



Opportunities and challenges with the shift to climate-adapted food consumption

Balancing nutrition, climate impact, and
acceptance in public and private meals

Mari Wollmar



Opportunities and challenges with the shift to climate-adapted food consumption

Opportunities and challenges with the shift to climate-adapted food consumption

Balancing nutrition, climate impact, and acceptance in
public and private meals

Mari Wollmar



© MARI WOLLMAR, 2025
ISBN 978-91-7963-217-5 (printed)
ISBN 978-91-7963-218-2 (pdf)
ISSN 0436-1121

The publication is also available in full text at:
<http://hdl.handle.net/2077/85276>

Subscriptions to the series and orders for individual copies sent to: Acta
Universitatis Gothoburgensis, PO Box 222, SE-405 30 Göteborg, Sweden or to
acta@ub.gu.se

Cover: Illustration by Alexandra Dahlqvist. Detailed information can be found on
page 117.

Photographer: Maja Kristin Nylander

Print: Stema Specialtryck AB, Borås, 2025



Abstract

Title: Opportunities and challenges with the shift to climate-adapted food consumption. Balancing nutrition, climate impact, and acceptance in public and private meals

Author: Mari Wollmar

Language: English

ISBN: 978-91-7963-217-5 (printed)

ISBN: 978-91-7963-218-2 (pdf)

ISSN: 0436-1121

Keywords: Iron, bioavailability, climate impact, activity level, carbon footprint, taste, sustainability

This thesis explores the transition toward climate-adapted food consumption, combining insights from both public and private domains. Through four studies, the thesis investigates the balance between reducing carbon footprint (CO₂e) and ensuring nutritional adequacy, revealing overlooked tensions in our shift toward sustainable diets.

Rather than presenting findings by individual studies, this thesis organizes results around three interrelated themes that emerged across all four papers. The first theme examines school meals as potential climate champions, revealing both opportunities and challenges in public meal settings. The second theme explores how gender shapes nutritional needs and dietary behaviors in climate-adapted food practices. The third theme investigates the relationship between physical activity levels and CO₂e, identifying pathways to unite active lifestyles with sustainability.

In school meal menus across Sweden, climate adaptation is taking center stage. Yet beneath these well-intentioned changes lies an unexpected nutritional dilemma. The analysis of municipal school meal programs revealed a troubling relationship, as CO₂e emissions decreased, iron bioavailability declined as well. This finding raises important questions about the nutritional adequacy of climate-adapted menus, especially for adolescent girls.

The paradox became particularly evident in soy-based meals. These meals contained the highest total iron, simultaneously they had the lowest amount of absorbable iron, with minimal bioavailability. None of the analyzed menus provided enough absorbable iron for female pupils with higher needs, highlighting

how climate-adapted meal planning may inadvertently create nutritional blind spots.

To address this challenge, hybrid recipe formulations that bridged the divide between climate goals and nutritional needs was developed. By combining plant ingredients with modest amount of meat together with vitamin C rich foods, these recipes achieved significant CO_{2e} reductions while maintaining adequate absorbable iron levels. Consumer evaluations revealed that these hybrid approaches maintained high acceptance levels, suggesting that balancing nutrition, taste, and sustainability is entirely possible.

Throughout this thesis, gender emerged as a powerful lens for understanding sustainable food transitions. A consistent pattern appeared: women demonstrated stronger climate consciousness in their food consumption but faced greater nutritional vulnerabilities when adopting low-carbon diets.

Female participants consistently consumed less energy than recommended, creating a nutritional deficit that impacts micronutrient intake. This was especially pronounced among physically active women, who averaged well below their estimated requirements. This is concerning given their elevated nutritional needs. When examining iron specifically, women's intake fell below recommendations regardless of dietary preference, with vegetarian and flexitarian diets presenting additional challenges.

