been observed between carbon and water [49,114]. Further, it made use of the pReCiPe score, which is a weighted combination of GHGE, LU, and FEU [115]. Although various environmental impact indicators were used, the environmental impact indicators in our study do not include other metrics like biodiversity loss and antibiotic use in poultry production, due to a lack of robust data. Data availability remains a challenge, even for the environmental indicators available. Food items consumed were linked to LCA data either by direct matching or extrapolation based on similarities in the type of food or production methods. The LCA datasets used had primary data for 94 to 242 foods and beverages, and food items without primary data were based on extrapolations. Despite the increased uncertainty due to extrapolations, we had complete LCA data for all our studies.

5. Implications for future research

Given the need to delineate pathways to achieve sustainable nutrition in specific contexts, this thesis focused on gaining a better understanding of individual-level factors influencing consumer behavior, evaluating the environmental sustainability of health-oriented dietary strategies and identifying health and sustainability co-benefits and trade-offs for two subpopulations in Europe. Still, as we work towards the development of more environmentally sustainable guidance for population and planetary health, more insight is needed into 1) the context in which dietary intake and food-related practices take place for specific subpopulations, 2) dietary changes needed that integrate a holistic perspective of sustainability for specific subpopulations, and 3) the impact of dietary guidance that incorporates both health and environmental sustainability objectives.

5.1. Better understand the context in which dietary intake and food-related practices take place for specific subpopulations

This thesis focuses on individual-level factors influencing food choice and food-related practices, particularly food waste behavior among European consumers and meat/alternative protein consumption behavior among community-dwelling older adults in Europe. Consumer food choice and food-related practices are complex and subject to multiple influences related to individual-level factors as well as social and physical environments and political and economic drivers. While many studies, including Chapter 2, Chapter 3, and Chapter 4, provide insights into various individual-level factors associated with food choice and food-related behavior, literature remains scattered with no overarching rationale or theoretical framework [69]. More research is needed to integrate such insights into an overarching theoretical framework of behavior change to better understand the context in which dietary intake and food-related practices take place for specific subpopulations to inform future dietary interventions. To realize behavior change, it is integral to understanding behavior in the broader food system, also addressing the influence of the built and retail environment on food-purchasing decisions [116]. One example of a framework that helps put behavior into context is the COM-B model of behavior [117], which recognizes that for any behavior to occur, individuals must have the Capability (e.g. knowledge, skills), Opportunity (e.g. social influences and physical environment), and Motivation (e.g. intentions, goals) to enact a concerned Behavior. Having a better understanding of the context of consumer behavior in terms of their capability and their environment can help identify what motivates dietary change as well as food-related practices like food waste prevention.

5.2. Identify dietary changes that integrate a holistic perspective of sustainability for specific subpopulations

More work is needed to develop context-specific environmentally sustainable diets taking into account nutritional, social, cultural, economic, and ecological circumstances to make such diets available, accessible, affordable, healthy, safe, and desirable [118]. While this thesis focuses primarily on environmental, nutritional, and acceptability dimensions of sustainable diets, the economic (e.g. affordability) and social aspects (e.g. animal welfare) are also important. One way to integrate these different dimensions into dietary guidelines is provided by mathematical optimization methods, which was applied in Chapter 5 and in various other settings [77]. Starting with a representative baseline diet of a specific subpopulation, one can optimize the diet for multiple environmental impact indicators, nutritional quality or adequacy, and cultural acceptability, and identify dietary changes need to achieve the best trade-off between various sustainability dimensions [119]. It is critical to do this for specific subpopulations, as differences in food culture, habits, and nutrient needs with regards to age, sex, country, ethnicity, etc. will lead to different optimized diets [120].
Further, such research should acknowledge trade-offs and feedbacks of the multiple components and the local-specific nature of food systems [121]. This thesis relies on LCA to determine the environmental impacts of food products, but it doesn't include other sustainability dimensions (e.g. animal welfare, livelihoods, biodiversity etc.). LCA is currently limited to certain temporal and spatial scales and does not take into account feedback loops. It is essential that research moves forward to utilizing metrics that are intrinsically holistic and capable of detecting nuanced effects (unintended consequences or feedback loop) [122]. Analyses should better quantify the diverse effects of food production and fishing/aquaculture on biodiversity and ecosystems. Integration of a more diverse range of biodiversity indicators are needed [112].

5.3. Evaluate the impact of dietary guidance that incorporate both health and environmental sustainability objectives

Future research should evaluate the healthiness and environmental sustainability of dietary change in individuals and populations who receive dietary guidance designed to decrease the environmental impact of the diet and improve health simultaneously. For instance, if the dietary advice to increase protein intake provided during the PROMISS trial was designed considering the environmentally-friendly dietary changes identified in Chapter 5, what would have been the impact on older adults' functional status and environmental impact of the diet? Sustainable food replacements should be the focus of future applied clinical nutrition research to assess the impact on overall nutrient intake. Most sustainable diets remain theoretical. Given the complexity of dietary change and the physiological and behavioral feedback loops that affect food choices, total amount of food eaten, and nutrient/energy density of the diet as a whole, what looks like simple food replacement on paper is seldom possible in practice [96]. Therefore testing a posteriori the acceptability, feasibility, or effectiveness of dietary recommendations designed based on evidence for sustainable diets or using diet optimization would add value to the theoretical solutions by identifying barriers and opportunities for change.

6. Implications for practice

The nutritional health of a population is contingent upon a resilient food system [123-125]. Nutritional and dietary recommendations that disregard environmental sustainability will have negative long-term consequences on the environment and in turn do not adequately promote and protect the nutrition and health of populations. While many overlaps between a healthy and environmentally sustainable diet exist, various trade-offs need to be made, as nutrient-rich foods are not always environmentally sustainable and environmentally sustainable foods are not always nutritious. Therefore, nutritionists and dieticians must play a role in outlining the way forward through their expertise for rigorous dietary assessment and analysis [125] and, together with public health authorities, in delivering messages to facilitate behavioral change required so that food choices are both healthy and sustainable [126]. At the end of both the MooDFOOD and PROMISS projects, the respective multidisciplinary consortiums came together to develop dietary strategies based on the research conducted in each project. Dietary strategies were developed and tailored for specific stakeholders, including policy-makers, health care professionals, food industry, dieticians, researchers, and the public. The results from this thesis guided the recommendations for environmentally sustainable strategies. The strategies developed for policy-makers can be found in in Box 1 and 2. The recommendations, which are also available for dieticians and other healthcare professionals, food industry, researchers and the public, can be retrieved on the projects' websites (https://moodfood-vu.eu/ and https://www.promiss-vu.eu/).

Box 1. MooDFOOD dietary strategies – Recommendations for policy-makers

Following a healthy dietary pattern, consistent with national dietary guidelines, may reduce depressive symptoms and improve mental health. A healthy dietary pattern includes:

- Lots of fruits and vegetables
- More legumes
- Wholegrain breads and cereals
- At least one serving of oily fish a week
- Dairy products
- Healthy vegetable oils
- Lower amounts of red and processed meats

As people move towards a healthy dietary pattern that is rich in plant foods like fruits, vegetables, and legumes, contains a moderate amount of sustainably sourced fish, and is low intake of red meat, their environmental footprint is reduced.

Box 2. PROMISS dietary strategies – Recommendations for policy-makers
• Older people should eat more plant-based protein such as legumes, cereals, nuts, and seeds, although it is not necessary to go completely vegan or vegetarian. • Older people should eat less animal-based protein (such as beef, lamb, and processed meats) and choose chicken and pork if meat is eaten. • Fish should not be eaten more than once a week, and when choosing fish, eco-labels on certified fish products such as the Marine Stewardship Council (MSC) logo, and Aquaculture Stewardship Council (ASC) logo should be considered.

