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Perspectives from Ghana, Ethiopia, and Finland

Esa-Pekka Nykänen

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To all those who, despite the endless stream of setbacks, continue working to preserve life.

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ABSTRACT

Modern food consumption harms both the environment and human health, contributing to diseases like cardiovascular conditions, type 2 diabetes, and cancer. Current food systems also drive climate change and biodiversity loss. Sustainability challenges differ by context: in low-income settings, the priority is economic access to nutritious diets; in high-income settings, reducing the overconsumption of red meat is key due to its high environmental footprint. This thesis examines sustainable diet strategies in Ghana, Ethiopia, and Finland through four key domains of diet sustainability: nutrition and health, economics, society, and environment. In this thesis, Ghana is considered a low-income setting, reflecting its focus on low-income households rather than national income classification.

In low-income settings, sub-studies I and II utilised linear programming to design nutritionally adequate and affordable diets for low-income families in Ghana and Ethiopia. While theoretically achievable, rural Ghanaian households below the extreme poverty line would have to rely on wild foods to meet their nutritional needs, raising concerns about feasibility. In Ethiopia, diets that were more diverse and culturally acceptable were attainable but more costly, highlighting affordability as a major constraint. However, the modelling did not account for nutrient bioavailability, behavioural factors, or the feasibility of long-term adherence.

In high-income Finland, sub-studies III and IV investigated nudging and policy interventions aimed at reducing red meat consumption. The “Dish of the Day” strategy and altering dish sequence had no effect, suggesting the need for stronger or culturally tailored approaches. Meat reduction policy acceptance was driven by perceived fairness, followed by environmental risk perception and political trust.

In conclusion, transitioning to sustainable diets requires context-specific strategies that take into consideration nutrition, economic feasibility, cultural acceptability and environmental impacts. Cultural and structural differences shape the effectiveness of interventions, which highlights the need for localised evaluation. Future research should include larger and more diverse samples and investigate strategies to enhance both the efficacy and public acceptance of sustainable diet policies.

KEYWORDS: Sustainable diet; meat reduction policy; cultural acceptability; affordability; biodiversity loss; nutrition

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TIIVISTELMÄ

Nykyiset ruokailutottumukset kuormittavat sekä ympäristöä että terveyttä, nostaen riskiä sairastua muun muassa sydän- ja verisuonitauteihin, tyypin 2 diabetekseen ja syöpään. Ruokajärjestelmät ovat myös merkittäviä ilmastonmuutoksen ja luontokadon ajureita. Ruoan kestävyyshaasteet ovat kontekstisidonnaisia: matalan tulotason maissa keskeistä on ravitsemuksellisesti riittävien ruokavalioiden saavutettavuus, kun taas korkean tulotason maissa painopiste on punaisen lihan liikakulutuksen vähentämisessä. Tämä väitöskirja tarkastelee strategioita kestävien ruokavalioiden edistämiseksi Ghanassa, Etiopiassa ja Suomessa, keskittyen neljään kestävyyden ulottuvuuteen: terveyteen, talouteen, yhteiskuntaan ja ympäristöön. Ghanaa käsitellään tässä työssä matalan tulotason kontekstina, sillä tutkimus kohdistuu pienituloisiin kotitalouksiin.

Osatutkimuksissa I ja II suunniteltiin lineaarisen optimoinnin avulla ravitsemuksellisesti riittäviä ja edullisia ruokavalioita vähävaraisille perheille Ghanassa ja Etiopiassa. Ghanan maaseudulla äärimmäisessä köyhyydessä elävien olisi turvauduttava villiruokiin, mikä herättää kysymyksiä kyseisten ruokavalioiden toteuttamiskelpoisuudesta. Etiopiassa monipuolisemmat ruokavaliot olivat teoreettisesti mahdollisia, mutta kalliimpia. Mallinnustutkimuksissa ei huomioitu ravintoaineiden imeytymistä, käyttäytymistekijöitä tai arvioitu ruokavalioiden pitkäaikaisen noudattamisen toteutettavuutta.

Suomessa osatutkimukset III ja IV tarkastelivat tuuppaamista ja politiikkatoimia punaisen lihan kulutuksen vähentämiseksi. "Päivän annos" -strategia ja tarjoilujärjestyksen muuttaminen eivät vaikuttaneet kulutukseen. Lihankulutuksen vähentämiseen tähtäävien poliittisten ohjauskeinojen hyväksyttävyyttä selittivät vahvimmin kokemus niiden reiluudesta, käsitys ympäristöriskeistä, ja luottamus poliittisiin päätöksentekijöihin.

Kestäviin ruokavalioihin siirtyminen edellyttää kontekstisidonnaisia ratkaisuja, jotka huomioivat ravitsemuksen, taloudellisen saavutettavuuden, kulttuurisen hyväksyttävyyden sekä ympäristövaikutukset. Tulevien tutkimusten tulisi pyrkiä laajempiin otoskokoihin sekä kehittää keinoja parantaa toimenpiteiden vaikuttavuutta ja hyväksyttävyyttä.

AVAINSANAT: Kestävä ruokavalio; lihan vähentäminen; kulttuurinen hyväksyttävyys; kohtuuhintaisuus; luontokato; ravitsemus.

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Abbreviations

AMDR	Acceptable Macronutrient Distribution Range
DoD	Dish of the Day
EER	Estimated Energy Requirement
ETB	Ethiopian Birr
FAO	Food and Agriculture Organization of the United Nations
GHS	Ghanaian Cedi
LP	Linear Programming
RNI	Reference Nutrient Intake
SEM	Structural Equation Modelling
TRD	Total Relative Deviation
USDA	United States Department of Agriculture
WHO	World Health Organization

List of Original Publications

This dissertation is based on the following original publications, which are referred to in the text by their Roman numerals:

I Nykänen, E-P., Dunning, H., Aryeetey, R.N.O., Robertson, A., Parlesak, A. Nutritionally Optimized, Culturally Acceptable, Cost-Minimized Diets for Low Income Ghanaian Families Using Linear Programming. *Nutrients,* 2018; *10*(4), 461. https://doi.org/10.3390/nu10040461

II Gurmu, A.B, Nykänen, E-P., Alemayehu, F.R., Robertson, A., Parlesak, A. Cost-Minimized Nutritionally Adequate Food Baskets as Basis for Culturally Adapted Dietary Guidelines for Ethiopians. *Nutrients*, 2019; *11*(9), 2159. https://doi.org/10.3390/nu11092159

III Nykänen, E-P., Hoppu, U., Löyttyniemi, E., Sandell, M. Nudging Finnish Adults into Replacing Red Meat with Plant-Based Protein via Presenting Foods as Dish of the Day and Altering the Dish Sequence. *Nutrients*, 2022; *14*(19), 3973. https://doi.org/10.3390/nu14193973

IV Nykänen, E-P., Räikkönen, J., Honkanen, A., Ahvenharju, S., Lalot, F., Tuomasjukka, S., Lagström, H. Mainstreaming Sustainable Consumption Through Regulation: Public Acceptance of New Meat Reduction Policies. *Sustainable Production and Consumption*, 2025. https://doi.org/10.1016/j.spc.2025.10.020 (In press).

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1 Introduction

The latest climate reports indicate an impending, unprecedented climate disaster (Ripple et al., 2024). Human dietary habits play a significant role in the climate crisis (Feigin et al., 2025) as global food systems produce approximately 34% of all man-made greenhouse gas emissions (Crippa et al., 2021). Additionally, global food systems are major drivers of biodiversity loss (Benton et al., 2021). The World Economic Forum (2025) has identified environmental risks, such as extreme weather events and biodiversity loss, as the most pressing global threats over the next 10-year period. Radical and swift changes to global food consumption are required to feed the estimated world population of 10 billion by 2050 (Willett et al., 2019). In low-income settings, improving access to nutritious diets is critical (Choudhury et al., 2025; Food and Agriculture Organization of the United Nations (FAO), 2021), while in high-income settings, reducing the overconsumption of red meat is a key priority (Smith & Myers, 2022).

Current food consumption patterns also pose substantial risks to human health (Afshin et al., 2019). Globally, unhealthy diets are considered one of the top health risks (World Health Organization (WHO), 2020), significantly contributing to the development of non-communicable diseases like cardiovascular disease, type 2 diabetes, and cancer (Afshin et al., 2019).

The global shift toward sustainable diets requires a drastic reduction in the intake of red meat and added sugar, and an increase in the intake of plant-based foods such as fruits, vegetables, and legumes (Willett et al., 2019). Transitioning to sustainable diets has been associated with multiple co-benefits such as improvements in greenhouse gas emissions, land use, and public health (Laine et al., 2021). Diets that are fully nutritious and low in greenhouse gas emissions have also been associated with an increase in life expectancy compared to diets that fulfil only the nutrient requirements (Cobiac & Scarborough, 2019).

However, there are large regional differences in changes that are required due to variations in current dietary patterns (Willett et al., 2019). Disparities in factors such as poverty (World Bank, 2025a), literacy and educational level (World Bank, 2025b, 2025c), and food accessibility (FAO et al., 2024) are pronounced between low- and high-income countries. This study focuses on Ghana and Ethiopia as examples of low-income settings, and Finland as a high-income setting. Although Ghana is classified as a lower-middle-income country (World Bank, 2024), it is included in the low-income category in this thesis, as the focus in both Ghana and Ethiopia is on low-income households.

A double burden of malnutrition, which is characterised by the coexistence of undernutrition and overweight (WHO, 2025a), is prevalent in both Ghana and Ethiopia (NCD RisC Collaboration, 2024). Additionally, a large share of the total consumer expenditure is spent on food in both countries (USDA Economic Research Service, 2023). This highlights the need for diets that emphasise affordability, accessibility, and nutritional adequacy in low-income settings.

In contrast, high-income countries like Finland face different challenges. A relatively small proportion of household expenditure is allocated to food (USDA Economic Research Service, 2023), and access to healthy food is generally not a major concern (FAO et al., 2024). Transitioning to sustainable diets in such settings has even been projected to reduce overall dietary costs (Springmann et al., 2021).

In Finland, undernutrition is relatively rare. However, more than half of the adult population is overweight or obese (NCD RisC Collaboration, 2024), and the majority consume more red or processed meat than recommended (Valsta et al., 2018). Given that red meat has the highest environmental footprint of all food products (Crenna et al., 2019), reducing its consumption should be a key focus of dietary sustainability efforts in Finland.

Despite growing awareness, there is a significant gap in research on effective strategies to promote sustainable diets across diverse socio-economic contexts. This thesis seeks to address that gap by generating new insights into context-specific strategies that support the adoption of diets beneficial to both human health and the environment.

The term strategy is commonly defined as “a careful plan or method for achieving a particular goal usually over a long period” (Britannica Dictionary, 2025). In this thesis, sustainable diet strategies refer to evidence-informed actions, interventions, and policy tools that aim to promote the adoption of diets that are nutritionally adequate, economically viable, culturally acceptable and environmentally responsible. This operational definition is based on the multidimensional framework for sustainable diets described by the FAO (2012a) and Drewnowski et al. (2020). This definition reflects the strategies, such as e.g. behavioural nudges, dietary modelling, public policy instruments, and communication efforts, which have been discussed in recent literature. The concept of sustainable diets is defined in detail in Chapter 2.1, as it will serve as the foundation for this thesis work.

2 Review of the Literature

2.1 Sustainable Diets

Sustainable diets consist of several attributes. A commonly used consensus definition for sustainable diets is that they are “those diets with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations” and are “protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources.” (FAO, 2012a). As illustrated in Figure 1, these multiple attributes are generally categorised under the following four main dimensions: ecological, human health, economic, as well as societal domains (Drewnowski et al., 2020).

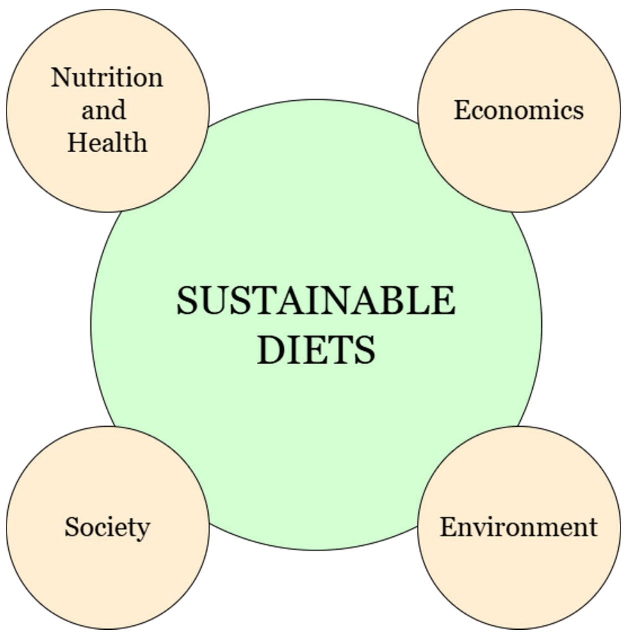

Figure 1. The four domains of sustainable diets. The writer’s own drawing. Modified from FAO, 2012a.

One prominent framework for sustainable diets is the 'planetary health diets' (Willett et al., 2019). These diets are designed to promote human health while staying within the planet's ecological limits. They aim to provide fully nutritious diets for a projected global population of 10 billion by 2050, taking into account rapid population growth and environmental constraints. Planetary health diets comprise mostly plant-based foods and only a small amount of seafood and poultry, with little to no red or processed meat, or e.g. added sugar. On a global level, transitioning to these diets would require significantly reducing the overconsumption of animal-based products while increasing the intake of plant-based proteins, fruits, and vegetables. Following a planetary diet has been associated with a range of health benefits, including a lower risk of obesity, type 2 diabetes, cardiovascular disease, and metabolic syndrome (Muszalska et al., 2025).

However, the extent and nature of dietary changes needed vary significantly across regions. These differences are shaped by existing dietary habits, cultural norms, economic conditions, and environmental factors (Willett et al., 2019). For example, non-industrial livestock systems are essential for nutrition and survival in areas where crop production is not possible (Abu Hatab et al., 2019).

Nevertheless, cutting down excessive red meat consumption remains a key element of sustainable eating patterns. There is a broad scientific consensus that red meat has the highest environmental impact of any single food item (Crenna et al., 2019). Between 1990 and 2018, the global consumption of unprocessed red meat increased by 88.1% (Miller et al., 2022). Currently, over one-third of the global land area is used for food production, and the share is increasing (FAO, 2023). This change in land use is mainly driven by the production of animal-based foods and is strongly linked with biodiversity loss (Benton et al., 2021). The production of meat necessitates converting vast areas of land to grow feed for livestock (Machovina et al., 2015), resulting in the transformation of natural habitats into agricultural land (Cabernard et al., 2024).

In terms of health impacts, excessive consumption of red meat has been linked with an increased risk of coronary heart disease, colorectal cancer, and type 2 diabetes (Blomhoff et al., 2023). Hence, moderating excessive red meat consumption would provide considerable benefits for both the environment and public health.

Besides these benefits, shifting to sustainable diets would also benefit the economy and social well-being. According to Johnston et al. (2014), the local economies would see increased employment and trade opportunities. Social benefits would include reduced health gaps and increased income in both developed and developing countries (Johnston et al., 2014).

Despite bringing highly valuable knowledge about diet sustainability, planetary health diets have also received criticism due to their price (Hirvonen et al., 2020). Hirvonen and colleagues (2020) compared the price of the planetary health diets across 159 countries and estimated that the diet is too expensive for at least 1.58 billion people. Their findings suggest that although obtaining such a diet is reasonably priced for most countries, a large number of people need either higher income, lower food prices, nutritional guidance, or their combination (Hirvonen et al., 2020).

2.2 Contextual Differences: Low- and High-Income Settings

Understanding contextual differences is crucial in developing effective sustainable diet strategies globally. Ghana, Ethiopia, and Finland were selected to represent diverse socioeconomic and cultural contexts in the study of sustainable diet strategies. Poverty, undernutrition, and limited dietary diversity are prevalent in Ghana and Ethiopia. Finland, as a high-income country, provides a contrasting context where overconsumption and environmental sustainability are key concerns. Together, these countries allow for a comparative analysis of how sustainable diet strategies must be tailored to different structural and cultural conditions.

Although Ghana is classified as a lower-middle-income country by the World Bank (2024), this thesis adopts a simplified classification that broadly distinguishes between low- and high-income settings. This decision is based on the observation that approximately one-fourth of the Ghanaian population lives below the international poverty line of $2.15 per day, and nearly 40% of total consumer expenditure is spent on food (World Bank, 2025a; USDA Economic Research Service, 2023). These indicators suggest that many of the conditions commonly observed in low-income settings—such as widespread poverty and high vulnerability to food insecurity—are also present in Ghana, particularly among socioeconomically disadvantaged populations.