Gender dynamics significantly shape sustainable food practices beyond just nutritional aspects. The thesis corroborate that women typically lead household shifts toward climate-friendly diets while experiencing more complicated relationships with food choices compared to men. Paradoxically, despite consuming fewer resources and making more climate conscious selections, women experience a greater risk of nutritional deficiencies and health impacts when households transition to sustainable diets.

The investigation of recreational athletes and young adults uncovered a clear relationship of dietary CO_{2e} emissions to activity level, with CrossFit athletes exhibiting the highest CO_{2e} emissions, followed by other highly-active individuals and moderately-active participants. The primary driver was not simply higher energy requirements but specifically how these needs were met, predominantly through animal-based protein sources.

Yet high CO_{2e} emissions was not inevitable. Several participants achieved notably lower CO_{2e} while maintaining high performance levels through strategic incorporation of plant-based protein sources. These examples challenge the assumption that athletic performance necessarily demands a high environmental

cost, suggesting that the barrier lies not in physiological requirements but in cultural norms and established beliefs about nutrition within sports communities. The findings question the assumption that low-carbon diets automatically promote health for all populations. The research shows that sustainable food systems require tailored approaches that consider gender-specific nutritional needs, diverse activity levels, and cultural contexts. The successful hybrid recipes and examples of low-CO_{2e} athletic diets demonstrate that balancing environmental and nutritional goals is achievable with thoughtful planning.

The path toward truly sustainable food systems must integrate bioavailability metrics into environmental assessments and address the social practices that shape our food choices. Only then can we create equitable transitions that protect both planetary boundaries and human wellbeing—especially for those leading the way in climate-conscious eating.

Svensk sammanfattning

Denna avhandling undersöker möjligheter och utmaningar med övergången till en klimatanpassad matkonsumtion. Avhandlingen kombinerar insikter från både offentliga måltider och privat matkonsumtion. Genom fyra studier utforskar avhandlingen balansen mellan att minska koldioxidavtrycket (CO₂e) och upprätthålla näringsmässigt korrekta måltider.

Resultaten presenterar inte som traditionellt varje delarbete för sig utan som en syntes som organiseras kring tre sammanlänkade teman som framkom i de fyra studierna som ingår i avhandlingen. Det första temat behandlar skolmåltider som en grogrund för framtida klimatsmarta konsumenter och vad som kan vara deras möjligheter och utmaningar. Det andra temat utforskar genus, hur olika näringsbehov och beteenden kan skilja omställningen till en klimatanpassad matkonsumtion. Det tredje temat undersöker sambandet mellan fysisk aktivitetsnivå och CO₂e, med fokus på hur det går att förena aktiva livsstilar med klimatpåverkan.

Klimatanpassning har blivit centralt i svenska skolkök. Analysen av kommunala skolmåltidsmatsedlar avslöjade ett oroande samband: när CO₂e minskade, sjönk även järnets biotillgänglighet. Detta fynd väcker viktiga frågor om näringsriktigheten i klimatanpassade menyer, särskilt för tonårsflickor.

Paradoxen blev särskilt tydlig i sojabaserade måltider. Trots att dessa måltider innehöll mest järn totalt sett, hade de lägst mängd absorberbart järn med minimal biotillgänglighet. Ingen av de analyserade menyerna tillhandahöll tillräckligt med absorberbart järn för flickor med högre behov, vilket visar hur klimatanpassad måltidsplanering oavsiktligt kan skapa näringsbrister.

För att anta denna utmaning utvecklades hybridrecept i delstudie II som visade på exempel på hur man kan överbrygga klyftan mellan klimatmål och näringsbehov. Genom att kombinera växtbaserade ingredienser med små mängder kött och C-vitaminrika livsmedel uppnådde dessa recept betydande CO₂e-minskningar samtidigt som de bibehöll godtagbara nivåer av absorberbart järn. Konsumentutvärderingar visade att dessa hybridlösningar behöll hög acceptans, vilket indikerar att det är möjligt att balansera näring, smak och klimatpåverkan.