A transition toward plant-based diets is essential for meeting the climate change mitigation targets and remaining within planetary boundaries [58,127,128]. Policies and other measures to increase the sustainability and nutritional value of diets in Europe are broadly related to reducing consumption of animal-based sources, however, the direction and extent depends on population groups. Nutritionists can set the standard for the required nature and extent of change in food consumption patterns through dietary guidance. Formulating dietary guidance should begin with evidence of the relationship between dietary patterns and health outcomes, and then to review the evidence for foods in terms of health and environmental sustainability [129]. Putting emphasis on nutritional adequacy in place of diet-disease risk relationships may lead to negative consequences, including the promotion of fortified processed foods in order to fulfill recommended intakes of nutrients, albeit their high content of fat and salt [130]. While fortified processed foods could play a role in improving health in select populations (e.g. protein enrichment for older adults), they are becoming more mainstream especially when it comes to ultra-processed meat and dairy replacements. Further, in addition to recommending consumption of certain food groups, another important strategy is to minimize food waste, including tips on how to improve consumers' ability to plan accurately, shop smartly, cook creatively, estimate food safety, and prolong the shelf-life of foods, and aligning this information with goals of consumers (e.g. health, convenience, food safety, etc.) [7].

In terms of policies, few national dietary guidelines panels across the world have explicitly incorporated environmental sustainability into its recommendations [131,132]. Nevertheless, more work is needed to translate the evidence into culturally acceptable, environmentally sustainable food-based recommendations for specific populations. The EAT-Lancet planetary health diet, for instance, provides a global direction for a healthy and sustainable diet but needs to be scaled down to each country/region [58]. Furthermore, a concerted effort is needed across the food system to change food environments to make the healthy and sustainable choice the easy choice. A holistic approach has to go beyond putting the responsibility solely on individuals [133]. For instance, the European Public Health Association has recognized an opportunity to implement sustainable healthy diets via the EU Common Agricultural Policy (CAP), which currently subsidizes meat and dairy, encouraging their production and consumption which is not environmentally sustainable [134]. Despite proposals for a reform to align with the European Green Deal, the CAP is very focused on the production side (e.g. sustainable farming practices). It must broaden its criteria to include the food system including consumption to build on the link between environmental sustainability and health of populations. Other policies influencing the food environment, such as food group-specific taxes, may be effective in reaching nutrition and environmental sustainability targets [135]. But the inclusion of nutritionists and dieticians in such policies is critical to identify win-wins and trade-offs between health and sustainability.

7. Overall conclusions

The food system is failing to deliver a healthy diet for humans and the planet. The high environmental impact and disease burden of current food systems necessitates urgent attention towards more environmentally sustainable food consumption. The findings of this thesis show that health-oriented diet interventions may have negative environmental outcomes if environmental sustainability is not taken into account in the development of recommendations. We showed that increasing consumption of recommended foods like vegetables, fruits, fish, legumes, and whole grains may lead to a net increase in the environmental impact of the diet if meat consumption is not reduced. Further, we showed that focusing on increasing protein intake leads to increases in environmental impact due to the tendency of favoring animal-based protein. This stresses the importance of promoting plant-based protein in place of animal-based protein. For older adults at risk of low protein intake, it would be important to maintain a healthy level of meat consumption but to replace meat types with a high environmental impact with low-impact meat types. Furthermore, individual-level factors including personal and psychographic factors were found to influence pro-environmental food consumption behavior.

In light of this thesis as well as previous literature, reducing consumption of meat and animal-based protein must be targeted in dietary guidance and interventions, and more efforts are needed to moderate fish consumption, replace foods with high environmental impact with lower impact foods, and achieve energy-balanced diets to have a reduced impact on the environment. Future research is needed to assess the environmental impact of dietary advice that considers the environmental impact of foods, and to better understand drivers of food choice and contextual barriers to better stimulate populations to consume healthier and more environmentally friendly diets. There is a plethora of variation across and within countries and over time in the nature of food consumption and the characteristics of food systems that a "one-solution-fits-all" mentality will not succeed. Therefore, it is important to develop nuanced guidance and interventions that considers both health and environmental sustainability aspects to promote the health of populations and the planet.

References

1. den Uijl LC, Jager G, de Graaf C, Waddell J, Kremer S (2014) It is not just a meal, it is an emotional experience - a segmentation of older persons based on the emotions that they associate with mealtimes. Appetite 83:287-296. https://doi.org/10.1016/j.appet.2014.09.002
2. Reinders I, Wijnhoven HAH, Jyväkorpi SK, Suominen MH, Niskanen R, Bosmans JE et al (2020) Effectiveness and cost-effectiveness of personalised dietary advice aiming at increasing protein intake on physical functioning in community-dwelling older adults with lower habitual protein intake: rationale and design of the PROMISS randomised controlled trial. BMJ Open 10 (11):e040637. https://doi.org/10.1136/bmjopen-2020-040637
3. Aleksandrowicz L, Green R, Joy EJM, Smith P, Haines A (2016) The impacts of dietary change on greenhouse gas emissions, land use, water use, and health: A systematic review. PLOS ONE 11 (11):e0165797. https://doi.org/10.1371/journal.pone.0165797
4. Frehner A, Zanten HHEV, Schader C, Boer IJMD, Pestoni G, Rohrmann S et al (2021) How food choices link sociodemographic and lifestyle factors with sustainability impacts. J Clean Prod 300:126896. https://doi.org/10.1016/j.jclepro.2021.126896
5. Verain MCD, Bartels J, Dagevos H, Sijtsema SJ, Onwezen MC, Antonides G (2012) Segments of sustainable food consumers: a literature review. Int J Consum Stud 36 (2):123-132. https://doi.org/10.1111/j.1470-6431.2011.01082.x
6. van Geffen L, van Herpen E, van Trijp H (2020) Household food waste—How to avoid it? An integrative review. In: Närvänen E, Mesiranta N, Mattila M, Heikkinen A (eds) Food Waste Management: Solving the Wicked Problem. Springer International Publishing, Cham, pp 27-55. https://doi.org/10.1007/978-3-030-20561-4_2
7. van Geffen L, van Herpen E, Sijtsema S, van Trijp H (2020) Food waste as the consequence of competing motivations, lack of opportunities, and insufficient abilities. Resources, Conservation & Recycling: X 5:100026. https://doi.org/10.1016/j.rcrx.2019.100026
8. Ajzen I (1991) The theory of planned behavior. Organ Behav Hum Decis Process 50 (2):179-211. https://doi.org/10.1016/0749-5978(91)90020-T
9. Graham-Rowe E, Jessop DC, Sparks P (2015) Predicting household food waste reduction using an extended theory of planned behaviour. Resour Conserv Recycl 101:194-202. https://doi.org/10.1016/j.resconrec.2015.05.020
10. Mondéjar-Jiménez J-A, Ferrari G, Secondi L, Principato L (2016) From the table to waste: An exploratory study on behaviour towards food waste of Spanish and Italian youths. J Clean Prod 138:8-18. https://doi.org/10.1016/j.jclepro.2016.06.018
11. Stancu V, Haugaard P, Lähteenmäki L (2016) Determinants of consumer food waste behaviour: Two routes to food waste. Appetite 96:7-17. https://doi.org/10.1016/j.appet.2015.08.025
12. Stefan V, van Herpen E, Tudoran AA, Lähteenmäki L (2013) Avoiding food waste by Romanian consumers: The importance of planning and shopping routines. Food Qual Prefer 28 (1):375-381. https://doi.org/10.1016/j.foodqual.2012.11.001
13. Visschers VHM, Wickli N, Siegrist M (2016) Sorting out food waste behaviour: A survey on the motivators and barriers of self-reported amounts of food waste in households. J Environ Psychol 45:66-78. https://doi.org/10.1016/j.jenvp.2015.11.007
14. Russell SV, Young CW, Unsworth KL, Robinson C (2017) Bringing habits and emotions into food waste behaviour. Resour Conserv Recycl 125:107-114. https://doi.org/10.1016/j.resconrec.2017.06.007