Consequently, the following chapters will discuss the challenges present in both low- and high-income settings using Ghana, Ethiopia, and Finland as case examples.

2.2.1 Dietary Habits and Diet-Related Diseases

Dietary habits and diet-related disease are shaped by the surrounding food systems, which influence which foods are available, their prices, and how culturally acceptable they are (Fanzo et al., 2020; WHO, 2018).

Life expectancy and the prevalence of diet-related diseases differ significantly between low and high-income settings. Table 1 highlights key health indicators in Ghana, Ethiopia, and Finland. For example, in 2022, the life expectancy was 64 years in Ghana, 66 years in Ethiopia, and 81 years in Finland (World Bank, 2025d). The Finnish adult population is also far more likely to be obese than Ghanaian or

Ethiopian adults (NCD RisC Collaboration, 2024). However, obesity and adult overweight are far less common in the poorest case country, Ethiopia, whereas adult underweight is significantly more prevalent in Ethiopia.

Table 1. Key health indicators in Ghana, Ethiopia, and Finland.

INDICATOR	GHANA	ETHIOPIA	FINLAND	SOURCES
LIFE EXPECTANCY IN YEARS	63.9	65.6	81.2	World Bank, 2025d
ADULT OBESITY (BMI >30)	Females 22.0% Males: 3.9% (2022)	Females 4.7%* Males: 1.1%* (2022)	Females 25.4% Males: 23.6% (2024)	Ghana Statistical Survey, 2022; NCD RisC Collaboration, 2024*; Finnish Institute for Health and Welfare, 2024
ADULT OVERWEIGHT (BMI 25-30)	Females 28.2% Males: 16.8% (2022)	Females 10.7%* Males: 5.9%* (2022)	Females 29.1%* Males 39.9 %* (2022)	Ghana Statistical Survey, 2022; NCD RisC Collaboration, 2024*
ADULT UNDERWEIGHT (BMI <18.5)	Females 6.0%* Males: 7.3%* (2022)	Females 21.8%* Males: 26.0%* (2022)	Females 1.8 %* Males: 0.9 %* (2022)	NCD RisC Collaboration, 2024*
STUNTING RATE IN CHILDREN AGED < 5 YEARS	17.4% (2022)	36.8% (2019)	3.0%** (2021)	Ghana Statistical Survey, 2022; Ethiopian Public Health Institute (EPHI), 2019; WHO, 2024a
TYPE 2 DIABETES PREVALENCE (>20 YEARS)	6.1% (2021)	3.3% (2021)	11.9% (2017)	Institute for Health Metrics and Evaluation (IHME), 2021.
PREVALENCE OF ANAEMIA IN NON-PREGNANT WOMEN (15-49 YEARS)	41.1% (2022)	23.6% (2016)	13.6% (2023)	Ghana Statistical Survey, 2022; Ethiopian Central Statistical Agency & ICF, 2016; WHO, 2024b

BMI = body mass index.
* Values are based on modelling, and therefore they are not directly comparable to other sources.
**No country-specific data for Finland regarding the prevalence of stunting in children under five are available from the WHO, Global Nutrition Report, or UNICEF. Therefore, the estimate for Northern Europe is used.

Similarly, the prevalence of stunting (low height for age) in children under five years was by far the highest in Ethiopia (36.8%); in Ghana, the prevalence declined to 17.4% in 2022, whereas in Northern Europe, the prevalence is only 3.0% (WHO, 2024a). In February 2025, the WHO, Global Nutrition Report, UNICEF or World Bank had no country-specific information for Finland regarding the prevalence of stunting in children under five years. Additionally, Ghanaian women aged 15-49 are over threefold more likely and Ethiopian women are almost twice as likely to have anaemia compared to Finnish women of the same age (WHO, 2024b).

The co-existence of both overnutrition and undernutrition indicates a double burden of malnutrition (WHO, 2016), specifically in Ghana and Ethiopia. These differences in the prevalence of diet-related diseases indicate that a specific focus must be placed on ensuring the nutritional adequacy of diets in Ghana and Ethiopia.

The typical diets in Ghana, Ethiopia, and Finland differ significantly. Diets in urban Ghana primarily consist of roots, tubers, plantain, and vegetables, with only a small share of animal-based products (Galbete et al., 2017). In rural areas, roots, tubers, and fermented corn products make up a large share of daily diets, whereas in urban areas, the share of red and processed meat is higher (Galbete et al., 2017). Food-related taboos and beliefs are reported in various parts of Ghana, affecting both animal and plant-based foods, including fruits like pineapple and banana (Colecraft et al., 2022).

According to the latest national dietary intake study in Ethiopia, diets are low in diversity: over half of the total diet consists of cereals and grains, and the consumption of meat and eggs is rarely reported (Kebede & Modes, 2013). Furthermore, conflicts witnessed in Ethiopia have been associated with a further decrease in dietary diversity (Muriuki et al., 2023). Religious traditions also strongly influence food consumption, with almost half of the population being Orthodox Christians who practice fasting (Ethiopian Central Statistical Agency & ICF, 2016), prohibiting the consumption of animal-sourced foods for over half of the days each year (Sewenet & Schwarcz, 2021). Fasting also influences food choices among the Muslim population, especially during Ramadan (Sewenet and Schwarcz, 2021).

In contrast to Ethiopia, Finland faces a different set of challenges for sustainable diets, shaped by cultural traditions and high meat consumption. Meat plays a central role in Finnish food traditions (Mäkelä & Rautavirta, 2018), which poses challenges for reducing its consumption. In Finland, despite high levels of education (World Population Review, 2024), income (World Bank, 2025e), health literacy (Okan et al., 2019), and growing environmental awareness (Finnish Ministry of Environment, 2025), dietary patterns remain suboptimal. According to the most recent national dietary intake study, FinDiet 2017, the consumption of fruits and vegetables was found to be below recommended levels, while the intake of animal-based products was reported to be high (Valsta et al., 2018).

Red meat is associated with the highest environmental impact of any single food item (Crenna et al., 2019). However, its consumption differs significantly by region. According to FAO (2024), the national meat supply was 71.25 kg in Finland, 17.91 kg in Ghana, and only 6.47 kg in Ethiopia per person per year. According to FinDiet 2017, Finnish men consumed an average of 760g of red and processed meat per week, far exceeding the recommended limit of 350g; overall, 93% of men and 60% of women surpassed this threshold (Valsta et al., 2018; Erkkola et al., 2024). Considering the detrimental effects of excessive meat consumption on both human health and the environment, sustainable diet strategies in Finland must focus specifically on meat reduction.

2.2.2 Price and Accessibility

Price and accessibility of healthy diets have been considered key elements to a successful and acceptable diet change strategy in socio-economically challenged populations (Gillies et al., 2021). In 2022, over 2.8 billion people lacked economic access to nutritious, safe, and sufficient food (FAO et al., 2024). The U.S.A. leaving the WHO (United States White House, 2025) and abolishing the United States Agency for International Development (BBC, 2025) may aggravate this issue, especially in low-income settings. In Ethiopia, for example, ongoing conflicts have been linked to reduced access to healthy diets (Muriuki et al., 2023).

The price of the diet is a far larger concern in low-income settings compared to high-income settings: In 2022, 71.5% of people residing in low-income countries were unable to afford a healthy diet, compared to only 6.3% in high-income countries (FAO et al., 2024).

Table 2 presents differences in poverty rates and consumer food expenses in the three case countries. In Ghana and Ethiopia, almost 40% of total consumer expenditures are spent on food compared to only 11.9% in Finland (Table 2, USDA Economic Research Service, 2023).

According to a large modelling study from 150 countries by Springmann et al. (2021), transitioning to healthy and sustainable diets would reduce the dietary costs by 22-34% in upper-middle to high-income countries, whereas in lower-middle and low-income countries, the costs would increase by 18-29% (Springmann et al., 2021). These findings indicate that the population residing in high-income settings is far more likely to be capable of eating in a health-promoting and environmentally sustainable manner.

Table 2. Population living in poverty and the share of total consumer expenditure spent on food in Ghana, Ethiopia, and Finland.

INDICATOR	GHANA	ETHIOPIA	FINLAND	SOURCE
POVERTY RATE AT $2.15 A DAY	25.21% (2016)	26.98% (2015)	0.02% (2021)	World Bank, 2025a
POVERTY RATE AT THE NATIONAL POVERTY LINES	23.40% (2016)	23.50% (2015)	12.70% (2021)	World Bank, 2025a
% OF TOTAL CONSUMER EXPENDITURE SPENT ON FOOD	38.20% (2022)	39.70% (2022)	11.90% (2022)	USDA Economic Research Service, 2023

2.2.3 Lack of Knowledge

Lack of knowledge about food sustainability has been widely acknowledged as one of the main barriers to adopting more sustainable eating patterns (Dupuits et al., 2024; Şahin Bayram and Kızıltan, 2024). In low-income settings, the strategic focus must be placed on producing and disseminating basic dietary knowledge, as knowledge is a prerequisite for action and an enabling element for any dietary change.

Low-income populations have been observed to have lower levels of food literacy (Araque-Padilla and Montero-Simo, 2025; Silva et al., 2023), which is a term referring to the understanding, abilities, and attitudes required to choose foods that support good health (Silva et al., 2023).

Most high-income countries have national food-based dietary guidelines (FAO, 2025), whereas many low-income countries lack basic knowledge about healthy eating; for example, only 11 African countries have established national food-based dietary guidelines (FAO, 2025). Furthermore, only 27% of food-based dietary guidelines in the low- or lower-middle-income countries include the mention of environmental sustainability compared to 47% of the upper-middle-income and high-income countries (James-Martin et al., 2022).

In addition to having poor access to information about sustainable diets, people residing in low-income settings are also more likely to have lower literacy and educational levels than those living in high-income countries (World Bank, 2025b, 2025c). Hence, the utilisation of the information is likely to be lower as well. Moreover, individuals in these contexts may need to prioritise acute food safety concerns due to their lived experiences with issues such as contaminated water or unhygienic food preparation environments (Isanovic et al., 2022).

Despite the presence of comprehensive dietary guidelines and a high level of education (Organisation for Economic Co-operation and Development (OECD), 2025)—for example, in Finland—no significant reductions in meat consumption have been observed (Valsta et al., 2018; Erkkola et al., 2024). The limited impact of knowledge in such contexts may be explained by psychological mechanisms like cognitive dissonance, which refers to the discomfort experienced when new information conflicts with existing beliefs or habits (Benningstad and Kunst, 2020). Additionally, the strong cultural significance of meat in Western diets (Chiles and Fitzgerald, 2018) likely contributes to resistance toward dietary change. These observations suggest that while knowledge is a necessary condition for adopting sustainable diets, it is not sufficient on its own.

Given these fundamental barriers, generating basic knowledge about nutritionally adequate diets that are both affordable and accessible should remain a priority—particularly in low-income settings—where it serves as a critical first step toward enabling the theoretical possibility of adopting sustainable diets.

2.3 Sustainable Diet Strategies in Low-Income Settings

In low-income settings, sustainable diet strategies must address multiple, overlapping challenges: undernutrition, food insecurity, limited dietary diversity, and limited economic resources. As defined in the introduction, this thesis uses the term *sustainable diet strategies* to refer to evidence-informed actions, interventions, and policy tools that aim to promote diets that are nutritionally adequate, environmentally responsible, economically viable, and culturally acceptable. In this chapter, the focus is on strategies relevant to low-income contexts, where affordability, accessibility and low levels of education act as major barriers to sustainable diets.

The strategies reviewed in this chapter include food security interventions, food waste reduction, and modelling approaches (particularly via linear programming (LP)) to develop food-based dietary guidelines. Dietary modelling is included as it is used as an analytical tool to generate knowledge about local diets, which consider multiple aspects of sustainable diets. This knowledge serves as a basis for developing nutritionally adequate and culturally adapted food-based dietary guidelines that are affordable for low-income populations. This knowledge can be considered a prerequisite for enabling the theoretical possibility of making sustainable dietary choices.

2.3.1 Improving Food Security and Accessibility to Food

Food security can be defined as consistent access to safe and nutritious foods (Pinstrup-Andersen, 2009). It comprises four pillars: access, availability, utilisation, and stability (Aborisade and Bach, 2014). Access involves having sufficient resources to obtain the necessary foods to build a healthy diet. Availability refers to having an adequate quantity of food that is either locally produced or imported. Utilisation relates to the skills and capacity to prepare food hygienically and safely. Stability refers to whether access to and availability of sufficient food are consistent and not impacted by sudden events such as economic fluctuation (Aborisade and Bach, 2014). Meeting the aforementioned food security criteria is crucial in adopting a sustainable diet (Johnston et al., 2014).

A Cochrane systematic review by Durao et al. (2020) investigated the impact of community-based interventions designed to enhance access to nutritious food in low- and middle-income countries (LMICs). The review included 59 studies, primarily from Africa and Latin America. Unconditional cash transfers were found to enhance food security, while the evidence regarding the effect of village savings and loans was of very low quality. Interventions that helped generate income did not seem to affect food security. The evidence was inconclusive regarding whether conditional cash transfers or interventions that lowered food prices, such as food vouchers and food and nutrition subsidies, improved food security (Durao et al., 2020).

Another systematic review by Doustmohammadian et al. (2022) investigated the effects of community-based participatory interventions and found that interventions focusing on providing education and support in agricultural production improved food security, specifically regarding availability, access, and utilisation.

2.3.2 Decreasing Food Waste

Approximately one-third of food produced goes to waste along the food supply chain, either during retail or by consumers (FAO, 2011). Reducing food waste across the food supply chain significantly alleviates environmental pressure (FAO, 2019). It is also linked to food prices as waste and inadequate storage methods reduce the overall food supply, which may lead to increased prices (FAO, 2011). Additionally, food waste causes economic losses for food producers, who may then have less income to invest in improving their production methods and storage facilities, especially in rural households (World Bank, 2020).

A systematic literature review by Rolker et al. (2022) examined food waste interventions, specifically in low- and middle-income countries. The interventions were classified as preventive, mitigative, or a combination of both. The review highlighted improving storage facilities and optimizing transportation logistics as effective strategies to minimize waste.

Pedrotti et al. (2023) investigated urban food waste in two distinct contexts: household-level waste in Kibera (Nairobi) and supply chain-level waste in Dhaka (Bangladesh). Their analysis focused on food waste occurring at the consumer and retail stages, particularly among mobile vendors and low-income households. Notably, the study did not address food losses during production or early post-harvest stages. To guide effective interventions, the authors propose a three-step approach: (1) analyse the food chain to identify likely waste hotspots; (2) identify key stakeholders and determine the appropriate level and type of intervention, taking into account factors such as affordability, availability, acceptability, and adaptability; and (3) develop and disseminate guidelines for implementing and monitoring the proposed changes (Pedrotti et al., 2023).

While improving food production methods and reducing food waste are also needed to reduce the environmental pressure caused by the current food system (Springmann et al., 2018), this thesis focuses only on dietary change.

2.3.3 Developing Food-Based Dietary Guidelines

To clarify the terminology used in this section, nutrient requirements define what nutrients are needed and in what amounts (WHO, 2025b), whereas food-based dietary guidelines describe how these requirements can be met through culturally appropriate food choices using locally available foods (FAO, 2025).

LP is a well-established tool for developing diets that are nutritious, affordable, and accessible to low-income populations using locally available food items (Parlesak, 2016). Since the 1950s, it has been used to optimize nutrient intake in human diets (Smith, 1959). This method has successfully addressed various dietary challenges, such as enhancing the nutritional value of food assistance programs (Rambeloson et al., 2008) and developing food-based dietary guidelines (Ferguson et al., 2004). LP has been applied to ensure nutritional adequacy as the algorithm only provides solutions that meet specified criteria (Smith, 1959), including the upper and lower limits for both macro and micronutrients (Parlesak, 2016). Another benefit of the LP methodology is that it also allows for the inclusion of dimensions such as the greenhouse gas emissions of individual foods (see e.g., Eustachio Colombo et al., 2024) and water footprints (Tompa et al., 2022).

LP has proven particularly useful in modelling food patterns for low-income populations. While it has frequently been applied in high-income countries to design diets for low-income groups (e.g., Faksová et al., 2019; Lauk et al., 2020; Parlesak, 2016), its use in low- and lower-middle-income countries has been more limited. For example, Parlesak et al. (2014) aimed to identify the most cost-effective locally available food baskets that would fulfil all nutrient requirements for a Mozambican six-member household. In the baseline scenario, only the top income quintile could afford a fully nutritious diet. However, when nutrient-dense foods such as beef liver and heart, dried fish, and fresh moringa leaves were included, the cost of the diet was significantly reduced, enabling the top three income quintiles to afford diets that met all nutrient requirements.