Genus framträdde som ett betydelsefullt perspektiv för att förstå en omställning till en klimatanpassad matkonsumtion. Kvinnor uppvisade starkare klimatmedvetenhet i sin matkonsumtion men tar även större näringsmässiga risker när de anammar en kost med ett lågt klimatavtryck.

Kvinnliga deltagare konsumerade genomgående mindre energi än rekommenderat, vilket skapade ett underskott av energi som i sin tur kan påverka

intaget av vitaminer och mineraler. Detta mönster var särskilt uttalat bland fysiskt aktiva kvinnor, som i genomsnitt låg betydligt under sina beräknade energibehov. Vid en noggrannare granskning av rapporterat totalt järnintag låg de aktiva kvinnornas intag under rekommendationerna oavsett kostmönster. Vegetarianer och flexitarianer hade svårast att nå den rekommenderade nivån.

Genus påverkar hållbara matvanor bortom enbart näringsaspekter. Avhandlingen bekräftar att kvinnor som ofta leder hushållens omställning till en klimatvänligare matkonsumtion, samtidigt upplever de en mer komplicerad relation till matval jämfört med de deltagande männen. Trots att kvinnor förbrukar färre resurser (äter mindre) och gör mer klimatmedvetna val, löper de samtidigt större risk för näringsbrist när hushållen ställer om till en mer klimatsmart matkonsumtion. Det framstår som orättvist att just de som leder omställningen samtidigt riskerar sin egen hälsa.

Undersökningarna av CrossFit utövare och aktiva unga vuxna avslöjade ett tydligt samband mellan fysisk aktivitetsnivå och CO₂e-utsläpp från kosten. CrossFit-utövare uppvisade de högsta CO₂e-utsläppen, följt av andra högaktiva individer och måttligt aktiva deltagare. Orsaken var inte enbart ett högre energibehov utan även hur dessa behov tillgodosågs, främst genom ett högt intag av animaliska livsmedel.

Detta var dock inte det genomgående mönstret. Flera deltagare hade märkbart lägre CO₂e-utsläpp samtidigt som de bibehöll höga prestationsnivåer, främst genom att de använde en högre grad av växtbaserade livsmedel. Dessa exempel utmanar antagandet att idrottsprestationer nödvändigtvis kräver ett högt CO₂e-utsläpp, vilket tyder på att hindret inte bara ligger i fysiologiska krav utan i kulturella normer och etablerade uppfattningar om hur en bör äta som idrottsutövare.

Resultaten ifrågasätter antagandet att en kost med lågt klimatavtryck automatiskt främjar hälsa för alla befolkningsgrupper. Avhandlingen visar att en hållbar matkonsumtion kräver skräddarsydda tillvägagångssätt som tar hänsyn till könsspecifika behov, olika aktivitetsnivåer och kulturella sammanhang.

Vägen mot en verkligt hållbar matkonsumtion måste både ta hänsyn till biotillgänglighet när klimatanpassade måltider planeras och hantera de sociala praktiker som formar våra matval.

Contents

INTRODUCTION	13
LIST OF ORIGINAL PAPERS.....	15
ABBREVIATIONS.....	16
Key nutritional and environmental concepts.....	16
BACKGROUND.....	17
Climate impact of foods	17
Measuring the climate impact of foods and meals.....	18
Shifting to a sustainable food consumption in Sweden	19
Public School Meal.....	22
Opportunities and challenges with a shift to a climate-adapted diet.....	24
Opportunities.....	24
Challenges.....	24
Iron.....	26
Meal development, taste preferences and acceptance	29
Physical Activity and Energy Requirements	30
Athletes as High-Energy Consumers.....	33
THEORY.....	35
Social practice theory as a theoretical framework	35
Origins and Development of Social Practice Theory.....	35
Mixed-methods design.....	39
Pragmatism in Mixed Method Research	39
The convergent parallel design	40
AIMS.....	43
Overall aim	43
Three Specific objectives.....	43
Aims in the included papers.....	45
METHODS	47
Data collection	47
Paper I.....	47
Paper II.....	47
Paper III.....	48
Paper IV.....	49