15. van der Werf P, Seabrook JA, Gilliland JA (2019) Food for naught: Using the theory of planned behaviour to better understand household food wasting behaviour. Can Geogr 63:478-493. https://doi.org/10.1111/cag.12519
16. Schanes K, Dobernig K, Gözet B (2018) Food waste matters - A systematic review of household food waste practices and their policy implications. J Clean Prod 182:978-991. https://doi.org/10.1016/j.jclepro.2018.02.030
17. Aschemann-Witzel J, De Hooge I, Amani P, Bech-Larsen T, Oostindjer M (2015) Consumer-related food waste: Causes and potential for action. Sustainability 7 (6):6457-6477. https://doi.org/10.3390/su7066457
18. Secondi L, Principato L, Laureti T (2015) Household food waste behaviour in EU-27 countries: A multilevel analysis. Food Policy 56:25-40. https://doi.org/10.1016/j.foodpol.2015.07.007
19. Cecere G, Mancinelli S, Mazzanti M (2014) Waste prevention and social preferences: the role of intrinsic and extrinsic motivations. Ecol Econ 107:163-176. https://doi.org/10.1016/j.ecolecon.2014.07.007
20. Koivupuro H-K, Hartikainen H, Silvennoinen K, Katajajuuri J-M, Heikintalo N, Reinikainen A et al (2012) Influence of socio-demographical, behavioural and attitudinal factors on the amount of avoidable food waste generated in Finnish households. Int J Consum Stud 36 (2):183-191. https://doi.org/10.1111/j.1470-6431.2011.01080.x
21. Verain MCD, Dagevos H, Antonides G (2015) Sustainable food consumption. Product choice or curtailment? Appetite 91:375-384. https://doi.org/10.1016/j.appet.2015.04.055
22. Tobler C, Visschers VHM, Siegrist M (2011) Eating green. Consumers' willingness to adopt ecological food consumption behaviors. Appetite 57 (3):674-682. https://doi.org/10.1016/j.appet.2011.08.010
23. Schösler H, de Boer J, Boersema JJ, Aiking H (2015) Meat and masculinity among young Chinese, Turkish and Dutch adults in the Netherlands. Appetite 89:152-159. https://doi.org/10.1016/j.appet.2015.02.013
24. Siegrist M, Visschers VHM, Hartmann C (2015) Factors influencing changes in sustainability perception of various food behaviors: Results of a longitudinal study. Food Qual Prefer 46:33-39. https://doi.org/10.1016/j.foodqual.2015.07.006
25. Gómez-Luciano CA, Vriesekoop F, Urbano B Towards food security of alternative dietary proteins: a comparison between Spain and the Dominican Republic. In, 2019.
26. Melendrez-Ruiz J, Buatois Q, Chambaron S, Monnery-Patris S, Arvisenet G (2019) French consumers know the benefits of pulses, but do not choose them: An exploratory study combining indirect and direct approaches. Appetite 141:104311. https://doi.org/10.1016/j.appet.2019.06.003
27. Onwezen MC, Bouwman EP, Reinders MJ, Dagevos H (2021) A systematic review on consumer acceptance of alternative proteins: Pulses, algae, insects, plant-based meat alternatives, and cultured meat. Appetite 159:105058. https://doi.org/10.1016/j.appet.2020.105058
28. Sanchez-Sabate R, Sabaté J (2019) Consumer attitudes towards environmental concerns of meat consumption: A systematic review. Int J Environ Res Public Health 16 (7):1220. https://doi.org/10.3390/ijerph16071220
29. de Boer J, Aiking H (2018) Prospects for pro-environmental protein consumption in Europe: Cultural, culinary, economic and psychological factors. Appetite 121:29-40. https://doi.org/10.1016/j.appet.2017.10.042
30. Rayner G, Barling D, Lang T (2008) Sustainable food systems in Europe: Policies, realities and futures. J Hunger Environ Nutr 3 (2-3):145-168. https://doi.org/10.1080/19320240802243209

31. Whitelock E, Ensaff H (2018) On your own: Older adults' food choice and dietary habits. Nutrients 10 (4). https://doi.org/10.3390/nu10040413
32. Rusu A, Randriambelonoro M, Perrin C, Valk C, Álvarez B, Schwarze A-K (2020) Aspects influencing food intake and approaches towards personalising nutrition in the elderly. J Popul Ageing 13 (2):239-256. https://doi.org/10.1007/s12062-019-09259-1
33. Kamphuis CB, de Bekker-Grob EW, van Lenthe FJ (2015) Factors affecting food choices of older adults from high and low socioeconomic groups: a discrete choice experiment. Am J Clin Nutr 101 (4):768-774. https://doi.org/10.3945/ajcn.114.096776
34. Locher JL, Ritchie CS, Roth DL, Sen B, Vickers KS, Vailas LI (2009) Food choice among homebound older adults: Motivations and perceived barriers. J Nutr Health Aging 13 (8):659-664. https://doi.org/10.1007/s12603-009-0194-7
35. Van Loo EJ, Hoefkens C, Verbeke W (2017) Healthy, sustainable and plant-based eating: Perceived (mis)match and involvement-based consumer segments as targets for future policy. Food Policy 69:46-57. https://doi.org/10.1016/j.foodpol.2017.03.001
36. Niva M, Mäkelä J, Kahma N, Kjærnes U (2014) Eating sustainably? Practices and background factors of ecological food consumption in four Nordic countries. J Consum Policy 37 (4):465-484. https://doi.org/10.1007/s10603-014-9270-4
37. De Backer CJS, Hudders L (2015) Meat morals: relationship between meat consumption consumer attitudes towards human and animal welfare and moral behavior. Meat Sci 99:68-74. https://doi.org/10.1016/j.meatsci.2014.08.011
38. De Backer CJS, Hudders L (2014) From meatless Mondays to meatless Sundays: Motivations for meat reduction among vegetarians and semi-vegetarians who mildly or significantly reduce their meat intake. Ecology of Food and Nutrition 53 (6):639-657. https://doi.org/10.1080/03670244.2014.896797
39. Mathur MB, Robinson TN, Reichling DB, Gardner CD, Nadler J, Bain PA et al (2020) Reducing meat consumption by appealing to animal welfare: protocol for a meta-analysis and theoretical review. Syst Rev 9 (1):3. https://doi.org/10.1186/s13643-019-1264-5
40. Graça J, Oliveira A, Calheiros MM (2015) Meat, beyond the plate. Data-driven hypotheses for understanding consumer willingness to adopt a more plant-based diet. Appetite 90:80-90. https://doi.org/10.1016/j.appet.2015.02.037
41. Smith AD, Herle M, Fildes A, Cooke L, Steinsbekk S, Llewellyn CH (2017) Food fussiness and food neophobia share a common etiology in early childhood. J Child Psychol Psychiatry 58 (2):189-196. https://doi.org/10.1111/jcpp.12647
42. Hung Y, Wijnhoven HAH, Visser M, Verbeke W (2019) Appetite and protein intake strata of older adults in the European Union: Socio-demographic and health characteristics, diet-related and physical activity behaviours. Nutrients 11 (4). https://doi.org/10.3390/nu11040777
43. Grasso S, Jaworska S (2020) Part meat and part plant: Are hybrid meat products fad or future? Foods 9 (12):1888. https://doi.org/10.3390/foods9121888
44. Lang M (2020) Consumer acceptance of blending plant-based ingredients into traditional meat-based foods: Evidence from the meat-mushroom blend. Food Qual Prefer 79:103758. https://doi.org/10.1016/j.foodqual.2019.103758
45. Macdiarmid JI (2013) Is a healthy diet an environmentally sustainable diet? Proc Nutr Soc 72. https://doi.org/10.1017/S0029665112002893
46. Tilman D, Clark M (2014) Global diets link environmental sustainability and human health. Nature 515:518-522. https://doi.org/10.1038/nature13959
47. Vieux F, Darmon N, Touazi D, Soler LG (2012) Greenhouse gas emissions of self-selected individual diets in France: Changing the diet structure or consuming less? Ecol Econ 75:91-101. https://doi.org/10.1016/j.ecolecon.2012.01.003
48. Heller MC, Keoleian GA (2015) Greenhouse gas emission estimates of U.S. dietary choices and food loss. J Ind Ecol 19 (3):391-401. https://doi.org/10.1111/jiec.12174