More recent applications of LP in low-income settings include Donkor et al. (2025), who used LP to design low-cost, nutritionally adequate, and culturally appropriate food baskets for Ghanaian adolescents. To enhance cultural acceptability, the optimisation included constraints for staple ingredients commonly used in Ghanaian cuisine, such as tomatoes, onions, and pepper. Although the authors did not explicitly aim to formulate national food-based dietary guidelines, their outputs are consistent with the basic foundations of food-based dietary guideline development.

In contrast, Paidipati et al. (2021) applied LP and goal programming to identify combinations of raw food items that meet energy and nutrient requirements in India. However, their model was based on a limited input database of only 20 raw food items and 14 nutrients, which constrained the diversity and feasibility of the resulting diets. As a result, the applicability of the findings to the development of food-based dietary guidelines is limited.

These findings, together with the overall scarcity of published LP-based diet modelling studies in low-income settings, underscore the need for more comprehensive and context-sensitive approaches to developing culturally appropriate and implementable food-based dietary guidelines in low-income settings.

2.4 Sustainable Diet Strategies in High-Income Settings

While sustainable diet strategies in low-income settings often focus on improving nutritional adequacy, affordability, and access to food, the challenges in high-income contexts are noticeably different. Daily meat consumption is far higher in the high- compared to low-income contexts (FAO, 2024c). This excessive intake of red meat has wide-ranging negative impacts on both public health and the environment (Willett et al., 2019; Afshin et al., 2019; Crenna et al., 2019).

Given the distinct challenges in high- and low-income settings, this section focuses specifically on strategies to reduce excessive meat consumption as it has been identified as a key lever for improving both public health and environmental outcomes in high-income settings.

2.4.1 Labelling and Information Provision Strategies

Labelling systems and information provision strategies have been widely studied as potential tools to influence meat consumption, especially in high-income settings. A recent systematic literature review found that most experimental studies aiming to change meat-eating behaviour have focused on information provision about, e.g., the health effects of meat consumption (Harguess et al. 2020). These studies generally reported positive effects on participants' willingness or intention to reduce meat intake. However, only one of the 27 included experiments measured actual meat consumption and seven relied on self-reported data.

Taillie et al. (2021) tested the effect of three text-only front-of-package warning labels in a US online experiment. Health or environmental labels, whether alone or in combination, had no statistically significant effects on meat dish selection. However, those participants who were subjected to health warnings had a higher likelihood of perceiving red meat as harmful to health.

Recent experimental studies have investigated the effect of pictorial warning labels. In an online experiment with UK adults, Hughes et al. (2023) investigated the effect of health, climate, and pandemic-themed pictorial warning labels in hypothetical meat meal selection. The authors found that all three labels influenced meal choices, and the reduction in the shares of meat-containing meals ranged from -7.4% to -10%. Similarly, Hughes et al. (2024) tested the effect of three different traffic light labels indicating the climate impact in an online environment. Red-only labels were associated with a 9.2% reduction in the share of chosen meat-containing meals. Red–orange–green labels reduced the share by 9.8%, whereas green-only labels had no effect.

In comparison, field experiments have observed smaller effects. Vasiljevic et al. (2024) tested the impact of warning labels about meat's environmental and health effects on meat consumption in two college cafeterias. Labels with and without images were tested. Even though the labels with images were perceived as more informative and influential, no statistically significant reduction in meat consumption was observed.

Brunner et al. (2018) investigated the effect of introducing traffic-light carbon labels in a university restaurant. The purchases of green-labelled, low-emission meat dishes rose by 11.5%, whereas the sales of red-labelled, high-emission dishes declined by 4.8%. In total, the intervention reduced the total emissions by 3.6%. Slapø and Karevold (2019) tested the effect of traffic-light and single-colour eco-labels in a Norwegian university cafeteria. The sales of meat dishes reduced by 9% during the first 20 days of the intervention with traffic-light labels, but during the second phase, the effect was not sustained. Single-colour labels had no impact.

In total, these findings suggest that while labelling and information provision strategies may influence perceptions and intentions, their direct impact on meat consumption may be limited.

2.4.2 Behavioural Nudging and Default Options

The aforementioned interventions with traffic light systems or health messages can be considered as *information nudging* (Calabro et al., 2024). Nudging is a tool that has effectively promoted sustainable and healthy food choices in certain contexts (Vandenbroele et al., 2020). Nudging is based on the idea that decision-making is influenced by cognitive factors such as framing, anchoring, and status quo bias (Thaler & Sunstein, 2008). The so-called “choice architecture”, which refers to modifying the environment in which the decisions are made instead of limiting the options available, may therefore influence the ultimate decision (Vandenbroele et al., 2020).

According to a systematic review, human dietary behaviour can be influenced by nudging approaches that employ social norms and modelling (Wright and Bragge 2018). One method to steer consumer food choices employing social norms involves altering the default options in food service environments (e.g. Campbell-Arvai et al., 2014; Hansen et al., 2019). In a randomized controlled field experiment, Hansen et al. (2019) conference participants were subjected to an invitation letter where a vegetarian meal was marked as the default option. Those subjected to an invitation with a default vegetarian meal were far more likely to choose a vegetarian meal instead of actively changing their choice to switch to a meat-based dish than those with a meat dish as a default option.

Similarly, Campbell-Arvai et al. (2014) found in their experiment on a university campus that using appealing meat-free default options resulted in a higher likelihood of choosing plant-based dishes compared to the control group. Of note, the experiment did not involve an actual meal; only a hypothetical choice was registered.

Furthermore, Just and Price (2013) employed a default option strategy by requiring elementary students to place a fruit or vegetable on their plates, which resulted in a higher share of elementary students eating them, but also led to an increase in food waste. Additionally, Radnitz et al. (2023) found that testing different menu formats to find optimal defaults resulted in a higher selection of vegan dishes in a college cafeteria.

Another approach to leverage the social norms is the “Dish of the Day” (DoD) strategy. It refers to presenting a certain dish as a Dish of the Day, and hence highlighting one's focus on it over other meal options, which may improve the target dishes' salience (Saulais et al., 2019).

The effectiveness of the DoD strategy has been studied in multiple settings (e.g., Campbell-Arvai et al., 2014; dos Santos et al., 2020; Hartwell et al., 2020; Zhou et al., 2019). Saulais et al. (2019) found that the effect of the DoD strategy was larger for the unpopular meat-free dishes among French employees. The effectiveness also increased with the number of dish options available to the participants. Hartwell et al. (2020) found the DoD strategy effective in increasing the number of vegetable dish choices among adolescent females, but not among males or the elderly. Other studies conducted among European adolescents (Dos Santos et al., 2020) or adults over 65 years old in Denmark, France, Italy, and the UK (Zhou et al., 2019) did not find the DoD strategy effective in increasing the choices of vegetable-based main dishes.

The sequence of foods may also influence food choices: A Cochrane review by Hollands et al. (2019) concluded that altering the proximity of foods may impact food choices, but the certainty of the evidence was very low. Similarly, a review article by Bucher et al. (2016) showed that changing the proximity of foods has shown potential in influencing food choices. Nevertheless, the authors highlight the need to quantify the changes in position more accurately.

Many nudging studies have been conducted in online environments. Hollands et al. (2019) and Bucher et al. (2016) have underscored the importance of performing more nudging studies in real-life settings and evaluating food choices with precise gram-level measurements.

Dos Santos et al. (2020) suggest that the cultural environment may influence the effectiveness of nudging. In Finland, Rantala et al. (2022) have previously investigated the effect of using three nudging strategies concurrently. The strategies included priming posters, positive nutrition labelling, and enhanced food item placement. The study found no impact on food choices. To the best of my knowledge, the effects of the DoD strategy have not been examined among Finnish adults.

2.4.3 Reducing Meat Consumption Through Policies

Considering the extensive impact of meat production on biodiversity and climate (Benton et al., 2021; Willett et al., 2019), more stringent meat reduction policies may be required. Meat consumption can also be targeted on a policy level: Röös et al. (2021) published a policy report titled "Policy Options for Sustainable Food Consumption – Review and Recommendations for Sweden". Currently, most policy instruments discussed in the literature focus on the environmental taxation of meat (Röös et al., 2021).

Nutrition policies are challenging to change without both political determination and support from the public (Cullerton et al., 2016). A cross-sectional study from the UK by Espinosa and Nassar (2021) suggests that food policies with high perceived effectiveness and acceptance from the public may be viewed more positively, whereas interventions that involved increased coercion or resulted in inequalities were deemed to be less acceptable.

The intrusiveness of the policies has been found to decrease acceptance. In Switzerland, Ammann et al. (2025) investigated the acceptance of five meat reduction policies. The results suggested that more intrusive policies were the least acceptable. Similarly, Richter and colleagues (2023) studied acceptance of 37 different meat reduction policies among Swiss stakeholders and found that the most intrusive meat reduction policies (e.g., introducing a mandatory cap on the proportion of meat products within the total retail selection) had a low acceptance rate. Pechey and colleagues (2022) found that the acceptance rates of six investigated meat reduction policies ranged from 27 to 48% among UK adults. Labels and media campaigns were the most accepted meat reduction policies, followed by incentive provisions, reduced availability, advertisement bans, and cost increases (Pechey et al., 2022).

Previously, an initiative to set a tax on meat products in the Netherlands caused a backlash in online forums (Michielsen and Van Der Horst, 2022). Similarly, implementing meat reduction policies may be challenging in Finland since meat remains the dominant protein source among Finnish consumers (Erkkola et al., 2022). Understanding how the public views meat reduction policies is crucial for politicians, as it can help them minimise the political risks associated with advancing initiatives that lack sufficient public support.

Understanding what drives public support for meat reduction policies is essential for effective policy design. A study by Pechey et al. (2022) in the UK specifically examined predictors of support for such policies. They found that factors like lower personal meat consumption, an intention to reduce meat intake, environmental concern, belief in health and ecological benefits, and trust in government were all positively associated with policy acceptance. In contrast, demographic variables such as gender, education, and ethnicity showed no significant effect.

To provide a broader perspective, Table 3 summarizes both direct predictors of meat reduction policy support and related findings from other policy domains, such as health, environmental, and transport policies. These studies highlight the importance of perceived policy fairness and effectiveness and the role of political trust and risk perception in shaping public attitudes.

Notably, the perceived intrusiveness of a policy tends to reduce its acceptance, a pattern observed across multiple domains. Additionally, some studies suggest that the influence of factors like environmental concern or risk perception may be mediated by how fair or effective the policy is perceived. For example, the findings from Fujii et al. (2004) suggest that the effect of environmental concern and acceptance of road pricing policy may be mediated by perception of policy fairness (Fujii et al., 2004). Similarly, Bamberg and Rölle (2003) found that the association between problem awareness and policy acceptance was mediated by perceived policy effectiveness.

Political trust also emerged as a key factor influencing policy support (e.g., Pechey et al., 2022; Tyler, 2001; Kim et al., 2013). It can be defined as an individual's belief in one's government wanting to do the best to benefit its citizens (Levi and Stoker, 2000). However, findings from Kim et al. (2013) and Schmöcker et al. (2012) suggest that the association may not be direct and instead may be mediated by perceptions of policy fairness, effectiveness, and violation of personal freedom.

Table 3. Predictors of public support for meat reduction and other sustainability policies.

Predictor	Effect on Policy Support	Notes / Mediators	Source(s)	Policy Domain
Personal meat consumption	Negative	Higher consumption linked to lower support	Pechey et al., 2022 Graça et al., 2020	Meat reduction
Intention to reduce meat intake	Positive		Pechey et al., 2022	Meat reduction
Environmental concern	Positive	May be mediated by perceived effectiveness/ fairness	Pechey et al., 2022 Bamberg & Rölle, 2003 Fujii et al., 2004	Meat reduction, Sustainable transport Road pricing
Belief in health benefits of reduction	Positive		Pechey et al., 2022	Meat reduction
Belief in environmental benefits	Positive		Pechey et al., 2022	Meat reduction
Trust in government (political trust)	Positive	May be mediated by fairness, effectiveness, or freedom concerns	Pechey et al., 2022 Kim et al., 2013 Schmöcker et al., 2012	Meat reduction Sustainable transport Road pricing
Perceived policy effectiveness	Positive	Strong predictor across policy domains	Bos et al., 2015 Espinosa & Nassar, 2021 Hall et al., 2018	Food Food Health
Perceived policy fairness	Positive	Strong predictor across policy domains	Bos et al., 2015 Bergquist et al., 2022 Drews & Van Den Bergh, 2016	Food Climate Environmental
Policy intrusiveness	Negative	Policy intrusiveness linked to lower acceptance	Diepeveen et al., 2013 Thaller et al., 2023	Food, Sustainable transport
Risk perception	Positive	May be mediated by fairness and effectiveness	DeBono et al., 2012; Bamberg & Rölle, 2003	Climate Sustainable transport
Gender, education, ethnicity	No significant effect		Pechey et al., 2022	Meat reduction
Importance of public health	No significant effect		Pechey et al., 2022	Meat reduction

2.5 Summary of Literature

Significant changes to global food consumption are necessary to address public health challenges in both low- and high-income settings. Shifting to sustainable diets would provide substantial benefits for the environment, local economies, and social well-being. However, there are considerable contextual differences based on the income levels of countries.

In low-income settings, factors such as the price and accessibility of sustainable diets and the lack of local food-based dietary guidelines are significant barriers to adopting sustainable diets. A large proportion of the population in low-income countries cannot afford a healthy diet (FAO et al., 2024), and transitioning to diets that are both healthy and environmentally sustainable is likely to increase the dietary costs (Springmann et al., 2021), making them even less accessible. In the case countries of Ghana and Ethiopia, a double burden of malnutrition exists (NCD RisC Collaboration, 2024). These findings indicate that special attention must be placed on developing diets that are affordable, accessible, and nutritionally adequate in low-income settings.

In contrast, in high-income settings, the average share of total consumer expenditures is low (USDA Economic Research Service, 2023), and the economic accessibility of healthy food is generally higher. Transitioning to healthy and sustainable diets has been estimated to decrease dietary costs even further (Springmann et al., 2021). In Finland, issues with undernutrition are relatively less prevalent. However, over half of the Finnish adult population is either overweight or obese (NCD RisC Collaboration, 2024). Additionally, a large majority of Finnish adults consume more than the recommended amount of red or processed meat (Valsta et al., 2019). Since red meat has the highest environmental footprint of all food products (Crenna et al., 2019), a special focus must be placed on reducing its intake among the Finnish population.

In conclusion, the literature reviewed highlights gaps in evidence regarding how to promote sustainable diets across different socioeconomic contexts. In low-income settings, challenges such as affordability, limited dietary diversity, and the absence of local food-based dietary guidelines are well documented. Nevertheless, practical solutions to address these challenges remain scarce. In high-income settings, excessive consumption of environmentally intensive foods, particularly red meat, poses a distinct sustainability challenge. The evidence on effective behavioural or policy interventions to address this challenge is still limited.

This thesis addresses these gaps by applying different methodological approaches in three country contexts: dietary modelling in Ghana and Ethiopia, and a nudging intervention and policy analysis in Finland. These countries were chosen to illustrate diverse structural and cultural conditions with unique dietary challenges.

3 Aims

This PhD thesis aims to develop new knowledge about sustainable diet strategies, which in this thesis are defined as evidence-informed actions, interventions, and policy tools that promote the adoption of diets that are nutritionally adequate, environmentally responsible, economically viable, and culturally acceptable.

The primary research question is:

> *How can sustainable diet strategies be designed and applied within specific socioeconomic and cultural contexts to support the transition toward more sustainable diets?*

The sub-questions and the corresponding sub-studies are:

1. *How can locally available foods be combined to form nutritionally adequate, affordable, and culturally acceptable diets for low-income populations in Ghana and Ethiopia?*

   Sub-study I: Development of affordable and nutritionally adequate diets for Ghanaian low-income families in urban and rural settings with minimal dietary changes.

   Sub-study II: Development of affordable and nutritionally adequate diets for Ethiopian low-income families in urban and rural settings with minimal dietary changes.

2. *What strategies can effectively encourage individuals in Finland to moderate meat consumption?*

   Sub-study III: Evaluation of a nudging intervention to replace red meat with plant-based protein in a Finnish self-service buffet.

   Sub-study IV: Investigation of public acceptance of meat reduction policies in Finland and its determinants.

This thesis contributes to the evidence base on how dietary transitions can be facilitated in diverse socioeconomic contexts. Additionally, it supports the development of sustainable and equitable food systems globally.

4 Materials and Methods

4.1 Research Approach and Study Designs

In this thesis, I have been studying sustainable diet strategies quantitatively. This study relies on a hypothetico-deductive model of science (Park et al., 2020). The process begins with identifying hypotheses from the literature, followed by designing and conducting an experiment, which results in new findings that contribute to the development of new theories, thereby completing a circular process.