Swedish food agency's food database (Papers I-IV).....	51
RISE Food Climate Database (Papers I-IV).....	51
Absorbable iron equation by Hallberg & Hulthén (2000) (Paper I-II)	52
Key factors influencing iron absorption.....	53
Algorithmic calculation process.....	53
Food records (Paper III-IV)	54
Interview methodology (Papers III-IV)	55
Semi-structured interviews	55
Physical activity (Paper III-IV)	56
Recipe development and consumer evaluations (Paper II)	57
Statistical analysis.....	58
Paper I.....	58
Paper II	59
Paper III.....	60
Paper IV	60
Software	60
 ETHICAL CONSIDERATIONS	 61
 RESULTS AND DISCUSSION	 63
Theme 1: School meals as climate champions.....	63
Current implementation (Paper I).....	63
Nutritional analysis and CO ₂ e.....	64
Hybrid recipe solutions (Paper II).....	66
Consumer acceptance and recipe development	68
Theme 2: Gender nutrition gaps in low-carbon diets.....	70
School meal programs: gender and nutrition.....	70
Women leading the climate-adaptation	73
Gendered elements of climate-conscious food practices.....	79
Theme 3. Balancing activity and CO ₂ e among young adult consumers.....	82
Higher activity levels and increased CO ₂ e.....	82
Protein sources: a key factor in climate impact	82
Balancing performance focus and CO ₂ e	83
The role of meal planning and barriers to change	84
A social practice theory perspective.....	84
Practice and pathways to change.....	85
 METHOD DISCUSSION	 87
Carbon footprint.....	87
Iron absorption algorithm	88

Algorithmic calculation process.....	88
Food records	92
Statistics.....	93
Paper I.....	93
Paper II	94
Paper III-IV.....	95
Mixed-methods research.....	96
GENERAL DISCUSSION	99
Challenges in climate-adapted food systems.....	99
Ethical considerations: agency and responsibility	99
Regional differences	100
Implementation challenges and nutritional concerns	101
Framework for school meal development	101
The relationship between CO ₂ e and iron bioavailability.....	102
Climate or nutritional trade-offs.....	102
Environmental and health impacts of meat.....	102
Fish as a middle ground option	104
Poultry: a popular alternative with many dimensions.....	104
Plant-based foods: environmental and health implications	105
Plant-based meat alternatives: opportunities and challenges.....	106
Promising solutions and applications	106
CONCLUSION.....	109
Future perspectives.....	111
Evidence base for climate-adapted diets	111
Nutritional considerations and challenges	111
Research priorities	112
Path forward.....	114
ACKNOWLEDGEMENTS	115
REFERENCES	118

Introduction

In a bustling school cafeteria, children eagerly line up for lunch—today, a plant-based meal inspired by new climate-conscious guidelines. At a nearby table, a teacher discusses her efforts to reduce her carbon footprint (CO₂e) with a fellow colleague. Across town, a family gathers around a dinner table, sharing a meal that aligns with their values of sustainability. Meanwhile, in a gym not far away, an athlete drinks a post-workout protein shake after an intense CrossFit session, striving to meet the elevated nutritional demands of a rigorous training routine. As societies around the world shift towards climate-adapted meals, from public institutions like schools to private homes, we celebrate these efforts to mitigate CO₂e emissions. But, beneath the surface of these choices, lies a more nuanced dilemma.

While plant-based meals often carry the promise of sustainability, they introduce difficulties in meeting diverse nutritional needs across different population groups. The challenge lies in ensuring that climate-conscious eating does not compromise essential nutrition. As we adapt our diets, we must also consider another vital aspect: taste. Sensory properties like flavor, texture, aroma and overall enjoyment of food should not be overlooked in the pursuit of sustainability. After all, food is more than fuel; it is a source of pleasure and culture, factors that influence long-term dietary adherence.