49. Vellinga RE, van de Kamp M, Toxopeus IB, van Rossum CTM, de Valk E, Biesbroek S et al (2019) Greenhouse gas emissions and blue water use of Dutch diets and its association with health. Sustainability 11 (21):6027. https://doi.org/10.3390/su11216027
50. Bot M, Brouwer IA, Roca M, Kohls E, Penninx BWJH, Watkins E et al (2019) Effect of multinutrient supplementation and food-related behavioral activation therapy on prevention of major depressive disorder among overweight or obese adults with subsyndromal depressive symptoms: The MooDFOOD Randomized Clinical Trial. JAMA 321 (9):858-868. https://doi.org/10.1001/jama.2019.0556
51. van Dooren C, Marinussen M, Blonk H, Aiking H, Vellinga P (2014) Exploring dietary guidelines based on ecological and nutritional values: A comparison of six dietary patterns. Food Policy 44:36-46. https://doi.org/10.1016/j.foodpol.2013.11.002
52. Sáez-Almendros S, Obrador B, Bach-Faig A, Serra-Majem L (2013) Environmental footprints of Mediterranean versus Western dietary patterns: beyond the health benefits of the Mediterranean diet. Environ Health 12 (1):118. https://doi.org/10.1186/1476-069X-12-118
53. Hendrie GA, Baird D, Ridoutt B, Hadjikakou M, Noakes M (2016) Overconsumption of energy and excessive discretionary food intake inflates dietary greenhouse gas emissions in Australia. Nutrients 8 (11):690. https://doi.org/10.3390/nu8110690
54. Parker RWR, Blanchard JL, Gardner C, Green BS, Hartmann K, Tyedmers PH et al (2018) Fuel use and greenhouse gas emissions of world fisheries. Nat Clim Chang 8 (4):333-337. https://doi.org/10.1038/s41558-018-0117-x
55. Araghi Y, Dijkema GPJ Alternative energy sources and energy infrastructure for Dutch greenhouses: Investigating growers' preferences. In: International Symposium for Next Generation Infrastructure Conference Proceedings: 30 September - 1 October 2014 International Institute of Applied Systems Analysis (IIASA), Schloss Laxenburg, Vienna, Austria, UCL STEaPP London, 2015. pp 199-203
56. Tom MS, Fischbeck PS, Hendrickson CT (2016) Energy use, blue water footprint, and greenhouse gas emissions for current food consumption patterns and dietary recommendations in the US. Environ Sys Decis 36 (1):92-103. https://doi.org/10.1007/s10669-015-9577-y
57. Behrens P, Kiefte-de Jong JC, Bosker T, Rodrigues JFD, de Koning A, Tukker A (2017) Evaluating the environmental impacts of dietary recommendations. Proc Natl Acad Sci USA 114 (51):13412. https://doi.org/10.1073/pnas.1711889114
58. Willett W, Rockstrom J, Loken B, Springmann M, Lang T, Vermeulen S et al (2019) Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems. Lancet 393 (10170):447-492. https://doi.org/10.1016/s0140-6736(18)31788-4
59. Reinders I, Visser M, Jyväkorpi SK, Niskanen RT, Bosmans JE, Ben ÂJ et al (in press) The (cost-)effectiveness of personalized dietary advice to increase protein intake on change in physical functioning in older adults with lower habitual protein intake: A randomized controlled trial. Eur J Nutr
60. Chen C, Chaudhary A, Mathys A (2019) Dietary change scenarios and implications for environmental, nutrition, human health and economic dimensions of food sustainability. Nutrients 11 (4):856. https://doi.org/10.3390/nu11040856
61. Gorissen SHM, Witard OC (2018) Characterising the muscle anabolic potential of dairy, meat and plant-based protein sources in older adults. Proc Nutr Soc 77 (1):20-31. https://doi.org/10.1017/s002966511700194x
62. Hallström E, Carlsson-Kanyama A, Börjesson P (2015) Environmental impact of dietary change: a systematic review. J Clean Prod 91:1-11. https://doi.org/10.1016/j.jclepro.2014.12.008

63. The Netherlands Nutrition Center (Voedingscentrum) (2018) Source document: Towards a more plant-based diet (in Dutch). Voedingscentrum, The Hague.
64. Garnett T (2011) Where are the best opportunities for reducing greenhouse gas emissions in the food system (including the food chain)? Food Policy 36:S23-S32. https://doi.org/10.1016/j.foodpol.2010.10.010
65. Springmann M, Wiebe K, Mason-D'Croz D, Sulser TB, Rayner M, Scarborough P (2018) Health and nutritional aspects of sustainable diet strategies and their association with environmental impacts: a global modelling analysis with country-level detail. Lancet Planet Health 2 (10):e451-e461. https://doi.org/10.1016/S2542-5196(18)30206-7
66. Godfray HCJ, Aveyard P, Garnett T, Hall JW, Key TJ, Lorimer J et al (2018) Meat consumption, health, and the environment. Science 361 (6399):eaam5324. https://doi.org/10.1126/science.aam5324
67. Springmann M, Spajic L, Clark MA, Poore J, Herforth A, Webb P et al (2020) The healthiness and sustainability of national and global food based dietary guidelines: modelling study. BMJ 370:m2322. https://doi.org/10.1136/bmj.m2322
68. Chai BC, van der Voort JR, Grofelnik K, Eliasdottir HG, Klöss I, Perez-Cueto FJA (2019) Which diet has the least environmental impact on our planet? A systematic review of vegan, vegetarian and omnivorous diets. Sustainability 11 (15):4110. https://doi.org/10.3390/su11154110
69. Graça J, Godinho CA, Truninger M (2019) Reducing meat consumption and following plant-based diets: Current evidence and future directions to inform integrated transitions. Trends Food Sci Tech 91:380-390. https://doi.org/10.1016/j.tifs.2019.07.046
70. Nucci D, Fatigoni C, Amerio A, Odone A, Gianfredi V (2020) Red and processed meat consumption and risk of depression: A systematic review and meta-analysis. Int J Environ Res Public Health 17 (18):6686. https://doi.org/10.3390/ijerph17186686
71. de Gavelle E, Leroy P, Perrimon M, Huneau J-F, Sirot V, Orset C et al (2019) Modeled gradual changes in protein intake to increase nutrient adequacy lead to greater sustainability when systematically targeting an increase in the share of plant protein. Clim Change. https://doi.org/10.1007/s10584-019-02592-6
72. Hengeveld LM, Pelgröm ADA, Visser M, Boer JMA, Haveman-Nies A, Wijnhoven HAH (2019) Comparison of protein intake per eating occasion, food sources of protein and general characteristics between community-dwelling older adults with a low and high protein intake. Clin Nutr ESPEN 29:165-174. https://doi.org/10.1016/j.clnesp.2018.10.013
73. Berner LA, Becker G, Wise M, Doi J (2013) Characterization of dietary protein among older adults in the United States: Amount, animal sources, and meal patterns. J Acad Nutr Diet 113 (6):809-815. https://doi.org/10.1016/j.jand.2013.01.014
74. Lonnie M, Hooker E, Brunstrom JM, Corfe BM, Green MA, Watson AW et al (2018) Protein for life: Review of optimal protein intake, sustainable dietary sources and the effect on appetite in ageing adults. Nutrients 10 (3). https://doi.org/10.3390/nu10030360
75. FAO (2020) The State of World Fisheries and Aquaculture 2020. Sustainability in action. Rome.
76. Kromhout D, Spaaij CJK, de Goede J, Weggemans RM (2016) The 2015 Dutch food-based dietary guidelines. Eur J Clin Nutr 70 (8):869-878. https://doi.org/10.1038/ejcn.2016.52
77. Brink E, van Rossum C, Postma-Smeets A, Stafleu A, Wolvers D, van Dooren C et al (2019) Development of healthy and sustainable food-based dietary guidelines for the Netherlands. Public Health Nutr 22 (13):2419-2435. 10.1017/S1368980019001435