This thesis used data from four different sub-studies (Table 4). The first two are modelling studies based on cross-sectional data from Ghana and Ethiopia. The third one is an intervention study conducted in Finland. In contrast, the fourth is based on cross-sectional data from an online survey with a representative sample of the Finnish population aged 18-75 regarding gender, age, and region. The studies are presented in more detail in the subsequent chapters.

Table 4. Summary of study designs used in sub-studies I–IV.

Study	Design	Country	Materials/ Participants	Data sources	Time
I	Cross-sectional modelling study	Ghana	266 food items in urban and 141 in rural areas	Food prices from urban (*n* = 11) and rural (*n* = 8) marketplaces Nutrient contents from food composition databases	2016
II	Cross-sectional modelling study	Ethiopia	205 food items in urban and 190 in rural areas	Food prices from urban (*n* = 5) and rural (*n* = 4) marketplaces Nutrient contents from food composition databases	2016
III	Intervention	Finland	Finnish adults aged 18-65, *n* = 163	Omnivores were nudged into plant-based protein sources in a real-world self-service buffet restaurant setting	2021
IV	Cross-sectional	Finland	Finnish adults aged 18-75, *n* = 1999	The acceptance of four meat reduction policies measured via an online survey	2024

4.2 Optimizing Healthy, Affordable, and Culturally Acceptable Diets in Ghana and Ethiopia

4.2.1 Collecting Data on Food Prices, Nutrient Contents, and Dietary Patterns from Ghana and Ethiopia

Sub-studies I and II aimed to develop nutritionally adequate, affordable, and culturally acceptable diets for low-income populations in Ghana and Ethiopia. The following types of data were needed for the following purposes:

- **Food prices** of locally available foods to optimize the diets in terms of affordability
- **Nutrient contents** of the foods to ensure that all nutrient requirements can be fulfilled
- **Local dietary patterns** to optimize the diets to be as similar to current dietary habits as possible (in other words, to maximize the cultural acceptability of the diets).

Food Prices

Due to the lack of existing food price data for Ghana in 2016, I organized and conducted primary data collection with two colleagues from University College Copenhagen and locally hired staff. Prices were collected between February and April 2016 from 11 urban and 8 rural marketplaces across Greater Accra, Central, Volta, and Ashanti regions. These included open-air markets, small shops, and supermarkets. In Ghana, prices were recorded for 266 food items in urban areas and 141 in rural areas. Between 1–11 prices were collected per item to reduce the effect of potential outliers. Additionally, I consulted agriculture teachers at Ngleshie Amanfro Senior High School to identify locally available wild foods, such as mangos and snails, which were included in the rural Ghanaian food baskets.

In Ethiopia, a local researcher and assistants collected prices for 205 urban and 190 rural food items from 5 urban and 4 rural marketplaces near Addis Ababa between August and September 2016. For each item, two to five price points were gathered from different vendors to improve reliability. Median prices were used in all modelling. To avoid bias from foreign presence, local staff conducted the data collection.

Nutrient Contents

I was in charge of combining the prices of Ghanaian foods with their corresponding nutrient contents. I used the West African food composition tables (FAO, 2012b) as the primary source of nutrient contents. In case data not being available, I used the following sources: Mozambican (Korkalo et al., 2011), American (SR28 (USDA, 2018), British (Public Health England, 2015), Danish (FoodData) (DTU Food, National Food Institute Denmark, 2018) Finnish (Fineli) (National Institute for Health and Welfare, 2018), and Norwegian (The Norwegian Food Safety Authority, 2018) food composition databases. I obtained the non-edible share of the foods, e.g. skin, bones, and peels, from the same sources. In cases where it improved accuracy, nutrient values for cooked foods were used instead of raw values.

In the case of Ethiopian foods, I organized the nutrient contents together with my colleague, the first author of sub-study II. The Ethiopian and West African Food Composition Tables (Ethiopian Health and Nutrition Research Institute, 1995; FAO, 2012b) were used as the primary sources of nutrient values. In the cases of missing data, the previously mentioned food composition tables and databases were used.

Local Dietary Patterns

There were no available data on local dietary habits in Ghana; therefore, food supply data from 31 applicable food categories in the FAO Food Balance Sheets were utilised (FAO, 2018). For Ethiopia, FAO food supply data included 37 applicable food groups, while the only available dietary intake study (Kebede & Modes, 2013) provided data on just 11 food categories. Due to the greater diversity in the FAO data, it was used as a proxy for food availability in both countries, as it offered more specific information regarding the local availability of food items.

4.2.2 Analysis: Linear Programming

I chose LP as the modelling tool for developing culturally acceptable diets for Ghana and Ethiopia (I and II) as it has proven to be a helpful tool in creating culturally acceptable and cost-effective food recommendations, providing the necessary amount of all recommended macro- and micronutrients based on locally available foods (Darmon et al., 2002; Parlesak, 2016). LP is a mathematical tool that is used to maximize or minimize a linear function with a set of constraints. LP consists of three characteristics: the goal function, the decision variables, and a list of linear constraints (Smith, 1959).

Goal Function Formula:

$$GF = c_0 + c_1X_1 + c_2X_2 + \cdots + c_nX_n,$$

where C denotes the food-specific constant (in this study, the price of one kilogram of the food item) and X represents the decision variable, i.e., the quantity of the respective food item.

In the studies conducted in low-income settings (I and II), the goal function was set to first:

i) minimize the price of the diet and second

ii) minimize deviation from the local food supply (FAO, 2018).

The decision variables were the amounts of each food from a list of locally available food items. The linear constraints were the energy and nutrient requirements: the estimated energy requirements (EERs), the acceptable macronutrient distribution ranges (AMDRs), and reference nutrient intakes (RNIs) set by the WHO and FAO (WHO & FAO, 2004; FAO, United Nations University, WHO, 2001). The sample diets were optimized to meet the dietary requirements for a four-member example family in Ghana and a five-member example family in Ethiopia based on average household sizes at the time (Ghana Statistical Service, 2011; Gillespie Foundation, 2014). A complete list of constraints is presented in Table 5. All food baskets developed in the sub-studies I and II fulfilled all nutritional requirements presented in Table 5, hence ensuring nutritional adequacy.

A measure called total relative deviation (TRD) from the food supply was used as a measure of cultural acceptability:

Total Relative Deviation (TRD) Formula:

$$TRD = \sum_{i=1}^{n} = \frac{abs(m_i - M_i)}{M_i},$$

where m_i stands for the total sum of weights in each food category, M_i for the food supply of the specific food category, and i stands for the running index of the food category (n = 31 in Ghana, n = 37 in Ethiopia).

Table 5. The estimated energy requirements (EERs), the acceptable macronutrient distribution ranges (AMDRs), and reference nutrient intakes (RNIs) which were used as constraints in the linear optimization of all calculated food baskets for low-income families in Ghana and Ethiopia. The requirements were obtained from WHO & FAO (2004) and FAO et al. (2001). Modified from original publications I and II.

	GHANA				ETHIOPI				
GENDER	FEMALE	MALE	FEMALE	MALE	FEMALE	MALE	FEMALE	MALE	FEMALE
AGE (YEAR)	18.0-29.9	30.0-59.9	8.0-8.9	5.0-5.9	30-59.9	30-59.9	14-14.9	8-8.9	5-5.9
ENERGY (KCAL)	2550	2850	1698	1467	2400	2950	2450	1830	1330
PROTEIN (G)	54-96	58-107	26.2-63.7	17.1-55.0	54-90	58-110	41-92	26-69	16-50
FAT (G)	56.7-85.0	47.5-95.0	28.3-56.6	24.5-48.9	53-80	49-98	54-82	31-61	22-44
SFAS (G)	<28.3	<31.7	<18.9	<16.3	<26.7	<32.8	<27.2	<20.3	<14.8
PUFAS (G)	17-28	19-32	11-19	10-16	16-27	20-33	16-27	12-20	9-15
N-3 PUFAS (G)	2.8-5.7	3.2-6.3	1.9-3.8	1.6-3.3	2.7-5.3	3.3-6.6	2.7-5.4	2.0-4.1	1.5-3.0
N-6 PUFAS (G)	14-23	16-25	9-15	8-13	13-21	16-26	14-22	10-16	7.4-12
TFAS (G)	<2.83	<3.17	<1.89	<1.63	<2.7	<3.3	<2.7	<2.0	<1.5
CHOLESTEROL (MG)	<300	<300	<300	<300	<300	<300	<300	<300	<300
CARBOHYDRATE (G)	351-478	392-534	233-318	201-275	330-450	406-553	337-459	252-343	183-249
FIBRE (G)	≥25.0	≥25.0	≥16.6	≥12.2	≥25.0	≥25.0	≥24.0	≥15.3	≥13.0
TOTAL SUGARS (G)	<31.9	<35.6	<21.2	<18.3	<30.0	<36.9	<30.6	<22.9	<16.6
NA (MG)	<2000	<2000	<2000	<2000	<2000	<2000	<2000	<2000	<2000
K (MG)	≥3510	≥3510	≥2337	≥1688	≥3510	≥3510	≥3371	≥2106	≥1831
CA (MG)	≥1000	≥1000	≥700	≥600	≥1000	≥1000	≥1300	≥700	≥600
MG (MG)	≥220	≥260	≥100	≥76	≥220	≥260	≥220	≥100	≥76
FE (MG)	≥29.4	≥13.7	≥8.9	≥6.3	≥29.4	≥13.7	≥32.7	≥8.9	≥6.3
ZN (MG)	≥4.9	≥7.0	≥5.6	≥4.8	≥4.9	≥7.0	≥7.2	≥5.6	≥4.8
SE (μG)	≥26	≥34	≥21	≥22	≥26	≥34	≥26	≥21	≥22
IODINE (μG)	≥150	≥150	≥120	≥90	≥150	≥150	≥150	≥120	≥90
VIT A-RAE (μG)	≥500	≥600	≥500	≥450	≥500	≥600	≥600	≥500	≥450
THIAMINE (MG)	≥1.10	≥1.20	≥0.90	≥0.60	≥1.1	≥1.2	≥1.1	≥0.9	≥0.6
RIBOFLAVIN (MG)	≥1.10	≥1.30	≥0.90	≥0.60	≥1.1	≥1.3	≥1.0	≥0.9	≥0.6
VIT B6 (MG)	≥1.30	≥1.30	≥1.00	≥0.60	≥1.3	≥1.3	≥1.2	≥1.0	≥0.6
VIT B12 (μG)	≥2.40	≥2.40	≥1.80	≥1.2	≥2.4	≥2.4	≥2.4	≥1.8	≥1.2
VIT C (MG)	≥45.0	≥45.0	≥35.0	≥30.0	≥45	≥45	≥40	≥35	≥30
VIT D (μG)					≥5.0	≥5.0	≥5.0	≥5.0	≥5.0
VIT E (MG)	≥7.5	≥10.0	≥7.0	≥5	≥7.5	≥10.0	≥7.5	≥7.0	≥5.0
FOLATE (μG)	≥400	≥400	≥300	≥200	≥400	≥400	≥400	≥300	≥200
NIACIN (MG)	≥16.0	≥14.0	≥12.0	≥8.0	≥16.0	≥14.0	≥16.0	≥12.0	≥8.0

RAE: retinol activity equivalent, SFAs, saturated fatty acids; PUFAs, polyunsaturated fatty acids; TFAs, trans-fatty acids; Vit, vitamin.

In Ghana and Ethiopia, the following measures were taken:

1. Constraining maximum TRDs: Limiting the weight of foods in each category to ensure similarity to the prevailing food supply patterns.
2. Improving food variety: Restricting the quantity of each food item within its food group to prevent developing a diet consisting of only a few food items.
3. Minimizing TRD: Adjusting the goal function to minimize the TRD while maintaining nutritional constraints and affordability based on poverty rates.

In this thesis, the term *food variety* is used to describe the number of distinct food items included in the modeled diets. This differs from *dietary diversity*, which typically refers to the number of food groups represented and is often measured using standardized indicators such as the Dietary Diversity Score (DDS) (Heidari-Beni et al., 2022) or Minimum Dietary Diversity for Women (MDD-W) (FAO & FHI 360, 2016). The primary aim of dietary diversity indices is to assess diet quality and micronutrient adequacy, particularly in settings where nutrient intake data are unavailable (Kennedy et al., 2007). In contrast, all modeled diets in this thesis were designed to meet established nutrient requirements, making the use of dietary diversity indices unnecessary. Therefore, *food variety* is used throughout this thesis to describe the diversity of foods in the modeled diets, without reference to food group classification.

The aim was to develop diets for low-income families. As previously mentioned, a significant proportion of the population living in low- and lower-middle-income countries cannot afford a healthy diet (FAO et al., 2024). Furthermore, shifting to healthy and sustainable diets has been associated with higher dietary costs in low and middle-income countries (Springmann et al., 2021). No constraints on environmental impacts, such as greenhouse gas emissions, were included in the diet modelling in Ghana and Ethiopia, as this could have resulted in the dietary solutions being unaffordable for those who are socioeconomically most challenged.

LP was performed using Microsoft Excel and its open-source add-in OpenSolver (Mason, 2012).

4.3 Nudging Food Choices at a Finnish Lunch Restaurant

4.3.1 Intervention Data Collection

The nudging study (III) was conducted at the Flavoria® Multidisciplinary Research Platform in Turku, Finland, between October and December 2021. The study design was informed by a targeted review of relevant literature that I had compiled during the planning phase. Finnish adult omnivores aged 18–65, who were Finnish-speaking omnivores without food allergies or intolerances, were invited to participate to avoid bias from participants who might not tolerate plant-based proteins (specifically fava bean protein) equally. The data collection for which I was mainly responsible was conducted during the COVID-19 pandemic. The changing COVID-19 situation and the resulting restrictions made participant recruitment challenging. As a result, a random sample with 163 participants was gathered.

A buffet lunch type of meal was offered to the participants in a Finnish lunch restaurant setting. The main dish options were a traditional Finnish dish, minced meat casserole, and a vegetarian version with fava bean protein.

- The minced meat casserole was made from pasta, minced beef, onions, meat bouillon, eggs, cow's milk, and spices.
- The fava-bean casserole was identical to the minced meat casserole, but with beef substituted with Härkis® (a plant-based protein similar to fried minced meat) and vegetable bouillon instead of meat bouillon.

The rationale behind choosing identical dishes except for the main protein source and bouillon was to control for potential bias resulting from one dish looking more appealing or having a nicer scent.

Each main dish and salad component had a corresponding electronic scale that measured the intake of each dish and registered it into a server. The full technical details of the Flavoria® Multidisciplinary Research Platform in Turku, Finland, have been reported by Koivunen et al. (2020).

The food items served included salad, bread, and drinks. The participants could choose as much food as they wanted without restrictions. After participation, free coffee, tea, and a small chocolate bar were served as a gift for the participants.

Sub-study III aimed to nudge Finnish adult omnivores to choose a dish with plant-based protein instead of red meat using two different nudging strategies: 1) sequence alteration and 2) DoD strategy. The study setting resembled a regular lunch buffet as much as possible to increase the generalizability of the results to other Finnish lunch restaurant settings. Finnish lunch restaurants typically serve salads before the main dishes; therefore, only the sequence of the main dishes was changed.

The main dishes were served right next to each other (See Figure 2). Sequence alteration was done only for the main dishes, which were next to each other and alternated between each other.

Two menus were designed:

- Dish of the Day Menu: Fava-bean casserole labelled as “Päivän annos” (Dish of the Day in Finnish) and highlighted with a light-green coloured box to steer participants towards this option.
- Standard Menu: Minced-meat casserole mentioned before fava-bean casserole without any labels or a green box.

Figure 2. View of the intervention study setting in sub-study III. Photo by Esa-Pekka Nykänen. Modified from original publication II.

Once the participants arrived at the study restaurant, they were assigned to one of the four treatments:

1. **Standard menu, meat first**: Participants received a standard menu, with the meat dish served before the dish with plant-based protein in the buffet line.

2. **DoD menu, meat first**: Participants received a DoD menu with the meat dish served before the dish with plant-based protein in the buffet line.
3. **Standard menu, plant-based first**: Participants received a standard menu, with the fava bean casserole served before the meat dish.
4. **DoD menu, plant-based first:** Participants received a DoD menu, with the fava bean casserole served before the minced meat casserole.

After finishing their meal, participants completed a survey with questions regarding factors such as e.g. sex, age, weight, and height.