As we explore the intricacy of diet, another layer of tension emerges. Nutritional and energy requirements are not one-size-fits-all. Factors such as age, gender, physical activity, and metabolic differences create a mosaic of individual needs. The challenge intensifies when we consider how physical activity, often recommended for optimal health, raises energy demands. In a world striving to reduce CO₂e, this increased need for energy, if met with the certain dietary choices, could lead to an unintended increase in CO₂e emissions. Through this thesis the intersection of climate-adapted food consumption and human nutrition is explored, grappling with some opportunities and challenges that arise in both public and private domains. The question remains: can we nourish our bodies and planet without compromise?

To further highlight the inherent conflicts of climate-adapted meals, this thesis is a synthesis of the four included papers and is organized around three interrelated themes.

First, the role of public-school meals in driving climate-adapted food consumption will be explored. Schools are not only spaces of education but also critical institutions in shaping habits such as eating. This section will explore how school meal programs can serve as a model for low-carbon, nutritionally sound diets, and the challenges they face in doing so.

Second, a gender perspective is important, as nutritional needs and dietary habits are often shaped by gendered roles and biological differences. This theme will cover how gender influences both the requirements of key nutrients, such as iron, and the broader societal dynamics that affect food choices.

Third, the thesis will address the conflict between the recommendation of physical activity and the CO₂e emissions of food. While physical activity is a cornerstone of health, its increased energy demands often lead to higher calorie consumption, which can inadvertently increase the carbon impact of one's diet. This theme looks in to if we can balance the climate impact of food with the nutritional requirements of active lifestyles.

Summing up, these themes offer a versatile view of the opportunities and challenges in achieving both planetary and personal sustainability through climate-adapted diets.

List of original papers

This thesis is based on the following papers, referred to in the text by their Roman numerals.

I. Wollmar M, Post A, Thorén Olausson A, Hulthén L, Sjöberg A.

Climate-adaptation practices, nutrition and absorbable iron in Swedish school meals (in manuscript)

II. Wollmar M, Post A, Elf M, Pettersson J, Prim M, Sjöberg A.

Balancing trade-offs — iron bioavailability, carbon footprint, and taste in hybrid school meal recipes (Submitted)

III. Wollmar M, Sjöberg A, Post A. (2022)

Swedish recreational athletes as subjects for sustainable food consumption: focus on performance and sustainability

International Journal of Food Sciences and Nutrition (2022)

<https://doi.org/10.1080/09637486.2022.2141208>.

IV. Wollmar M, Post A, Sjöberg A. (2024)

Food choice, activity level, and carbon footprint: exploring potential for sustainable food consumption practices in young adults

Frontiers in Nutrition (2024) 11:2024

<https://doi.org/10.3389/fnut.2024.1449054>

The two published research papers are both published open access, distributed under the terms of the Creative Commons Attribution Licence (CC BY 4.0). This permits use, sharing, adaptation, distribution, and reproduction in any medium or format, as long as given appropriate credit to the original author(s) and the source, providing a link to the Creative Commons licence¹, and indicating if changes were made.

¹<https://creativecommons.org/licenses/by/4.0/>

Abbreviations

BMR	Basal metabolic rate
CO ₂ e	Carbon dioxide equivalent
EI/RMR	Energy intake relative to resting metabolic rate
ID	Iron deficiency
IDA	Iron deficiency anemia
IPCC	Intergovernmental Panel on Climate Change
JAR	Just-About-Right (scale used in sensory evaluation)
LCA	Life Cycle Assessment
LCIA	Life-cycle impact assessment
MET	Metabolic equivalent
NNR	Nordic Nutrition Recommendations
PAL	Physical Activity Level
PBMA	Plant-based meat alternatives
SDG	Sustainable Development Goals

Key nutritional and environmental concepts

Carbon footprint: The quantifiable measure of greenhouse gas emissions, expressed as carbon dioxide equivalents, associated with a product, service, or activity throughout its complete lifecycle from production to disposal.