78. Hollander A, De Jonge R, Biesbroek S, Hoekstra J, Zijp MC (2019) Exploring solutions for healthy, safe, and sustainable fatty acids (EPA and DHA) consumption in The Netherlands. Sus Sci 14 (2):303-313. 10.1007/s11625-018-0607-9
79. Poore J, Nemecek T (2018) Reducing food's environmental impacts through producers and consumers. Science 360 (6392):987-992. https://doi.org/10.1126/science.aaq0216
80. van de Kamp ME, van Dooren C, Hollander A, Geurts M, Brink EJ, van Rossum C et al (2018) Healthy diets with reduced environmental impact? – The greenhouse gas emissions of various diets adhering to the Dutch food based dietary guidelines. Food Res Int 104:14-24. https://doi.org/10.1016/j.foodres.2017.06.006
81. Kim BF, Santo RE, Scatterday AP, Fry JP, Synk CM, Cebron SR et al (2020) Country-specific dietary shifts to mitigate climate and water crises. Global Environ Chang 62:101926. https://doi.org/10.1016/j.gloenvcha.2019.05.010
82. Carlsson-Kanyama A, González AD (2009) Potential contributions of food consumption patterns to climate change. Am J Clin Nutr 89 (5):1704S-1709S. https://doi.org/10.3945/ajcn.2009.26736AA
83. Alexander P, Brown C, Arneth A, Finnigan J, Moran D, Rounsevell MDA (2017) Losses, inefficiencies and waste in the global food system. Agric Syst 153:190-200. https://doi.org/10.1016/j.agsy.2017.01.014
84. Springmann M, Godfray HCJ, Rayner M, Scarborough P (2016) Analysis and valuation of the health and climate change cobenefits of dietary change. Proc Natl Acad Sci USA 113 (15):4146-4151. https://doi.org/10.1073/pnas.1523119113
85. World Economic Forum (WEF) (2019) Meat: the future series: Alternative proteins. Prepared by the Oxford Martin School, Oxford University for the World Economic Forum's Meat: the Future dialogue series, Cologny/Geneva, Switzerland.
86. Parodi A, Leip A, De Boer IJM, Slegers PM, Ziegler F, Temme EHM et al (2018) The potential of future foods for sustainable and healthy diets. Nat Sustain 1 (12):782-789. https://doi.org/10.1038/s41893-018-0189-7
87. Kumar P, Chatli MK, Mehta N, Singh P, Malav OP, Verma AK (2017) Meat analogues: Health promising sustainable meat substitutes. Crit Rev Food Sci Nutr 57 (5):923-932. https://doi.org/10.1080/10408398.2014.939739
88. Wickramasinghe K, Breda J, Berdzuli N, Rippin H, Farrand C, Halloran A (2021) The shift to plant-based diets: are we missing the point? Glob Food Sec 29:100530. https://doi.org/10.1016/j.gfs.2021.100530
89. Hu FB, Otis BO, McCarthy G (2019) Can plant-based meat alternatives be part of a healthy and sustainable diet? JAMA 322 (16):1547-1548. https://doi.org/10.1001/jama.2019.13187
90. Tso R, Forde CG (2021) Unintended consequences: Nutritional impact and potential pitfalls of switching from animal- to plant-based foods. Nutrients 13 (8):2527. https://doi.org/10.3390/nu13082527
91. Clément T, Joya R, Bresson C, Clément C (2018) Market developments and policy evaluation aspects of the plant protein sector in the EU. Agrosynergie EEIG for the European Commission,, Brussels, Belgium.
92. Berrazaga I, Micard V, Gueugneau M, Walrand S (2019) The role of the anabolic properties of plant- versus animal-based protein sources in supporting muscle mass maintenance: A critical review. Nutrients 11 (8):1825. https://doi.org/10.3390/nu11081825
93. van Vliet S, Burd NA, van Loon LJ (2015) The skeletal muscle anabolic response to plant- versus animal-based protein consumption. J Nutr 145 (9):1981-1991. https://doi.org/10.3945/jn.114.204305

94. Lonnie M, Johnstone AM (2020) The public health rationale for promoting plant protein as an important part of a sustainable and healthy diet. Nutr Bull 45 (3):281-293. https://doi.org/10.1111/nbu.12453
95. Barré, T, Perignon M, Gazan R, Vieux F, Micard V et al (2018) Integrating nutrient bioavailability and co-production links when identifying sustainable diets: How low should we reduce meat consumption? PLOS ONE 13 (2):e0191767. 10.1371/journal.pone.0191767
96. Mertens E, van't Veer P, Hiddink GJ, Steijns JMJM, Kuijsten A (2017) Operationalising the health aspects of sustainable diets: a review. Public Health Nutr 20 (4):739-757. https://doi.org/10.1017/S1368980016002664
97. Shim J-S, Oh K, Kim HC (2014) Dietary assessment methods in epidemiologic studies. Epidemiol Health 36:e2014009-e2014009. https://doi.org/10.4178/epih/e2014009
98. Freedman LS, Guenther PM, Dodd KW, Krebs-Smith SM, Midthune D (2009) The population distribution of ratios of usual intakes of dietary components that are consumed every day can be estimated from repeated 24-hour recalls. J Nutr 140 (1):111-116. https://doi.org/10.3945/jn.109.110254
99. Ortega RM, Pérez-Rodrigo C, López-Sobaler AM (2015) Dietary assessment methods: dietary records. Nutr Hosp 31 Suppl 3:38-45. https://doi.org/10.3305/nh.2015.31.sup3.8749
100. Molag ML, de Vries JHM, Ocké MC, Dagnelie PC, van den Brandt PA, Jansen MCJF et al (2007) Design Characteristics of Food Frequency Questionnaires in Relation to Their Validity. Am J Epidemiol 166 (12):1468-1478. https://doi.org/10.1093/aje/kwm236
101. Block G (1989) Human dietary assessment: Methods and issues. Prev Med 18 (5):653-660. https://doi.org/10.1016/0091-7435(89)90036-4
102. Garcia-Larsen V, Luczynska M, Kowalski ML, Voutilainen H, Ahlström M, Haahtela T et al (2011) Use of a common food frequency questionnaire (FFQ) to assess dietary patterns and their relation to allergy and asthma in Europe: pilot study of the GA2LEN FFQ. Eur J Clin Nutr 65:750. https://doi.org/10.1038/ejcn.2011.15
103. Beukers MH, Dekker LH, de Boer EJ, Perenboom CWM, Meijboom S, Nicolaou M et al (2014) Development of the HELIUS food frequency questionnaires: ethnic-specific questionnaires to assess the diet of a multiethnic population in The Netherlands. Eur J Clin Nutr 69:579. https://doi.org/10.1038/ejcn.2014.180
104. Visser M, Elstgeest LEM, Winkens LHH, Brouwer IA, Nicolaou M (2020) Relative validity of the HELIUS food frequency questionnaire for measuring dietary intake in older adult participants of the Longitudinal Aging Study Amsterdam. Nutrients 12 (7):1998. https://doi.org/10.3390/nu12071998
105. Kaaks R, Ferrari P, Ciampi A, Plummer M, Riboli E (2002) Uses and limitations of statistical accounting for random error correlations, in the validation of dietary questionnaire assessments. Public Health Nutr 5 (6a):969-976. https://doi.org/10.1079/phn2002380
106. Natarajan L, Pu M, Fan J, Levine RA, Patterson RE, Thomson CA et al (2010) Measurement error of dietary self-report in intervention trials. Am J Epidemiol 172 (7):819-827. https://doi.org/10.1093/aje/kwq216
107. Kipnis V, Carroll RJ, Freedman LS, Li L (1999) Implications of a new dietary measurement error model for estimation of relative risk: application to four calibration studies. Am J Epidemiol 150 (6):642-651. https://doi.org/10.1093/oxfordjournals.aje.a010063
108. Mertens E, Kuijsten A, Geleijnse JM, Boshuizen HC, Feskens EFM, Veer Pvt (2019) FFQ versus repeated 24-h recalls for estimating diet-related environmental impact. Nutrition Journal 18
109. French CD, Arsenault JE, Arnold CD, Haile D, Luo H, Dodd KW et al (2020) Within-person variation in nutrient intakes across populations and settings: Implications for the