4.3.2 Analysis: Ordinal Logistic Regression

After the data collection, I was in charge of the data management and analysed the data together with a biostatistician. The main outcome variable in sub-study III was the choice of the main dish (minced meat casserole, fava-bean casserole, or both). Since both the treatment and main dish choice were categorical variables, ordinal logistic regression was used for analysis. The first step involved a univariate model, which was later adjusted for gender, age group, and body mass index group.

The differences in background factors between treatments were assessed using different statistical tests: differences in categorical variables (e.g., gender and employment status) were studied with Fisher's Exact tests with Monte Carlo estimates, and age differences were studied with the Kruskal-Wallis tests. Due to the non-normality of the data, the body mass index was logarithmically transformed and examined with a one-way analysis of variance.

Linear models were used to analyse the mean meal weights, salad amounts, and the proportion of the meat-containing main dish in the meal weight. Studentized residuals were employed to check the assumptions for the linear models.

The data analysis for sub-study III was conducted with SAS software, V9.4 of the SAS System for Windows.

4.4 Surveying Finnish Consumers' Acceptance of Meat Reduction Policies

4.4.1 Consumer Panel Survey Data

The sub-study focusing on determinants of meat reduction policy acceptance (IV) was pre-registered (AsPredicted, 2025). I designed the registered hypotheses together with my thesis supervisor. The goal was to ensure that the findings could be generalized to the Finnish adult population. Therefore, a representative sample of

1999 Finnish individuals aged 18-75 was collected. Quotas were set to match Finnish demographics by gender, age group, and geographical region.

An independent polling company, Innolink Oy, conducted the data collection in May 2024. The survey included background questions on gender, age, and education, as well as questions on risk perception of biodiversity loss and climate change, political trust, and personal meat consumption. The survey was designed by a multidisciplinary team of researchers from the BIODIFUL project.

The participants were asked to evaluate the perceived effectiveness, acceptance, fairness, and intrusiveness of each of the following four meat reduction policies on a scale of 1-7 (1= very weak, 7= very strong):

1. “Meat products that are most harmful to the environment will be heavily taxed” (Röös et al., 2021)
2. “Discount sales of meat products will be prohibited (does not apply to red-labelled waste discount products)” (Richter et al., 2023)
3. “Shelf space for meat products in stores will be limited” (Richter et al., 2023)
4. “The consumption of meat products will be limited to no more than half of the current consumption” (Röös et al., 2021)

Political trust has been observed to be associated with higher acceptance of meat reduction policies (Pechey et al., 2022). It was measured by adapting an instrument developed by Devine et al. (2020): The term 'political decision-makers' was used instead of 'government’ to encompass trust in Finland’s entire governing body, rather than the current government. This adjustment was conducted to take into account the recent changes in the composition of the government and in its political aims.

The online survey for sub-study IV was designed to address multiple research questions, necessitating a shorter format to avoid overburdening respondents. Consequently, three items from the original eight were selected based on confirmatory factor analysis conducted on a similar dataset of 1,000 Finnish individuals from the same research group. The items with the highest factor loadings were selected: Item number 1 “The political decision-makers have good intentions,” 2 “The political decision-makers understand the needs of my community,” and 5 “In general, the political decision-makers usually do the right thing.”

Sub-study IV aimed to investigate whether environmental risk perception affects the acceptance of meat reduction policies in Finland. Environmental risk perception was assessed using a bi-factor structure, comprising three items related to climate change and three items related to biodiversity loss, following the validated method developed by Lalot et al. (2025). This method allows for the modelling of a general environmental risk factor while accounting for domain-specific variance.

The items were adapted from van der Linden's (2014) perceived risk of climate change scale. For the biodiversity loss items, the term "climate change" was replaced with "biodiversity loss." The six items assessed (1) the perceived likelihood of personal harm, (2) the perceived seriousness of the threat to Finland, and (3) the level of concern, each measured separately for climate change and biodiversity loss. Responses were recorded on a 7-point Likert scale (1 = strongly disagree, 7 = strongly agree). As with the political trust items, only the three with the highest factor loadings were included due to space constraints.

4.4.2 Analysis: Structural Equation Modelling

After the data collection, I curated the data and analysed it based on the pre-registered analysis plan. Two senior co-authors provided methodological guidance regarding the practicalities of conducting structural equation modelling (SEM) and the use of MPlus software version 8.10. SEM was chosen as the analysis method in sub-study IV to assess both:

1. The direct effects of environmental risk perception and political trust on the acceptance of four meat reduction policies
2. The indirect effects of environmental risk perception and political trust on the acceptance of meat reduction policies via perceived policy fairness, effectiveness, and intrusiveness.

SEM is a statistical analysis method that allows the investigation of complex psychological phenomena (MacCallum and Austin, 2000). It enables the simultaneous testing of multiple hypotheses and the determination of the direction of effect. Both observed variables and latent variables representing hypothetical constructs can be integrated into the analysis. In sub-study IV, both environmental risk perception and political trust were treated as latent constructs representing phenomena that cannot be measured directly. Similarly, SEM allows for the modelling of mediating variables (MacCallum and Austin, 2000), which in this case were perceived fairness, effectiveness, and intrusiveness.

Compared to methods like multiple regression, a major benefit of SEM is that it tests the fit of the entire model rather than just individual coefficients. However, despite its ability to model complex phenomena, SEM cannot verify causality due to the use of cross-sectional data (Bollen and Pearl, 2013).

As previously mentioned, studies from related fields have identified perceived policy effectiveness, fairness, and intrusiveness as common proximal predictors of policy acceptance. Similarly, environmental risk perception and political trust have been found to influence policy acceptance as distal predictors. In sub-study IV, the aim was to investigate proximal (perceived policy effectiveness, fairness, and intrusiveness) and distal predictors of meat reduction policies in Finland. The entire hypothesis formulation process, including the theoretical rationale and literature synthesis, is described in detail in sub-study IV. Figure 3 illustrates the pre-registered hypotheses tested in sub-study IV, excluding those concerning direct residual effects of environmental risk perception and political trust on policy acceptance.

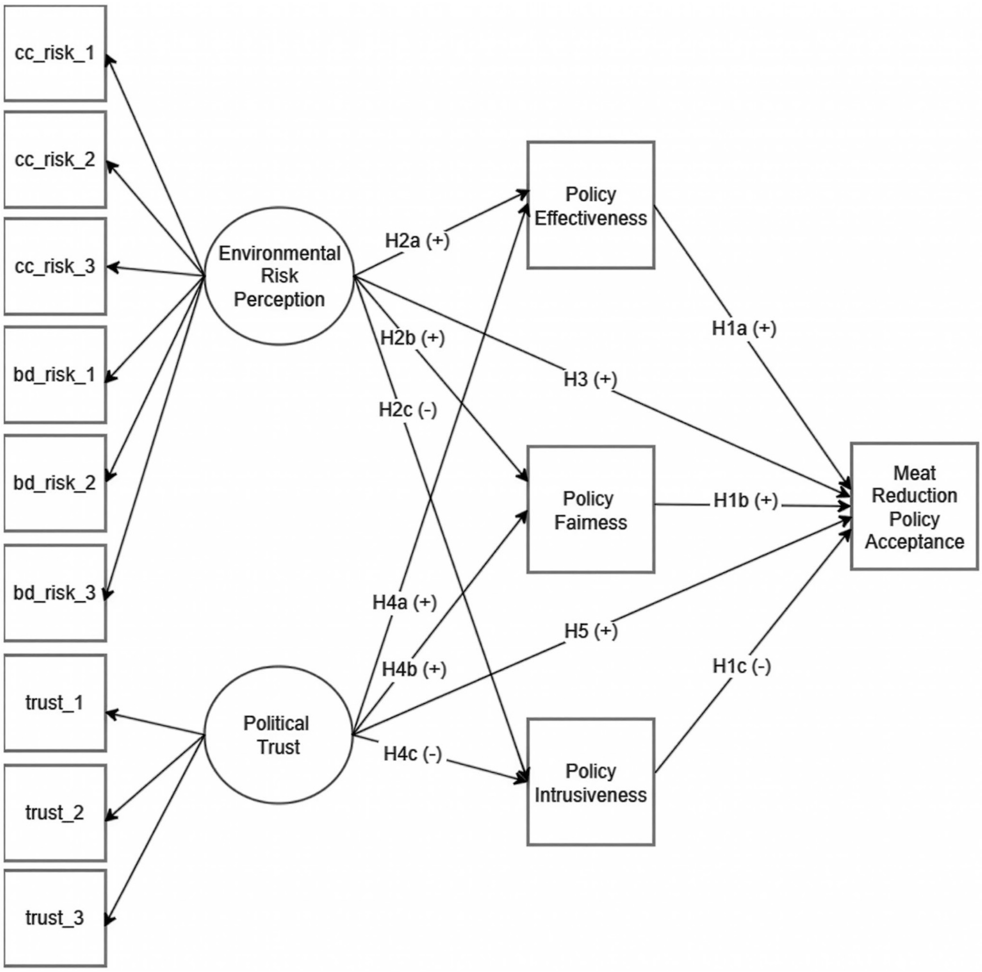

Figure 3. Conceptual model illustrating the main pre-registered hypotheses (H) from sub-study IV, focusing on the psychological and political determinants of public acceptance of one meat reduction policy (meat tax). Circles represent latent constructs measured using multi-item scales. Solid arrows with plus symbols (+) indicate hypothesized positive associations; dashed arrows with minus symbols (–) indicate hypothesized negative associations. The figure does not depict hypotheses concerning direct residual effects of environmental risk perception and political trust on policy acceptance, which were tested but are not visualized here. *cc_risk1–3* are items measuring climate change risk perception, *bd_risk1–3* are items measuring biodiversity loss risk perception, and *trust1–3* are items measuring political trust. Modified from original publication IV.

The fitness of the structural equation model was assessed using the following criteria from MacCallum et al. (1996) and Steiger (2007):

- Root Mean Square Error of Approximation (RMSEA): < 0.07
- Standardized Root Mean Square Residual (SRMR): < 0.08,
- Comparative Fit Index (CFI): > 0.95,
- Tucker–Lewis Index (TLI): > 0.95
- Akaike Information Criterion (AIC): the smallest value of the compared measurement models.

A SEM was created to test the pre-registered hypotheses. The determinants of policy acceptance were evaluated using a separate model for each policy. The SEM analysis was performed using Mplus version 8.10.

Previous research suggests that individuals who consume meat may be less supportive of meat reduction policies (Graça et al., 2020). Therefore, meat consumption in binary format (1 = omnivore, 0 = non-meat-eater) was added as a control variable to the models.

Previous studies by Huber et al. (2020) and Thaller et al. (2023) have identified that perceived policy effectiveness, fairness, and intrusiveness correlate with each other. Hence, these variables were permitted to covary in the model.

Differences in the background characteristics between meat-consuming and non-meat-consuming participants were analysed using the Kruskal-Wallis test for normally distributed variables and the Fisher-Freeman-Halton test for non-normally distributed variables using the IBM SPSS Statistics version 29.

4.5 Considerations of Research Ethics

Only price, food supply, and nutritional composition data were used in sub-studies I and II. As no human participants were involved, no ethical permission was required.

Sub-study III was conducted at the Flavoria® Multidisciplinary Research Platform. The Flavoria® study protocol was reviewed and ethically approved by the Ethics Committee for Human Sciences at the UTU, Humanities and Social Sciences Division (37/2021).

In sub-studies III and IV, all participants gave informed consent before participating in the study. Each participant had the opportunity to drop out at any given time without any consequences. The survey company Innolink, which collected the data for sub-study IV, removed all identifiers from the data, and therefore the study involved no risk to the participants' confidentiality. The principles of the Declaration of Helsinki were fully adhered to in the research process, and the European Union’s General Data Protection Regulation (GDPR) was strictly followed in all studies.

5 Results

5.1 Strategies for Developing Sustainable Diets in Ghana and Ethiopia

5.1.1 Prices of Diets Meeting All Nutrient Requirements

Using the LP methodology to minimize the diet cost while applying the nutritional constraints (AMDRs and RNIs) showed that a fully nutritious diet could be achieved for as little as 6.4 Ghanaian Cedis (GHS) (USD 1.7) for an urban, and GHS 7.7 (USD 2.0) per day for a rural four-member Ghanaian family (Table 6). It is important to note that these food baskets represent initial, theoretical calculations. They were generated without constraints on cultural acceptability or food variety. As such, they reflect minimum-cost solutions that meet nutrient requirements but should not be interpreted as realistic or socially acceptable diets.

In both settings, the only animal-based food was beef liver, which constituted less than 1% of the total weight. The LP algorithm did not select any foods derived from live animals (e.g., milk or eggs), fish, seafood, fruits, or crops used for sugar, oil, or stimulants when optimizing to find the most cost-efficient combination of foods to meet the nutritional and energy requirements.

The LP algorithm was also allowed to add locally available wild foods to the rural diets in order to assess whether this would increase the feasibility of the diet. This strategy reduced the price of the rural food basket to GHS 4.2 (USD 1.1) per day (Table 6). However, the share of wild foods ended up constituting over two-thirds of the total weight of the resulting food baskets for rural areas. The selected wild foods were green leafy vegetables and giant African snails (Table 6).

Similarly, as in Ghana, the LP algorithm identified a list of local foods that would fulfill all nutrient requirements of Ethiopian families at the lowest possible cost (Table 7). For an Ethiopian five-member family, the cheapest fully nutritious diets cost 31 and 38 Ethiopian Birr (ETB) (1.1 and 1.3 United States Dollars (USD)) for urban and rural areas, respectively. Both suggested food baskets were high in maize products and included seeds, vegetables, barley, beans, and pulses, and contained a small amount (less than 1%) of beef liver.

Table 6. Initial theoretical food baskets for Ghanaian four-member families (urban, rural, and rural with wild foods), calculated without constraints on cultural acceptability or food variety. Modified from original publication I.

Category	Food Item	UFB	RFB	RWFB
		Weight (g)	Weight (g)	Weight (g)
Cereals and cereal products	Banku flour	551		
	Maize flour, white, refined		61	
	Millet, red, whole grain	1255	546	
	Oats, dried	36	31	
	Wheat, whole grains	63		
Roots and tubers	Cassava, flour, gari, yellow		726	900
Legumes	Cowpea, white, dried	2		
	Groundnut, dried		68	21
	Groundnut, paste		1	
	Groundnut, roasted			35
	Soy bean, flour		568	69
Nuts and seeds	Coconut, immature kernel, fresh	333	297	318
Vegetables	Cabbage, green	229		
	Cocoyam leaves		59	
	False sesame (yaudo) leaves, dried	129		
	Okra, dried, ground		112	
Animal & vegetable oils & fats	Soy oil	26		
	Vegetable oil	58	6	144
Products from slaughtered animals	Beef liver	10	14	4
Miscellaneous	Salt, iodized	17	17	15
Wild foods	Dandelion			744
	Jew's mallow (ademe) leaves			1726
	Giant African snails			938
	Water leaves			329
	Total weight in grams	**2709 (12 foods)**	**2507 (13 foods)**	**5243 (12 foods)**
	Total cost in GHS (USD)	**6.4 (1.7)**	**7.7 (2.0)**	**4.2 (1.1)**

UFB, Urban Food Basket; RFB, Rural Food Basket; RWFB, Rural Wild Food Basket; GHS, Ghanaian Cedi; USD, United States Dollar.

Table 7. Initial theoretical food baskets for Ethiopian five-member families (urban and rural), calculated without constraints on cultural acceptability or food variety. Modified from original publication II.

Category	Food Item	UFB	RFB
		Weight (g)	**Weight (g)**
Wheat and products	Wheat, whole grains	8	
Barley and Products	Barley, black, whole grain	33	128
Maize and Products	Maize, white, flour, refined	903	1192
	Maize, white, on cob, roasted	36	
	Maize, white, whole kernel, dried		133
	Maize, yellow, flour, whole-grain		80
Sorghum and Products	Sorghum, whole grain, raw	209	7
Beans	Broad beans, split	154	19
	Kidney beans, big		96
Groundnuts (shelled eq.)	Groundnut, paste	4	
Pulses and Products	Linseed, dried		35
	Linseed, roasted	7.7	
	Niger seed, raw		12
	Niger seed, dried	56	42
SEsame seed	Sesame seeds, whole, dried	105	90
Vegetables, other	Spinach, raw	26	98
	Pepper, sweet, red, raw	143	
	Pepper, sweet, green, raw	34	
	Peppers, chili, raw		159
	Ginger, roots, dried	13	
Oilcrops oil, other	Niger oil	12	
Meat, fish, other	Beef liver	16	14
Spices, other	Salt, iodized	22	22
Eggs	Egg, small, chicken, raw		52
Milk (excluding butter)	Milk, cow, 1.5% fat	80	
	Yoghurt, whole milk, plain	54	
	Total weight (# of foods)	**1916 (19 items)**	**2183 (16 items)**
	Total cost in ETB (USD)	**38.0 (1.3)**	**31.0 (1.1)**

UFB, Urban Food Basket; RFB, Rural Food Basket; ETB, Ethiopian Birr; USD, United States Dollar.