Bioavailability: The extent to which ingested nutrients are absorbed in the digestive tract and subsequently utilized in metabolic processes, representing the physiological efficiency of nutrient utilization rather than dietary content.

Absorbable iron: The fraction of total dietary iron that can be effectively absorbed across the intestinal epithelium and incorporated into functional compounds within the body, determined by both dietary composition and physiological factors.

Heme iron: Iron incorporated within the porphyrin ring structure of hemoglobin and myoglobin proteins, exclusively found in animal-derived foods, characterized by superior absorption efficiency (15-35%) that remains relatively consistent regardless of meal composition.

Non-heme iron: Iron not associated with heme-containing proteins, present in both plant and animal sources, with substantially lower absorption efficiency that is highly influenced by enhancing and inhibiting dietary factors consumed simultaneously.

Background

The background section establishes how food systems contribute to climate change. It examines Swedish school meal programs, which evolved from charitable initiatives in the early 20th century to universal free meals today, historically focused on improving children's health and academic performance but now also take responsibility for reducing the climate impact of food. The section then systematically examines both the opportunities and challenges of climate-adapted diets, highlighting the tensions between traditional nutritional recommendations and environmental considerations. Emphasis is placed on nutritional considerations such as iron intake and bioavailability, with attention to significant gender differences in dietary patterns, iron requirements, and deficiency risks. It proceeds to analyze how meal development methodologies and individual taste preferences influence dietary choices and their resulting climate impact. The background also explores how varying physical activity levels affect nutritional requirements, with special attention given to athletes as a distinct demographic group with substantially higher energy requirements, examining how their nutritional needs can be met while minimizing environmental consequences.

Climate impact of foods

The global food system significantly impacts environmental change, though this impact is frequently underestimated. Our food production and distribution networks alter Earth's ecosystems by releasing greenhouse gases and disrupting ecological systems (Tubiello et al., 2021).

The food system is a major source of greenhouse gases, making up about one-fifth to one-quarter of all human-caused emissions (IPCC, 2022). Farming alone produces over 50% of global methane and 75% of nitrous oxide emissions (FAO, 2020). Including related activities like fertilizer manufacturing, transportation, processing, and waste management, food systems account for 20-40% of human CO_{2e} emissions (Rosenzweig et al., 2020), with recent research suggesting it accounts for about one-third of total human-generated greenhouse gases (Crippa et al., 2021).

The livestock sector represents a significant contributor to climate change. Animal agriculture generates approximately 8-10.8% of global greenhouse gas emissions (IPCC, 2022), with cattle playing a particularly important role in this climate impact (O'Mara, 2011). Through biological processes such as enteric fermentation and manure management, these animals produce substantial methane emissions (Sejian et al., 2011). Furthermore, beef production requires extensive land use, which often leads to deforestation and reduces the Earth's capacity to naturally capture carbon. (Gerber et al., 2015).

Farming methods add further complexity to this issue. Growing crops, from rice fields (Qian et al., 2023) to large single-crop farms, releases significant amounts of greenhouse gases, including nitrous oxide and carbon dioxide (Basheer et al., 2024; IPCC, 2022). Intensive farming not only creates immediate emissions but also damages soil health, reducing the land's ability to store carbon (IPCC, 2022; Shameem et al., 2019).

The food system's environmental impact extends past just production to include transportation, processing, and distribution. The global food supply chain mostly depends on fossil fuel-powered vehicles (Tchoukouang et al., 2024), while processing, packaging, refrigeration, and storage use considerable energy and produce additional greenhouse gases (Shabir et al., 2023). These systems transform food from a necessity into a difficult environmental challenge.

The considerable environmental impact of food systems presents numerous opportunities to cut emissions across supply chains. Food choices and consumption habits are particularly powerful ways to reduce food-related greenhouse gases (Schanes et al., 2016; Scheuermann et al., 2024; Schulze et al., 2024). Food production and consumption affect our climate at every stage, from farming to waste disposal. With our growing understanding of these relationships, we now need reliable methods to measure the climate impact of various foods and meals—enabling people to make more sustainable choices in their everyday lives.