use of external estimates in modeling usual nutrient intake distributions. Adv Nutr 12 (2):429-451. https://doi.org/10.1093/advances/nmaa114
110. Cucurachi S, Scherer L, Guinée J, Tukker A (2019) Life cycle assessment of food systems. One Earth 1 (3):292-297. https://doi.org/10.1016/j.oneear.2019.10.014
111. Nemecek T, Jungbluth N, i Canals LM, Schenck R (2016) Environmental impacts of food consumption and nutrition: where are we and what is next? Int J LCA 21 (5):607-620. https://doi.org/10.1007/s11367-016-1071-3
112. Hadjikakou M, Ritchie EG, Watermeyer KE, Bryan BA (2019) Improving the assessment of food system sustainability. Lancet Planet Health 3 (2):e62-e63. https://doi.org/10.1016/S2542-5196(18)30244-4
113. Bertoluci G, Masset G, Gomy C, Mottet J, Darmon N (2016) How to build a standardized country-specific environmental food database for nutritional epidemiology studies. PLOS ONE 11 (4):e0150617. https://doi.org/10.1371/journal.pone.0150617
114. Gephart JA, Davis KF, Emery KA, Leach AM, Galloway JN, Pace ML (2016) The environmental cost of subsistence: Optimizing diets to minimize footprints. Sci Total Environ 553:120-127. https://doi.org/10.1016/j.scitotenv.2016.02.050
115. Tyszler M, Kramer G, Blonk H (2016) Just eating healthier is not enough: studying the environmental impact of different diet scenarios for Dutch women (31–50 years old) by linear programming. Int J LCA 21 (5):701-709. https://doi.org/10.1007/s11367-015-0981-9
116. Story M, Kaphingst KM, Robinson-O'Brien R, Glanz K (2008) Creating healthy food and eating environments: Policy and environmental approaches. Annu Rev Public Health 29 (1):253-272. https://doi.org/10.1146/annurev.publhealth.29.020907.090926
117. Michie S, van Stralen MM, West R (2011) The behaviour change wheel: A new method for characterising and designing behaviour change interventions. Implement Sci 6 (1):42. https://doi.org/10.1186/1748-5908-6-42
118. Dekker SC, Kraneveld AD, van Dijk J, Kalfagianni A, Knulst AC, Lelieveldt H et al (2020) Towards healthy planet diets—A transdisciplinary approach to food sustainability challenges. Challenges 11 (2):21. https://doi.org/10.3390/challe11020021
119. Gazan R, Brouzes CMC, Vieux F, Maillot M, Lluch A, Darmon N (2018) Mathematical optimization to explore tomorrow's sustainable diets: A narrative review. Adv Nutr 9 (5):602-616. https://doi.org/10.1093/advances/nmy049
120. Vieux F, Perignon M, Gazan R, Darmon N (2018) Dietary changes needed to improve diet sustainability: are they similar across Europe? Eur J Clin Nutr 72 (7):951-960. https://doi.org/10.1038/s41430-017-0080-z
121. Béné C, Oosterveer P, Lamotte L, Brouwer ID, de Haan S, Prager SD et al (2019) When food systems meet sustainability – Current narratives and implications for actions. World Dev 113:116-130. https://doi.org/10.1016/j.worlddev.2018.08.011
122. Gustafson D, Gutman A, Leet W, Drewnowski A, Fanzo J, Ingram J (2016) Seven food system metrics of sustainable nutrition security. Sustainability 8 (3):196. https://doi.org/10.3390/su8030196
123. Rose D, Heller MC, Roberto CA (2019) Position of the Society for Nutrition Education and Behavior: The importance of including environmental sustainability in dietary guidance. J Nutr Educ Behav 51 (1):3-15.e11. https://doi.org/10.1016/j.jneb.2018.07.006
124. Fanzo J, Bellows AL, Spiker ML, Thorne-Lyman AL, Bloem MW (2020) The importance of food systems and the environment for nutrition. Am J Clin Nutr 113 (1):7-16. https://doi.org/10.1093/ajcn/nqaa313
125. Lartey A, Meerman J, Wijesinha-Bettoni R (2018) Why food system transformation is essential and how nutrition scientists can contribute. Ann Nutr Metab 72 (3):193-201. https://doi.org/10.1159/000487605

126. Clonan A, Holdsworth M (2012) The challenges of eating a healthy and sustainable diet. Am J Clin Nutr 96 (3):459-460. https://doi.org/10.3945/ajcn.112.044487
127. Rockström J, Edenhofer O, Gaertner J, DeClerck F (2020) Planet-proofing the global food system. Nature Food 1 (1):3-5. https://doi.org/10.1038/s43016-019-0010-4
128. Clark MA, Domingo NGG, Colgan K, Thakrar SK, Tilman D, Lynch J et al (2020) Global food system emissions could preclude achieving the 1.5° and 2°C climate change targets. Science 370 (6517):705-708. https://doi.org/10.1126/science.aba7357
129. Tapsell LC, Neale EP, Satija A, Hu FB (2016) Foods, nutrients, and dietary patterns: Interconnections and implications for dietary guidelines. Adv Nutr 7 (3):445-454. https://doi.org/10.3945/an.115.011718
130. Ernstoff AS, Stylianou KS, Goldstein B (2017) Response to: Dietary strategies to reduce environmental impact must be nutritionally complete. J Clean Prod 162:568-570. https://doi.org/10.1016/j.jclepro.2017.05.205
131. Garnett T, Gonzalez FC (2016) Plates, pyramids, planet - developments in national healthy and sustainable dietary guidelines: A state of play assessment. Food and Agriculture Organization of the United Nations and Food Climate Research Network, Rome, Italy.
132. Herforth A, Arimond M, Álvarez-Sánchez C, Coates J, Christianson K, Muehlhoff E (2019) A global review of food-based dietary guidelines. Advances in nutrition (Bethesda, Md) 10 (4):590-605. https://doi.org/10.1093/advances/nmy130
133. Garnett T (2014) Three perspectives on sustainable food security: efficiency, demand restraint, food system transformation. What role for life cycle assessment? J Clean Prod 73:10-18. https://doi.org/10.1016/j.jclepro.2013.07.045
134. Tetens I, Birt CA, Brink E, Bodenbach S, Bugel S, De Henauw S et al (2020) Food-Based Dietary Guidelines – development of a conceptual framework for future Food-Based Dietary Guidelines in Europe: report of a Federation of European Nutrition Societies Task-Force Workshop in Copenhagen, 12–13 March 2018. Br J Nutr 124 (12):1338-1344. https://doi.org/10.1017/S0007114520002469
135. Latka C, Kuiper M, Frank S, Heckelei T, Havlík P, Witzke H-P et al (2021) Paying the price for environmentally sustainable and healthy EU diets. Glob Food Sec 28:100437. https://doi.org/10.1016/j.gfs.2020.100437