Milk products formed 7% of the total weight of the urban food basket, while the rural food basket contained a small amount of eggs (2.4%) (Table 7).

Each of the food baskets optimized for the lowest cost in Ghana and Ethiopia consisted of only 12 to 19 food items, depending on the setting (Tables 6 and 7). The compositions of the lowest-cost food baskets for both urban and rural areas in Ghana and Ethiopia deviated significantly from the food supply data from the FAO (2018).

Understanding which nutrients are so-called "expensive" nutrients that influence the price of healthy diets can be beneficial in the development of effective food policies. The application of LP revealed that not all nutritional constraints become active when identifying the cheapest combination of food items that meet nutrient requirements. The nutrients that determine the cost are referred to as active constraints (see Table 8 for the full list). In practice, once the food basket meets the lowest requirement of the cost-controlling nutrient, all other nutrient requirements are automatically satisfied.

The results showed that the primary nutrients whose lower recommended limits controlled the cost of the cheapest fully nutritious food baskets for both Ghanaian and Ethiopian family members were n-3 fatty acids, calcium, iodine, and vitamins A, B_3, C, and E. Specifically, the lower limit of n-3 fatty acids determined the cost of the cheapest food basket for all family members in both urban and rural areas of Ghana and Ethiopia, except for Ghanaian adult females living in urban areas. Similarly, the lower limit of iodine determined the cost of all food baskets for all family members in both urban and rural settings in Ghana and Ethiopia, even when wild foods were included in the Ghanaian rural food baskets.

The upper limits of total sugar and saturated fatty acids determined the cost of fully nutritious food baskets for all family members in both urban and rural areas of Ghana, even when wild foods were included in the rural food baskets. The upper levels of protein and sodium influenced the cost in both Ghana and Ethiopia, while the upper limit of n-6 fatty acids influenced the cost only in Ethiopia.

Interestingly, the upper limit of protein determined the cost of fully nutritious food baskets for the majority of family members in both urban and rural areas of Ghana and Ethiopia. The only exceptions were a girl living in urban areas of Ethiopia and boys living in both urban and rural areas of Ethiopia. If more protein had been allowed in the food baskets, the price would have *decreased* as a result.

Table 8. Nutrients acting as active constraints in the initial theoretical food baskets for Ghanaian and Ethiopian families, calculated without constraints on cultural acceptability or food variety. “Active constraints” refer to the nutrients whose lower or upper limits determine the cost of the diet in the linear programming model. Meeting these constraints ensures that all other nutrient requirements are simultaneously satisfied. Modified from original publications I and II.

Country	Limits	Member (age)	Macronutrients					Minerals		Trace Elements		Vitamins						
			Protein	SFA	n-3 PUFA	n-6 PUFA	Total sugar	Sodium	Calcium	Iron	Iodine	Vit A	Vit B_2	Vit B_3	Vit B_9	Vit B_{12}	Vit C	Vit E
Ghana	Lower limit	Female (18-29.9)			R	UW			UR	UR	URW		R	RW		UW	U	
		Male (30-59.9)			UR	W			R		URW	U	UR	UR		UW	U	R
		Female (8-8.9)			UR	W			UR		URW	U	R	URW	U	W	U	R
		Male (5-5.9)			UR	W			UR		URW	U	R	URW		W	U	R
	Upper limit	Female (18-29.9)	URW	URW	W		URW	URW										
		Male (30-59.9)	URW	URW	W		URW	URW										
		Female (8-8.9)	URW	URW	W		URW											
		Male (5-5.9)	URW	URW	W		URW											
Ethiopia	Lower limit	Female (30–59.9)			UR				UR	R	UR	UR		U	R		UR	UR
		Male (30–59.9)			UR				UR		UR	UR			R		UR	UR
		Female (14)			UR				UR		UR	UR		U	R		UR	UR
		Female (5)			UR				UR	UR	UR	R		U		UR	UR	UR
		Male (8)			UR				UR		UR	UR		UR	R		UR	UR
	Upper limit	Female (30–59.9)	UR			R		UR										
		Male (30–59.9)	UR			UR		UR										
		Female (14)	R			UR												
		Female (5)	UR			UR		UR										
		Male (8)				UR												

PUFA, polyunsaturated fatty acids; R, rural food basket; SFA, saturated fatty acids; U, urban food basket; Vit, Vitamin; W, rural food basket including wild foods.

5.1.2 Culturally Acceptable and Nutritious Diets

In order to increase the cultural acceptability and feasibility of the diets, the food baskets were diversified by limiting the share of individual foods per food group in both Ghana and Ethiopia. The resulting food baskets had increased variety, which was associated with price increases in each setting. A similar phenomenon was observed when making the food baskets more culturally acceptable by minimizing the TRD from the local food supplies. Minimizing the deviation and, hence, making the transition less challenging resulted in price increases in both urban and rural environments in Ghana and Ethiopia.

In order to assess what would be the most culturally acceptable diet for low-income Ghanaian families living under the poverty lines of USD 3.1 and 1.9, another strategy was tested. Assuming that half of the household income is allocated to food, the total daily food budget for those families living in moderate and extreme poverty was estimated as USD 3.1 and 1.9 per day, respectively. Instead of minimizing the *cost*, the required *change* in dietary habits was minimized. This was done by minimizing the total *deviation* from the local food supply patterns.

The cheapest fully nutritious food basket for rural Ghanaian families cost more than the estimated food budget of USD 1.9 (Table 6). Therefore, obtaining a fully nutritious food basket was not possible without including wild foods in the food basket (Table 6). In urban areas, a food basket costing USD 1.9 included 22 food items, while a rural basket with wild foods contained 30 items.

Increasing the food budget to USD 3.1 per day (moderate poverty), resulted in increased food variety: a food basket costing USD 3.1 with minimum deviation from the local food supply consisted of 36 food items in the urban areas, and in the rural areas of Ghana, with wild foods, it had 39 food items, and without them 31. Also, the shares of foods from food groups became more similar to those reported by the FAO's food supply data. The same phenomenon was observed when including wild foods in the rural food baskets: as the food budget was increased to USD 3.1 per day, the share of wild foods decreased dramatically from 71% of the total weight to 5%. Hence, the more money that could be spent on food, the more feasible fully nutritious food baskets became as a result.

Culturally acceptable food baskets for the lowest-income families in Ethiopia were calculated with some modifications to the methods used in Ghana. Based on the average household food expenditure of the families with below median income, a maximum food budget of ETB 71.2 (USD 2.45) was determined. This budget was used as a reference to calculate food baskets with minimum deviation from the local food supply. These food baskets consisted of 48 and 64 foods in urban and rural areas of Ethiopia. When compared with the Ethiopian Public Health Institute's National Food Consumption Survey (Kebede & Modes, 2013), obtaining a fully nutritious diet with minimum changes to current food supply patterns would require substituting sorghum and teff with maize and increasing the share of legumes and nuts in the diets. Reductions would have to be made in the consumption of dairy products, roots, tubers, and sweets.

5.2 Strategies for Reducing Meat Consumption in Finland

5.2.1 Nudging Meal Choices

The study had a higher participation rate among women (59.5%) (Sub-study III, Table 1). The four treatment groups did not differ statistically in terms of gender, age, body mass index, frequency of trying new ingredients, or prior experience with Härkis®. However, there were statistically significant differences in employment rates between the treatments ($p < .05$). Participants who received DoD menu while being presented to the meat dish first were more likely to be employed and less likely to be students (66.7% and 16.7%, respectively) compared to those participants who also received DoD menu, but who were served the vegetarian dish first before the meat dish (47.5% and 45.0%, respectively) (Sub-study III, Table 1).

The results showed that the sequence alteration of main dishes or being subjected to a DoD menu did not significantly influence the choice of main dish before ($p = .13$) or after adjusting for gender, body mass index group, and age group ($p = .23$) (Table 9). Similarly, these strategies did not affect the proportion of minced meat casserole in the total meal weight prior ($p = .18$) or after ($p = .33$) adjusting for confounders (Table 10). Furthermore, the sequence alteration and DoD strategies did not significantly affect the total meal weights or the amount of salad selected.

Table 9. Main dish choices in Finnish lunch buffet by treatment and participant characteristics. Ordinal logistic regression was the choice of analysis method. Modified from original publication III.

	Choice of main dish			Crude model	Multi-variable model*
	Only fava-bean dish (%)	**Both main dishes (%)**	**Only minced meat dish (%)**	**p-value**	**p-value**
Treatment					
Standard menu, meat first	17.5% (*n* = 7)	35.0% (*n* = 14)	47.5% (*n* = 19)	.13	.23
Dish of the day menu, meat first	35.7% (*n* = 15)	26.2% (*n* = 11)	38.1% (*n* = 16)		
Standard menu, fava-bean first	15.4% (*n* = 6)	38.5% (*n* = 15)	46.2% (*n* = 18)		
Dish of the day menu, fava-bean first	15.4% (*n* = 6)	66.7% (*n* = 26)	18.0% (*n* = 7)		
Gender				.004	.002
Women	28.9% (*n* = 28)	40.2% (*n* = 39)	30.9% (*n* = 30)		
Men	9.5% (*n* = 6)	42.9% (*n* = 27)	47.6% (*n* = 30)		
BMI Group				.09	.056
18.5 - 24.9	25.0% (*n* = 20)	41.3% (*n* = 33)	33.8% (*n* = 27)		
25 - 29.9	22.9% (*n* = 11)	41.7% (*n* = 20)	35.4% (*n* = 17)		
> 30	6.5% (*n* = 2)	41.9% (*n* = 13)	51.6% (*n* = 16)		
AGE GROUP				.70	.626
18 - 29	24.1% (*n* = 14)	34.5% (*n* = 20)	41.4% (*n* = 24)		
30 - 44	27.1% (*n* = 13)	39.6% (*n* = 19)	33.3% (*n* = 16)		
45 - 65	14.3% (*n* = 8)	50.0% (*n* = 28)	35.7% (*n* = 20)		

BMI = body mass index. * Included variables: treatment, gender, BMI group, and age group.

Table 10. Proportion of minced meat casserole in the total meal weight by treatment, gender, body mass index group, and age group using linear models. For interpretation, a value of e.g. 0.47 corresponds to 47% of the total meal weight. Modified from original publication III.

	Share of minced meat casserole in the total meal weight (95% CI)	Crude model	Multi-variable model*
		p-value	p-value
Treatment			
Standard menu, meat first	0.47 (0.39, 0.55)	.18	.33
Dish of the day menu, meat first	0.36 (0.28, 0.44)		
Standard menu, fava-bean first	0.46 (0.37, 0.54)		
Dish of the day menu, fava-bean first	0.39 (0.31, 0.48)		
Gender		<.001	<.001
Women	0.35 (0.30, 0.40)		
Men	0.53 (0.46, 0.59)		
BMI Group		.25	.11
18.5 - 24.9	0.40 (0.34, 0.46)		
25 - 29.9	0.42 (0.34, 0.50)		
> 30	0.49 (0.40, 0.59)		
Age group		.69	.70
18 - 29	0.44 (0.36, 0.51)		
30 - 44	0.39 (0.31, 0.47)		
45 - 65	0.43 (0.36, 0.50)		

BMI = body mass index. * Adjusted variables: treatment, gender, BMI group, and age group.

5.2.2 Change Through Regulation? The Acceptance of Meat Reduction Policies

The acceptance of four strong meat reduction policies (two focusing on price increases and two on reducing the availability of meat) was investigated among a representative sample of Finnish adults aged 18-75 years (n = 1999). The policies had acceptance rates ranging from 25% to 35%. Heavy taxation of the most environmentally harmful meat products was the most acceptable policy, with 35% acceptance, while the prohibition of discount sales was the least acceptable, with 25% acceptance (Figure 4). A notable share of participants, 20% to 24% depending on the policy, remained neutral.

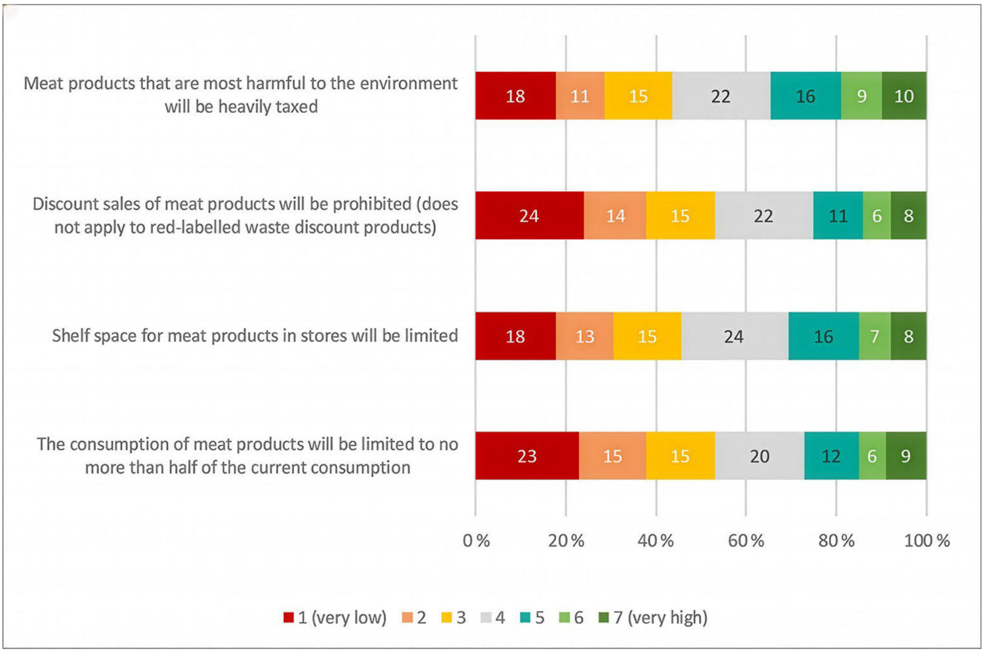

Figure 4. The acceptance of meat reduction policies among Finnish adults aged 18-75 years (n = 1999). Modified from original publication IV.

Figure 5 displays literature-based hypothesized regression pathways between environmental risk perception, political trust, and policy effectiveness, fairness, and intrusiveness. Environmental risk perception and political trust were both treated as latent constructs, which were measured via multiple items each. A separate structural equation model was created for each policy. Figure 5 shows the estimated standardized coefficients of the final model created to investigate the determinants of discount prohibition policy acceptance.

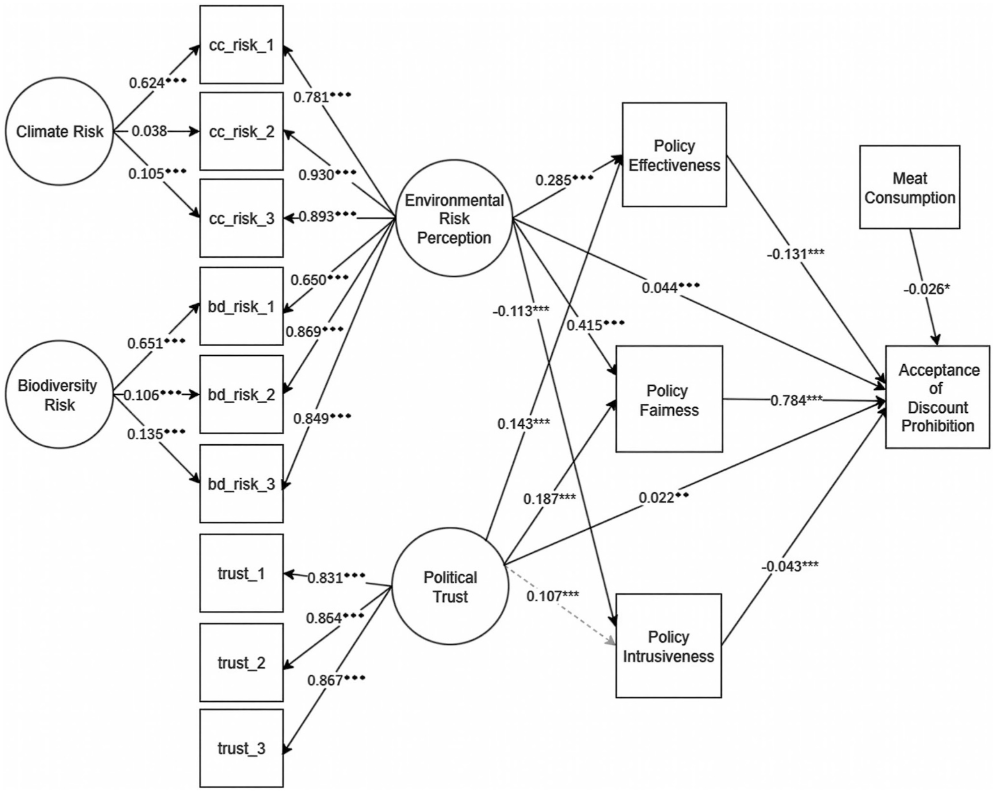

Figure 5. A graphic illustration of the final structural equation model presenting how environmental risk perception and political trust impact, directly and indirectly, the acceptance of the prohibition of meat discount sales through perceived effectiveness, fairness, and intrusiveness of the policy. Solid black arrows mark supported hypotheses, whereas a dashed grey arrow marks rejected hypotheses. Each line represents a regression line with estimated standardized coefficients. Square objects are measured items, whereas circles represent latent constructs measured using multi-item scales. *cc_risk_1–3* are items measuring climate change risk perception, *bd_risk_1–3* are items measuring biodiversity loss risk perception, and *trust_1–3* are items measuring political trust. *** p < .001, ** p < .01, * p < .05. Modified from original publication IV.

The models created to examine predictors of meat reduction policy acceptance explained a large share of the variation in acceptance for all four policies ($0.788 < R^2 < 0.828$). This suggests that key factors influencing policy acceptance were identified.

The results of the SEM showed that the primary factor influencing policy acceptance was perceived fairness ($0.729 < \beta_s < 0.784$, $p_s < .001$), with perceived policy effectiveness being the next most significant ($0.131 < \beta s < 0.163$, $p_s < .001$) (Table 11). Policy intrusiveness negatively impacted acceptance, though the effect was minor ($-0.073 < \beta_s < -0.043$, $p_s < .001$).

Table 11. Summary of the structural equation modelling results. All bolded paths in the left column were preregistered hypotheses. All four policies' estimated standardized coefficients are presented as a range. Modified from original publication IV.

Preregistered Hypotheses (Path Name)	Range of Estimated Standardized Coefficients	P_s
Effectiveness -> Acceptance (+)	$0.131 < \beta_s < 0.163$	< .001
Fairness -> Acceptance (+)	$0.729 < \beta_s < 0.784$	< .001
Intrusiveness -> Acceptance (-)	$-0.073 < \beta_s < -0.043$	< .001
Risk -> Effectiveness (+)	$0.286 < \beta_s < 0.453$	< .001
Risk -> Fairness (+)	$0.415 < \beta_s < 0.470$	< .001
Risk -> Intrusiveness (-)	$-0.143 < \beta_s < -0.109$	< .001
Risk -> Acceptance (+) (Total Effect)	$0.412 < \beta_s < 0.484$	< .001
Risk -> Effectiveness -> Acceptance*	$0.037 < \beta_s < 0.074$	-
Risk -> Fairness -> Acceptance*	$0.326 < \beta_s < 0.352$	-
Risk -> Intrusiveness -> Acceptance*	$0.005 < \beta_s < 0.010$	-
Risk -> Acceptance (+)**	$0.037 < \beta_s < 0.072$	< .01
Trust -> Effectiveness (+)	$0.103 < \beta_s < 0.143$	< .001
Trust -> Fairness (+)	$0.175 < \beta_s < 0.187$	< .001
Trust -> Intrusiveness (-)	$0.088 < \beta_s < 0.132$	< .01
Trust -> Acceptance (+) (Total Effect)	$0.162 < \beta_s < 0.182$	< .001
Trust -> Effectiveness -> Acceptance*	$0.017 < \beta s < 0.019$	-
Trust -> Fairness -> Acceptance*	$0.128 < \beta s < 0.146$	-
Trust -> Intrusiveness -> Acceptance*	$-0.008 < \beta s < -0.005$	-
Trust -> Acceptance (+)**	$0.006 < \beta_s < 0.031$	< .01 .062*** < .05 .646****
Meat Consumption -> Acceptance (-)	$-0.054 < \beta_s < -0.023$	< .05

* Indirect effect, ** Direct residual effect.
*** Policy #2: Discount prohibition (β = 0.022, p = .062).
**** Policy #4: 50% reduction in meat consumption (β = 0.006, p = .646).

All preregistered hypotheses were supported except for one: The original hypothesis was that those with higher political trust would view the policies as less intrusive compared to those with low trust, but instead, those with higher political trust viewed policies as *more* intrusive compared to those with low trust (Table 11).

The analysis revealed that both environmental risk perception and political trust played a role in policy acceptance: The total impact of environmental risk perception on policy acceptance was substantial when considering both direct and indirect effects ($0.412 < \beta_s < 0.484$, $p_s < .001$) (Table 11). The majority of the effect was indirect via perceived effectiveness, fairness, and intrusiveness. After adjusting for the indirect effects, the direct residual effect was small but yet significant (Table 11).

When accounting for both direct and indirect effects, political trust moderately influenced policy acceptance ($0.162 < \beta_s < 0.182$, $p_s < .001$) (Table 11). Again, the majority of the effect was indirect (Table 11). However, after considering the indirect effects through policy effectiveness, fairness, and intrusiveness, the direct residual impact of political trust on the acceptance of a discount prohibition ($\beta = 0.022$, $p = .062$) and 50% meat consumption reduction was not significant ($\beta = 0.006$, $p = .646$) (Table 11).

6 Discussion

6.1 Summary of the Findings

This thesis investigated sustainable diet strategies in Ghana, Ethiopia, and Finland. The methodology of each sub-study was tailored to the specific socioeconomic and cultural conditions of the study settings.

In low-income settings, LP was used to model nutritionally adequate diets based on locally available foods. The initial cost-minimised food baskets in Ghana and Ethiopia included only small shares of animal-based products and consisted of 12–19 food items. However, these diets were unaffordable for rural Ghanaian families living in extreme poverty unless wild foods were included. Following these diets would require substantial changes from current consumption patterns. Increasing food budgets improved food variety, which highlights the trade-off between cost and palatability. These findings underscore the importance of considering economic constraints and local food culture in designing feasible diet strategies for low-income populations.

In high-income settings, the focus was on reducing red meat consumption via nudging and policy interventions. The real-world nudging intervention in Finland tested the DoD and sequence alteration strategies but found no significant effects on meal choices. This suggests that subtle nudges may be insufficient in contexts with strong cultural preferences for meat. The survey-based study on public acceptance of meat reduction policies revealed that perceived fairness was the strongest predictor of support, followed by policy effectiveness, environmental risk perception, and political trust. These findings suggest that public perceptions and trust play a significant role in advancing sustainable diet policies.

Distinct methodologies were chosen for the sub-studies conducted in Ghana, Ethiopia, and Finland to reflect the structural and cultural differences. While the sub-studies were not designed for direct comparison, the findings highlight a need for context-sensitive approaches when developing sustainable diet strategies.

6.2 Toward Nutritionally Adequate and Affordable Diets in Low-Income Settings

LP was used as a modelling tool to design nutritionally adequate diets. While it is not a strategy or intervention itself, it supports the development of sustainable diet strategies by identifying how a nutritious diet can be formed and accessed with limited economic resources.

The simplest cost-minimized food baskets developed for Ghana and Ethiopia included only small amounts of animal-based products and consisted of 12–19 food items. In Ghana, cereals, roots, and tubers dominated the baskets, while in Ethiopia, cereals (especially maize), vegetables, beans, and sesame seeds made up the majority. However, adopting these diets would require substantial changes to current dietary habits.

Food baskets were slightly more expensive in rural areas than in urban areas. This aligns with findings from rural South Australia: Previously, Ward et al. (2012) observed that although healthy foods were costlier in rural areas, the possibility of assembling a healthy food basket did not differ significantly between urban and rural settings.

In rural Ghana, the cost-minimized diets were not affordable for low-income families unless wild foods were included. A similar challenge has been reported in Vietnam, where individuals living below the updated international poverty line of USD 2.15 per day were unable to afford a healthy diet (Van et al., 2024).

While incorporating wild foods could help bridge the affordability gap in Ghana, their use is limited. Only 40% of households across six regions in Ghana report collecting wild foods (Cooper et al., 2018), which significantly limits their potential as a widespread dietary solution. The use of wild foods is further constrained by factors such as seasonal availability, geographic access, time-intensive harvesting, and the presence of potentially harmful substances like nitrates (Matallana González et al., 2010). Therefore, relying on wild foods cannot be considered a sustainable or scalable diet strategy.

However, an increase of USD 0.1 per day in the food budget would be enough to afford the cheapest food basket that meets all nutrient requirements for families living in rural Ghana. The observed price-determining nutrients in most of the designed cost-minimized diets were n-3 fatty acids, iodine, and vitamins A, B_3, C, and E. These findings are largely consistent with global patterns: a study by Bai et al. (2021), which analysed the cost of nutritionally adequate diets in 177 countries, identified calcium and vitamins A, B_2, B_9, B_{12}, C, and E as the most cost-influential nutrients. Thus, the results from Ghana and Ethiopia align closely with global averages.

A common issue with using LP in diet optimization is that it selects a limited number of foods (see e.g. Maillot et al., 2010; Wilson et al., 2013). Similarly, the simplest cost-minimized diets designed in this study only contained 12-19 food items, depending on the area. Following such a diet likely leads to diets becoming too repetitive over long durations (Parlesak et al., 2016), and therefore, diet optimization with LP cannot be recommended without including measures to increase cultural acceptability.

6.3 Balancing Cultural Acceptability and Economic Constraints in Sustainable Diet Design

To improve cultural acceptability, diets were diversified and aligned more closely with local food supply patterns, which increased both variety and cost. While these strategies enhanced feasibility, especially when combined with local food budget constraints, affordability remained a major barrier, particularly for rural populations living in poverty.

Using the local food budgets as price limits resulted in the most feasible dietary solutions. Applying price limits, while increasing food variety and minimizing the required change from current eating patterns, can be recommended to be applied simultaneously when designing culturally acceptable and fully nutritious diets for populations living in low-income settings.

However, when applying the international poverty line of USD 1.90 as a daily food budget, rural Ghanaian families could not afford a nutritionally adequate diet without including wild foods. In contrast, wild foods were not considered in the urban diet models. Even with their inclusion in rural areas, diets that closely resembled local food supply patterns remained limited in variety, comprising only 30 items in rural areas and 22 in urban areas. This restricted variety may lead to dietary monotony, making long-term adherence difficult. Moreover, although these food baskets met all nutritional requirements, greater food variety may offer additional health benefits, such as improved gut microbiota through increased beneficial bacteria and reduced pathogenic bacteria (Huang et al., 2022).

These findings suggest that the cost of the diet is a significant barrier to maintaining a healthy diet, considering that approximately one-fourth of the Ghanaian population lives below the current poverty line of USD 2.15 (World Bank, 2025a). Transitioning to healthy and sustainable diets has been observed to increase dietary costs in low- and lower-middle-income countries (Springmann et al., 2021). Adding more constraints to LP models is likely to increase the cost of the diet (Parlesak et al., 2016). Incorporating environmental sustainability constraints, such as limits on greenhouse gas emissions, would likely further increase the cost of the diet in Ghana. Achieving a diet that is both healthy and environmentally sustainable would likely be unaffordable for an even larger share of the population than the one-fourth currently living on less than USD 2.15 per day. This highlights the need to develop strategies that balance affordability and environmental sustainability.

Increasing the daily food budget to USD 3.10 led to more diverse food baskets that were closer to the food supply patterns reported by the FAO (2018). These diets required fewer changes from existing consumption habits, making them more culturally acceptable. Thus, higher food budgets enable the design of diets that better align with local food preferences.

In Ethiopia, a daily food budget of USD 2.45 was determined based on the average household food expenditure of families with incomes below the median. The food baskets with minimum deviation from local food supply patterns comprised 48 items in urban areas and 64 items in rural areas of Ethiopia, covering items from all 11 food groups used in the national dietary intake study (Kebede and Modes, 2013). Hence, in Ethiopia, minimising the deviation from the local food supply resulted in developing food baskets with relatively high dietary diversity. Given the high prevalence of low dietary diversity in Ethiopia, particularly in rural areas (Jateno et al., 2023), the optimised food baskets may offer a useful starting point for addressing this nutritional health challenge. Nevertheless, their practical feasibility and long-term acceptability require further investigation.

6.4 Behavioural Nudges for Dietary Change: Cultural and Contextual Limits in High-Income Settings

The nudging study found that neither altering the sequence of main dishes nor presenting a DoD menu influenced food choices among Finnish working-aged omnivores. To date, no research has examined the combined use of these strategies in Finland. In this study, applying them—either separately or in combination—did not lead to significant changes in food selection before or after adjusting for gender, age, and body mass index. These null results suggest that the nudging might not be effective in the Finnish cultural context, where meat plays a significant role (Mäkelä & Rautavirta, 2018).

A Cochrane review by Hollands et al. (2019) found that the evidence supporting the effectiveness of altering dish sequences to reduce consumption of targeted foods was of very low certainty. Only a few studies have tested the effect of sequence alteration in food choices in buffet restaurants (Kongsbak et al., 2016; Wansink and Hanks, 2013) or salad bars (Rozin et al., 2011). However, direct comparisons are difficult due to differences in study designs and cultural contexts. For example, Wansink and Hanks (2013) arranged foods from healthy to unhealthy and vice versa at an American health conference buffet, noticing a dramatic decrease in the selection of bacon (54% vs. 5% of participants) when it was served as the second compared to the second-to-last item in a seven-item buffet line. Similarly, Kongsbak et al. (2016) conducted a small (n = 65) nudging intervention in Denmark that altered the sequence of several food items simultaneously and found an increase in the intake of salad and pasta, but no statistically significant effect on the intake of meatballs.

Rozin et al. (2011) placed eight different food items either on the edge or in the middle of the table, making them harder for participants to reach. This experiment, conducted in an American university cafeteria, did not affect the chosen amounts of chicken.

The changes in sequence were small in this study, as the main dishes were served right next to each other. Participants were aware of the available main dishes as they had received a menu before entering the buffet lines. In Finland, salad items are typically served before the main dishes in buffet restaurants, so it was logical to test only smaller changes in dish sequence. The main dishes served in this study were also highly similar. Therefore, the studies cannot be directly compared. If the participants had been fully unaware of which dishes were being served, the effect might have been slightly different.

Rantala et al. (2022) suggest that the change in dish sequence must be large enough before it starts to influence food choices. Therefore, the findings from Kongsbak et al., Wansink and Hanks, and Rozin and colleagues could potentially be explained by the larger magnitude of changes made to the dish sequence. Another potential explanation for the differing findings might be different cultural contexts. Furthermore, reducing meat consumption might be particularly difficult compared to other food items due to its strong role in Western culture (Chiles and Fitzgerald, 2018). Considering that in Finland salad components are typically served at the beginning and main dishes at the end of the buffet lines, there is relatively little room for a reasonably-sized main dish sequence alteration in Finnish lunch restaurants.

Previous studies conducted in high-income settings examining the effect of the DoD strategy have yielded varied results, potentially influenced by the specific context in which they were conducted. For example, the DoD strategy did not affect teenagers' likelihood of choosing a vegetarian main dish in Denmark, France, Italy, or the U.K. (Dos Santos et al., 2020).

Saulais et al. (2019) found that French employees had a higher probability of choosing a vegetarian meal when it was presented as a DoD, with the selection rising from 34% to 60% when one option was presented, and from 23% to 53% when a second vegetarian meal was available. Hartwell et al. (2020) found that the DoD strategy had different impacts among various population groups: among teenage females, the choice of vegetarian dishes increased, but there was no effect among males or the elderly. Furthermore, Zhou and colleagues (2019) found that the strategy did not increase the probability of elderly Europeans choosing a vegetarian dish. However, the effect was stronger among women than men, as well as among participants from the UK and Denmark, relative to those from France. In this study, the DoD strategy did not affect Finnish adult omnivores' main dish choices or the amount of salad selected.

Considering the results of previous studies and this study, more research is needed to assess the effectiveness of sequence alteration and DoD strategies in promoting more plant-based diets in high-income settings. However, it is also possible that such voluntary nudges may be insufficient to produce substantial dietary shifts. Stronger, potentially non-voluntary measures may be required to shift consumption patterns toward more sustainable diets.

6.5 Public Perceptions and Political Trust: Cultural and Political Dimensions of Meat Reduction Policy Support in Finland

Overall, public support for strong meat reduction policies in Finland was relatively low. Among adults, acceptance rates for four different policy measures ranged from 25% to 35%. The fairly low acceptance rates could potentially be attributed to the intrusive nature of the policies (Ammann et al., 2025; Diepeveen et al., 2013; Pechey et al., 2022). Another significant factor influencing acceptance might be the long cultural traditions of eating meat (Mäkelä & Rautavirta, 2018). Furthermore, the latest national dietary intake study from Finland shows that 93% of Finnish men and 60% of Finnish women exceed the current weekly allowance of red and processed meat (Valsta et al., 2018). Therefore, the high consumption of red meat in Finland is likely to influence the acceptance rates.