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SUMMARY

Introduction

Food systems are at the nexus of human and planetary health. The health and environmental impacts of present-day food production and consumption are relatively well understood and include all forms of malnutrition and noncommunicable diseases, as well as climate change, biodiversity loss and environmental degradation. Dietary choices in particular play a critical role in linking human health, nutrition and the environment. Poor quality diets, which contain low amounts of vegetables, fruit, and whole grains, high amounts of refined carbohydrates, fats, sodium, added sugars, red and processed meat, and excessive calories, pose threats to public health and place a high burden on natural resources. This is further compounded by high amounts of food waste, the majority stemming from households in Europe, which results in unnecessary and avoidable environmental degradation and perpetuated social inequalities. While the evidence for what constitutes a healthy and sustainable diet is increasing, it is clear that there is no one-size-fits-all solution and that we need solutions tailored to different contexts, including nutritional needs and health considerations of specific subpopulations, that deliver high human health benefits and low environmental impacts.

Embedded within two European-wide projects, this thesis explores individual- and diet-level factors related to sustainable nutrition for two subpopulations in Europe, namely overweight adults with subsyndromal depressive symptoms (MooDFOOD project) and older adults (PROMISS project). The overall aim of this thesis is to evaluate the environmental impact of health-oriented dietary guidance and provide insight into how to make such guidance more environmentally sustainable. The two main objectives of this thesis are:

1. To identify individual-level factors that pose as opportunities and challenges to achieving more environmentally sustainable food-related behavior, and
2. To assess the environmental impact of dietary change due to health-oriented dietary guidance.

In order to address these objectives, we applied diverse quantitative methods and used personal, cognitive, behavioral and dietary data collected within the MooDFOOD and PROMISS projects, and linked food consumption data with nutritional and life cycle assessment (LCA) data to assess the environmental sustainability of diets and dietary change. This thesis takes a holistic approach to diets, considering nutrition recommendations, the environmental impact of food consumption, and the adaptability to European cultural contexts, to inform the development of environmentally sustainable dietary guidance to promote health among European subpopulations.

Individual-level factors that pose as opportunities and challenges to achieving more environmentally sustainable food-related behavior

In Chapter 2 of this thesis, we identified socio-demographic predictors of food waste behavior (FWB) in Denmark and Spain. Because self-reported food waste underestimates actual amount of food wasted, we hypothesized a new model for food waste as an aggregate of self-reported food waste and food-related behaviors, including planning routines, shopping routines, practices related to handling leftovers and food beyond its best-before date, and food preparation practices. Using structural equation modeling based on confirmatory factor analysis, we found that age, employment status, sex and household size were associated with FWB, and that the number of socio-demographic predictors of FWB differed by country. Nevertheless, consistent with previous research, our findings show that socio-demographic factors provide modest power in predicting FWB.

In Chapter 3, we ascertained the level of acceptability to consume alternative, more sustainable protein sources among older adults aged 65y+ living in the United Kingdom (UK), the Netherlands, Poland, Spain and Finland. Dairy-based protein was the most accepted protein source, with 75% of the respondents reporting dairy to be acceptable or very acceptable, followed by meat- and seafood-based protein, with approximately 62% reporting (high) acceptability. With regards to alternative, more sustainable protein sources, 58% of the respondents reported to accept plant-based protein, which is promising compared to 20% who reported to accept single-cell protein, 9% to accept insect-based protein and 6% to accept in vitro meat-based protein. Further, we found that valuing health, sensory appeal, and price when making food choices, as well as gender and country of residence were found to influence acceptance, although not consistently across all the protein sources. While fussy eaters were less likely to accept eating alternative, more sustainable protein sources, older adults who were more active in sustainable food consumption (e.g. purchases organic food) and who were highly educated were more likely to accept eating alternative, more sustainable sources.

In Chapter 4, older consumers from the UK, the Netherlands, Poland, Spain and Finland were grouped into segments based on their meat consumption and meat liking to better understand their meat consumption behavior. Three groups of older consumers were identified: heavy meat consumers, medium meat consumers, and light meat consumers. The groups differed significantly in several socio-demographics and background characteristics, appetite, protein intake, attitudes towards meat and plant-based ‘meat’ substitutes, and liking of protein sources other than meat. The light meat consumer segment was accounted by more older adults who were female, living alone, with low appetite and at higher risk of low protein intake compared to the medium and heavy meat consumer segments. Health and sustainability food choice motives were important determinants for being classified as a medium or light meat consumer compared to a heavy meat consumer whereas food fussiness, sensory appeal, and familiarity were important determinants for being classified as a heavy meat consumer compared to a light meat consumer. Light meat consumers had more negative attitudes towards meat and more positive attitudes towards plant-based 'meat' substitutes with regards to health, environmental reasons, taste and animal welfare.

On the one hand, we found that health and sustainability food choices motives, 'green' eating behavior and positive attitudes towards plant-based 'meat' substitutes may serve as facilitators to the acceptability of alternative, more sustainable protein sources and low meat consumption among older adults. On the other hand, placing more importance on sensory appeal and familiarity when making food choices and having positive attitudes towards meat may be barriers to environmentally sustainable food-related behavior among older adults in Europe. Other individual-level factors, including socio-demographic characteristics and food fussiness, showed mixed results in terms of FWB, acceptability of alternative protein sources and meat consumption behavior.

Environmental impact of dietary change due to health-oriented dietary guidance

In Chapter 5, we conducted mathematical optimization techniques to identify dietary changes to increase protein intake to 1.2 g/kg body weight (BW)/d in Dutch older adults. Starting from an average habitual diet of 1354 older adults (56-101y) from the Longitudinal Aging Study Amsterdam cohort, we modelled several diets by applying nutritional, environmental, and acceptability conditions and calculated the differences in intakes between the modelled diets and the average diet to determine what and how much change in food intake is needed. We found that increasing protein intake from the habitual intake of 1.0 g/kg BW/d to 1.2 g/kg BW/d without considering greenhouse gas emissions (GHGE) resulted in an increase in animal protein and a 5-12% increase in GHGE in men and 9-14% increase in women. To achieve a high-protein diet aligned to the Dutch food-based dietary guidelines with a moderate GHGE reduction (i.e. ≤50% reduction), the quantity of fish had to be reduced to one serving per week and meat needed to be reduced to 500 grams per week (i.e. the amount recommended by the national food-based dietary guidelines). However, no change in total meat intake was needed for women (consumption was already within healthy limits). Further, a replacement of beef/lamb and processed meat with poultry and pork was needed, as well as increases in whole grains, nuts, and meat/dairy alternatives and decreases in discretionary food products like sweets for both men and women. GHGE reductions greater than 50% resulted in a shift in the protein animal- to plant protein ratio to one favoring plant protein and to larger changes from the habitual diet, compromising the supposed cultural acceptability of the diet.