The acceptance rates align with those from the U.K. (Pechey et al., 2022): 27% of U.K. residents supported policies that increased the price of meat, whereas 40% accepted policies that reduced the availability of meat. However, the policies investigated in this study can be considered more coercive than those by Pechey et al. (2022) as they impact all meat-eaters daily.

Perceived fairness was the most significant predictor of policy acceptance. This aligns with the findings from studies in related fields (Bos et al., 2015; Clayton, 2018; Bergquist et al., 2022; Thaller et al., 2023), which have emphasized that perceived fairness is a more significant factor than the perception of policy effectiveness. However, others have found the opposite effect (see, e.g., Huber et al., 2020). In this study, the focus was on environmental risk perception, and hence, participants were asked how they viewed the effectiveness in terms of *protecting nature*. If the participants had been asked about the policies' effectiveness in *reducing meat intake*, the perception of effectiveness might have become a more significant predictor of policy acceptance.

Perceived intrusiveness of the policy had a small negative effect on policy acceptance, implying that once fairness and effectiveness have been adjusted for, the role of intrusiveness is small. This finding aligns with those from Thaller et al. (2023), who studied the acceptance of low-carbon mobility policies. To gain a more holistic picture of the phenomenon, more studies are needed to fully understand the role of intrusiveness on meat reduction policy acceptance.

The results showed that the environmental risk perception had a large total effect on policy acceptance when considering both direct and indirect effects. This is consistent with previous studies: for example, Stancu et al. (2023) found that Finns with high environmental concern perceived meat as less sustainable than vegetarian alternatives. The finding could also be potentially attributed to Finns viewing biodiversity loss as a serious threat, as 80% consider halting biodiversity loss an urgent cause (Finnish Ministry of Environment, 2025).

The environmental risk perception influenced policy acceptance mostly indirectly via effectiveness, fairness, and intrusiveness. This finding aligns with those suggested by Fujii et al. (2004) and Bamberg and Rölle (2003).

These results may be explained by the tendency of individuals who perceive climate change and biodiversity loss as serious risks to emphasize the positive consequences of meat reduction policies. As a result, they may assess such policies as more effective and fair, and less intrusive, compared to those with a lower perception of environmental risks.

Political trust had a moderate total effect on policy acceptance. However, when accounting for indirect effects through perceived effectiveness, fairness, and intrusiveness, the direct association between political trust and policy acceptance became nonsignificant for two of the four policies—namely, the prohibition of discounts and the policy to halve meat consumption. In these cases, the influence of political trust was fully mediated by perceptions of effectiveness, fairness, and intrusiveness, with fairness being the most prominent pathway.

This mediation effect has been observed in previous studies, such as those by Kim et al. (2013) and Schmöcker et al. (2012), which examined these three pathways concurrently. One possible explanation is that individuals with high political trust are more likely to believe that policymakers will design policies that are just and equitable.

The finding that political trust influences policy acceptance is consistent with prior research in this area, including Pechey et al. (2022), as well as studies from related fields (Eykelenboom et al., 2019; Gunarathne et al., 2020; Hammar & Jagers, 2006; Harring & Jagers, 2013; Kallbekken & Sælen, 2011; Konisky et al., 2008).

In contrast to the preregistered hypothesis, political trust correlated positively with intrusiveness. It may be that high-trust individuals have higher expectations of political decision-makers. For example, they might expect less intrusive policy measures from decision-makers and hence rate the proposals as more intrusive due to their expectations. However, more studies are needed to better understand this phenomenon.

6.6 Strengths and Limitations

One of the key strengths of this thesis is its inclusion of diverse socioeconomic and cultural contexts, which enables a comparative lens across low- and high-income settings. This structure makes visible how the feasibility of sustainable diet strategies is shaped by local conditions. The thesis provides valuable knowledge about the importance of contextual tailoring when designing and implementing sustainable diet strategies.

The sub-studies conducted in Ghana and Ethiopia were the first recorded attempts to create fully nutritional and culturally acceptable diets for low-income families in these countries. The food price data was collected on-site with the help of local staff under the researchers' supervision. This ensured a minimum level of feasibility for the developed food baskets.

However, several limitations of the LP methodology should be acknowledged. Modelling food preferences and cultural acceptability using LP is inherently challenging, and the palatability of the optimized diets may therefore be limited. It also does not incorporate behavioural, social, or psychological factors influencing food choices.

Although cooked nutrient values were used where appropriate, the model does not fully account for nutrient bioavailability or the complex interactions between nutrients and food matrices. For example, diets high in phytates and low in vitamin C may inhibit iron absorption, even if total iron content appears sufficient (Piskin et al., 2022). Additionally, the initial models could not guarantee adequate levels of all essential amino acids due to the low quantity of pulses and animal-based products in the food baskets.

A major limitation is that the validity of LP-optimized results depends heavily on the quality of input data. In this study, the cultural acceptability of the diets for low-income families in Ghana and Ethiopia was based on food supply data from the FAO (2018), as no suitable national dietary intake studies were available. These data provide only per capita estimates and do not account for the variation across subpopulations (e.g., by age, sex, or region), limiting the ability to model tailored dietary solutions. Moreover, the data lacked detail on many individual food items, further constraining the modelling process. Access to more detailed, individual-level national dietary survey data on food consumption habits would likely improve both the reliability and acceptability of the modeled diets.

Environmental impacts were not included in the models due to the absence of relevant data for the case countries. Nevertheless, the developed diets were low in animal-based products, suggesting that their environmental footprint is likely to be relatively moderate.

Alternative modelling approaches may offer improvements where relevant data is available. For example, cluster-based optimization methods, as proposed by Colombo et al. (2023), may better capture population heterogeneity than standard LP. Combining clustering with multi-objective optimization can result in more realistic and acceptable diets, while also accounting for multiple sustainability domains (Bashiri et al., 2025).

The cost estimates did not account for expenses related to food preparation, energy use, storage, or food waste. Additionally, beverages other than cow and soy milk were excluded from the modelling due to their minimal contribution to nutritional adequacy. However, access to clean drinking water is essential and should be considered in future cost estimates. While drinks such as tea and coffee were also excluded, their cultural significance may influence the acceptability of modeled diets. Future studies should assess the role of such drinks in dietary patterns and consider their inclusion where relevant.

Seasonality was not accounted for due to funding constraints. As a result, the optimized food baskets may include items that are only seasonally available or affordable, which could further reduce the practical feasibility of the diets. Seasonal variation in food availability and prices is known to impact both dietary diversity and food security, for example, among rural Ethiopian households (Aweke et al., 2022).

Wild foods were included in the modelling where data were available, as they can contribute meaningfully to nutrient intake, especially in rural and low-income contexts. In contrast, home-grown foods were excluded. While home production can enhance food variety in some rural areas, not all households have access to land or resources for cultivation—even in rural settings. Including home-grown foods could have introduced bias by overestimating their availability and accessibility for low-income families.

The nudging study conducted in Finland took place in a real-world buffet restaurant setting and was the first study to examine the effect of sequence alteration on food choices among Finnish adults in such an environment. The importance of conducting interventions in real-world settings has been emphasized by researchers such as Hollands et al. (2019) and Bucher et al. (2016). The main dishes offered to the participants were identical except for the primary protein source—red meat versus fava bean protein. This methodological choice accounted for potential bias arising from factors such as appearance, colour, or scent. Additionally, the changes made to the dish sequence were small and resembled changes that could be implemented in other Finnish buffet restaurants.

The nudging study was conducted during the COVID-19 pandemic, which resulted in challenges in recruiting participants. Recruitment was conducted through multiple channels, including advertisements at the restaurant and on Facebook, invitations to those in the Functional Foods Forum's consumer register, users of the MyFlavoria® mobile app, and email lists of staff working in the same university hospital building. Additionally, email lists of student organizations and staff members were utilised. Despite using several recruitment channels, a fairly low sample size of 163 Finnish participants was gathered. The sample represents urban, working-age Finnish omnivores who are likely to be relatively health-conscious. The findings may be cautiously generalized to urban Finnish meat-eaters without dietary restrictions who eat in buffet-style lunch settings. Future nudging studies should aim for larger, stratified samples and include rural populations, individuals with dietary restrictions, and diverse socioeconomic backgrounds.

The models created to study predictors of meat reduction policy acceptance explained a large share of the variation in acceptance for all four policies. This suggests that key factors influencing the acceptance of meat reduction policies have been successfully identified. The analysis was based on a large, representative sample of the adult Finnish population aged 18–75. Therefore, the results can be generalized to this population and potentially to other high-income Western countries with similarly high levels of meat consumption, although cultural and political differences must be considered. The use of SEM enabled the investigation of complex relationships, including both direct and indirect effects, thereby increasing the validity of the findings. The measurement model showed high internal consistency and composite reliability for both environmental risk perception and political trust.

Even though the proposed policies primarily affected omnivores, a robustness check excluding non-meat-eaters confirmed that their inclusion did not significantly bias the results (see Sub-Study IV). Meat consumption was accounted for using broad dietary categories (meat-eaters versus non-meat-eaters). An additional robustness check controlling for beef consumption frequency showed that the results remained largely consistent. However, the direct effect of political trust on the acceptance of a ban on discount sales became statistically significant. This result indicates that political trust has a stronger independent effect on policy acceptance once differences in beef consumption frequency are accounted for. Interestingly, this effect was not observed for the other price-related policy—the meat tax. One possible explanation is the wording of the tax policy, which referred to taxing meat products with the highest environmental impacts. Frequent beef consumers may not recognize that beef has the highest environmental footprint, and therefore may not perceive the tax as directly targeting their consumption

Several limitations should be acknowledged. Perceived policy acceptance, effectiveness, fairness, and intrusiveness were measured using single items. For example, perceptions of fairness were assessed with the question: "*How fair do you consider these actions from your own and other people's perspectives?*". This phrasing allowed for multiple interpretations. Given that meat reduction policies affect various domains—including health, the environment, animal welfare, and personal dietary habits—participants may have considered a range of factors when responding. The use of single-item measures was driven by survey length and funding constraints, although multi-item scales would have provided more nuanced data. Despite this limitation, previous studies (e.g., Jagers et al., 2024) have employed similar approaches, and Nagy (2002) argues that single-item measures may offer higher face validity than multi-item scales.

Additionally, the policy statements were brief and lacked specific details, such as tax percentages or targeted meat types. Therefore, acceptance rates should be interpreted with caution.

Previous research has identified individual-level factors—such as intentions to reduce meat consumption, perceived importance of environmental responsibility, and beliefs about the health benefits of eating less meat—as influential in shaping attitudes toward meat reduction policies (Pechey et al., 2022). Including these variables in future study designs could yield deeper insights into the predictors of policy acceptance.

Finally, due to the cross-sectional design of the study, causal relationships cannot be established. Future research should employ experimental or longitudinal designs and focus more explicitly on omnivores, who represent the primary target group for meat reduction policies.

6.7 Practical Implications

The findings from Ghana and Ethiopia show that the costs of a fully nutritious diet could be decreased by the cultivation of foods that are high in cost-delimiting nutrients. Their production could be potentially increased via both commercial and subsistence farming. Reducing the cost of foods that contain the aforementioned nutrients by e.g., through agricultural policies, would also result in lowering the cost of a healthy diet in Ghana and Ethiopia.

Intervention studies should be conducted to assess whether the optimized food baskets are feasible for Ghanaian families. The use of wild foods may also be inhibited by the considerable amount of time spent on harvesting them, or food-specific taboos or beliefs observed among certain subpopulations in Ghana (Colecraft et al., 2022).

When conducting sub-studies I and II, Ghana and Ethiopia lacked national food-based dietary guidelines. The findings of these sub-studies were utilised in the development of the first food-based dietary guidelines for Ghana and Ethiopia, published in 2023 and 2022, respectively (Federal Government of Ethiopia et al., 2022; Ghana Ministry of Food and Agriculture & University of Ghana School of Public Health, 2023). The LP strategies developed for these sub-studies can be adapted to various low-income settings, provided the local cultural context is considered.

The null results from both the DoD and sequence alteration strategies suggest that a more comprehensive approach with additional elements, such as price incentives, might be necessary to influence meat consumption in Finland. The study results, along with findings from another nudging study on product placement conducted in Finland (Rantala et al., 2022), also suggest that the magnitude of sequence alteration may need to be large enough for the strategy to work in lunch contexts. However, this may not be viable in all lunch situations, considering the limited serving space, which is the case in most Finnish buffet lines. At the global level, the effectiveness of these nudging strategies has to be assessed in each cultural context.

The SEM results indicate that policy attributes, particularly perceived fairness, are major determinants of meat reduction policy acceptance. Hence, policy formulation and communication are likely to affect the acceptance of strict meat reduction policies. Policymakers should emphasize fairness and equality when designing meat reduction policies, and the benefits should be communicated clearly to increase their acceptance.

The results suggest that acceptance can also be improved by increasing political trust and/or environmental risk perception. However, previous studies have shown that an increased perception of risk may ultimately lead to inaction or even denial of the issue, as individuals may use their resources to cope with fear instead of trying to solve the issue itself (Peters et al., 2013; Witte & Allen, 2000). Hence, increasing political trust may be a safer but more challenging method to increase the acceptance of meat reduction policies. Levels of political trust are low and have even decreased in some countries (e.g., Citrin & Stoker, 2018; Devine & Valgarðsson, 2023). Despite this, the focus should be on clear and consistent communication, which may increase trust in government (Rufai & Bunce, 2020) and consequently the acceptance of the policies.

7 Conclusions

This doctoral thesis investigated how sustainable diet strategies can be designed and applied within specific socioeconomic and cultural contexts to support the transition toward more sustainable diets. It contributes to understanding how nutrition, affordability, cultural acceptability, and environmental sustainability can be addressed in context-specific ways. The findings from four sub-studies are synthesised below using the multidimensional framework for sustainable diets defined by the FAO.

- **Nutrition and health**

  In Ghana and Ethiopia, LP was used to model nutritionally adequate diets for low-income households based on locally available foods. The results showed that such diets may be theoretically achievable, but in rural Ghana, families living below the extreme poverty line could not afford them without relying heavily on wild foods. These findings highlight the need for targeted interventions to improve dietary adequacy. However, the modelling did not account for nutrient bioavailability, assess the feasibility of implementation or the likelihood of uptake. Hence, the optimised diets should not be interpreted as directly applicable strategies for dietary change.

- **Economic affordability**

  Affordability emerged as a major barrier to sustainable diets. Even small increases in food budgets significantly improved the feasibility of nutritionally adequate diets. However, enhancing cultural acceptability—by increasing food variety and aligning with local food supply patterns—was associated with higher costs. These findings suggest that policy measures to reduce the cost of nutrient-dense foods are essential, particularly for low-income populations. The modelling also showed that specific nutrients (e.g., n-3 fatty acids, iodine, vitamins A, C, and E) disproportionately influence diet cost, offering a potential focus for agricultural and subsidy policies.

- **Societal and cultural acceptability**

  Cultural norms and dietary traditions have a strong impact on the feasibility of dietary changes. In Ghana and Ethiopia, minimising deviation from current food supply patterns increased diet costs, which indicates a trade-off between cultural acceptability and affordability. In Finland, behavioural nudging interventions (dish sequence alteration and DoD strategy) did not significantly affect meat consumption, suggesting that such approaches may be insufficient in contexts with strong cultural preferences for meat. Future strategies should be culturally tailored and supported by the implementation of well-designed food policies.

- **Environmental impact**

  Although environmental constraints were not included in the diet models due to data limitations, the low share of animal-based products in the modelled diets suggests a relatively moderate environmental footprint. The thesis also examined policies aimed at reducing excessive meat consumption, a major contributor to climate change and biodiversity loss. In Finland, public acceptance of meat reduction policies was primarily influenced by perceived fairness, with political trust and environmental risk perception emerging as important distal predictors. These findings suggest that the acceptance of meat reduction policies could be increased via deliberate communication and attention to equity concerns.

Together, these findings address the primary research question by demonstrating how sustainable diet strategies can be designed and applied within specific socioeconomic and cultural contexts. Overall, the sub-studies show that sustainable diet strategies must be tailored to local structural and cultural conditions. Future research should include larger and more diverse study populations to improve the generalizability of findings and support the development of more effective solutions for sustainable diet transitions.

8 Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this work, the author used Microsoft Copilot to assist with language editing and improving readability. All content was subsequently reviewed and edited by the author, who assumes full responsibility for the final version of the publication.

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