In Chapter 6 and Chapter 7, the environmental impact of dietary change in a real-life setting was assessed in the context of two diet interventions. Randomized controlled trials were carried out 1) to examine the effect of food-related behavioral activation therapy applying Mediterranean-style dietary guidelines on the prevention of depression in overweight adults with subsyndromal depressive symptoms (MooDFOOD, n=744) and 2) to examine the effect of dietary advice aiming at increasing protein intake on physical functioning in older adults with lower habitual protein intake (PROMISS, n=120). Both interventions led to a net increase in the environmental impact of the diet.

While dietary changes towards a Mediterranean-style dietary pattern were hypothesized to reduce the environmental impact of the diet, our findings indicated otherwise (Chapter 6). We found that adults who received food-related behavioral activation therapy applying Mediterranean-style dietary guidelines increased intake of vegetables, fruit, fish, pulses/legumes and whole grains and decreased intake of sweets/extras relative to the control group. These changes were found to have no impact on GHGE, land use (LU) and pReCiPe score, but to have a 4% increase in fossil energy use (FEU).

Based on findings from Chapter 5, we hypothesized that dietary advice aiming at increasing protein intake would favor animal-based protein and increase the environmental impact of the diet, which was confirmed in Chapter 7. Dutch older adults who received dietary advice aiming at increasing protein intake largely increased protein intake from animal-based foods and PROMISS protein-enriched food products, and marginally from plant-based foods relative to the control group. These changes were found to increase GHGE by 16%, land use by 13%, terrestrial acidification by 20% and marine eutrophication by 26%.

Conclusion

This thesis shows that dietary changes towards a healthier diet does not necessarily lead to a more environmentally sustainable diet. This stresses the need for explicit incorporation of environmental sustainability considerations into the development of dietary guidance, whether working with groups and individuals with specific health and nutritional needs or in setting national food-based dietary recommendations. This thesis also shows that personal factors (e.g. socio-demographics) and psychographic factors (e.g. attitudes and preferences) influence dietary choice and food waste behavior, but only explain a small fraction of consumer behavior. Results from the trial studies show that dietary change towards healthier diets is possible, but that individual or behavioral factors may encumber change in consumption of certain products like meat.

To have a reduced impact on the environment, studies from this thesis and from literature show that reducing consumption of meat and animal-based protein must be targeted in dietary guidance and interventions. In addition, trade-offs of fish consumption need to be carefully considered, and more efforts are needed to replace high impact foods with lower impact foods and improving possible energy imbalances. Fish consumption needs to be moderated, as the environmental impact as determined by LCAs is low but the biodiversity impact immense. Nevertheless, an increase in fish consumption was mainly responsible for an increase in FEU of the diet among those who received dietary advice aligned with the Mediterranean-style dietary pattern. When it comes to achieving high-protein diets among older adults, we found that an ample amount of meat could remain in the diet but a change in meat type is needed, more specifically fully replacing beef and lamb and partially replacing processed meat with poultry. Meat and dairy substitutes displayed an important role in achieving high-protein diets with low environmental impact in the modelling study while protein-enriched food

products showed to be promising for increasing protein intake with limited environmental impact in older adults in real life.

Future research is needed to assess the environmental impact of dietary advice that considers the environmental impact of foods, and to better understand drivers of food choice to better stimulate populations to consume healthier and more environmentally friendly diets. Nutritionists can play an important role in setting the standard for dietary change, but they need to develop interdisciplinary knowledge to consider the broader food system and how it affects diet, nutrition, and the health of populations and the environment. The diversity in food production and consumption patterns, food cultures, and health and nutritional needs necessitates tailored solutions to improve the health and environmental sustainability of diets. Therefore, it is important to develop dietary guidance and interventions that consider environmental sustainability aspects discussed in this thesis in addition to health and nutritional needs of subpopulations to promote the human health and planetary health.

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LIST OF PUBLICATIONS

Peer-reviewed scientific articles

Grasso AC, Hung Y, Olthof MR, Brouwer IA, Verbeke W (2021) Understanding meat consumption in later life: A segmentation of older consumers in the EU. Food Qual Prefer, 93: 104242.

Grasso AC¸ Olthof MR, van Dooren C, Broekema R, Visser M, Brouwer IA (2021) Protein for a healthy future: How to increase protein intake in an environmentally sustainable way in older adults in the Netherlands. J Nutr, 151(1): 109-119.

Grasso AC, Olthof MR, van Dooren C, Roca M, Gili M, Visser M, Cabout M, Bot M, Pennix BWJH, van Grootheest G, Kohls E, Hegerl U, Owens M, Watkins E, Brouwer IA (2019) Effect of food-related behavioral activation therapy on food intake and the environmental impact of the diet: Results from the MOODFOOD Prevention Trial. Eur J Nutr, 59: 2579-2591.

Grasso AC, Hung Y, Olthof MR, Verbeke W, Brouwer IA (2019) Older consumers' readiness to accept alternative, more sustainable protein sources in the European Union. Nutrients, 11(8): 1904.

Grasso AC, Olthof MR, Boevé AJ, van Dooren C, Lähteenmäki L, Brouwer IA (2019) Socio-demographic predictors of food waste behavior in Denmark and Spain. Sustainability, 11(12): 3244.

Grasso AC & McDermott AY (2018) More foot, less fork: Unraveling the what, why, and how of increasing physical activity in patients. Nutr Today, 53(1): 26-34.

Book chapters

Manjella A, **Grasso AC**, Wasike V (2020) African leafy vegetables go back to school: Farm to school networks embrace biodiversity for food and nutrition in Kenya. In Agrobiodiversity, School Gardens and Healthy Diets. Routledge.

Grasso AC (2016) Ethiopia. In K. Alba (Ed). At the table: Food and family around the world. p 77-84. ABC-CLIO, LLC.

ABOUT THE AUTHOR

Alessandra Grasso was born in Massachusetts (USA) in 1990 and grew up in Virginia. She obtained her Bachelor of Science in Engineering Science (specialization in Nanomedicine) from the University of Virginia in 2012, and her Master of Science in Public Health (concentration in International Health and Human Nutrition) from Johns Hopkins Bloomberg School of Public Health in 2015. During her studies, Alessandra worked as a research assistant for a childhood obesity prevention project in Baltimore (USA), to improve access to and consumption of healthier foods among low-income urban families. Later she had the opportunity to spend three months in Addis Ababa (Ethiopia) for an internship with Jhpiego, where she supported a project promoting nutrition-sensitive agriculture. Her experience in Ethiopia, and interest to understand the causal pathways that link agriculture to nutrition in food insecure populations, brought Alessandra to pursue a research fellowship with the U.S. Borlaug Fellows in Global Food Security program. As part of the program, she partnered with Bioversity International and conducted qualitative research in Busia (Kenya) to explore the role of agricultural biodiversity in promoting healthy diets and strengthening livelihoods. After receiving her master's degree, Alessandra worked for over a year in Addis Ababa (Ethiopia) at a monitoring and evaluation consulting firm involved in projects across the development sector.

Following her interest in research on the link between food, health and the environment, Alessandra started her PhD project in 2017 with the Health Sciences department at the Vrije Universiteit Amsterdam (the Netherlands) on the environmental impact of food and food-related behavior for MooDFOOD and PROMISS (results presented in this thesis). As part of her PhD project, Alessandra was involved in teaching and supervising Bachelor and Master students and co-led the nutrition journal club for the department. In 2019, she was awarded the Amsterdam Public Health, Health Behavior and Chronic Disease Travel Grant to spend three months in with the Agro-food Marketing and Consumer Behavior research group at Ghent University. In 2021, she was selected to participate in the 26th seminar of the European Nutrition Leadership Platform Essential Program. Currently, Alessandra works as a consultant at Blonk Sustainability Tools in Gouda (the Netherlands), where she is working on a variety of projects related to sustainable nutrition and diets.