Measuring the climate impact of foods and meals

Life Cycle Assessment (LCA) studies measure environmental impacts through multiple indicators including global-warming potential, which is expressed as carbon dioxide equivalents (CO₂e) (Cucurachi et al., 2019). CO₂e standardizes greenhouse gases based on their warming impact over 100 years, with carbon dioxide equal to 1, methane equal to 25, and nitrous oxide equal to 298 (Glossary:Greenhouse Gas (GHG) - Statistics Explained, 2020). This CO₂e metric

is widely used to calculate and compare the climate impact of food products (Röös et al., 2013) and serves as the primary measurement in this thesis. CO₂e is a key metric for measuring greenhouse gas emissions across a food product's lifecycle. Research shows that CO₂e effectively correlates with other environmental impacts like land use and acidification (van Dooren et al., 2018), making it a reliable proxy for broader environmental assessment (Harrison et al., 2022). This makes CO₂e particularly useful for evaluating dietary impacts and shaping sustainable food policies (Aldaya et al., 2021; Ran et al., 2024).

Shifting to a sustainable food consumption in Sweden

This thesis is framed within global sustainability initiatives, as guided by climate science authorities and international development frameworks (IPCC, 2022; UN General Assembly, 2015). Research indicates that food systems contribute approximately 25-30% of global greenhouse gas emissions (IPCC, 2022). The 2030 Agenda emphasizes climate-resilient food practices and connects to several Sustainable Development Goals relevant to this project: health and well-being, gender equality, responsible production and consumption, and climate action (UN General Assembly, 2015). Additionally, the European Green Deal promotes healthier, more sustainable food choices, including plant-based diets, to reduce environmental impacts (European Commission & Directorate-General for Communication, 2021).

Research shows that moving toward plant-based diets helps achieve sustainability goals (Aiking & de Boer, 2020; Aleksandrowicz et al., 2016; Willett et al., 2019). The Nordic nutrition recommendations (NNR2023) now integrate nutritional advice with climate concerns, promoting more plant foods and less animal products (Blomhoff et al., 2023). Diets with limited animal products typically produce less CO₂e, with vegetarian diets found to benefit both climate and health (Aleksandrowicz et al., 2016; Hansson et al., 2024). Even diets containing moderate amounts of animal products but abundant in fruits, vegetables, nuts, legumes, and whole grains provide health advantages (Aleksandrowicz et al., 2016; Stubbendorff et al., 2022; Willett et al., 2019).

The climate impact of food is receiving growing attention in scientific literature and key strategies to reduce CO₂e include adopting plant-based diets (Willett et al., 2019) and consuming only enough food to maintain energy balance. This could reduce CO₂e by about 20% (Hallstrom et al., 2015; Ridoutt et al., 2017).

Plant-based diets offer important climate benefits but come with their own considerations. Plant-based diets typically generate lower CO₂e emissions because they avoid animal products, which require significantly higher CO₂e per kilogram to produce than plant foods (Carlsson-Kanyama & González, 2009). Research such as the EAT-Lancet Commission study suggests the possibility of meeting both climate and most nutritional objectives (Willett et al., 2019).

Plant-based diets help address climate concerns, but we must ensure they provide proper nutrition. Plant foods typically contain fewer calories by volume than animal-based foods, meaning people need to eat larger portions to meet energy requirements, though plants can offer substantial nutrients (Milner et al., 2015; Ridoutt et al., 2017). This creates a challenge when designing diets that are both sustainable and nutritious. Many climate-adapted dietary frameworks, including the EAT-Lancet diet, do not fully account for how well minerals are absorbed from plant sources (Beal et al., 2023; Leonard et al., 2024). While plant-based eating is a promising climate strategy, it requires careful consideration to deliver both nutritional and climate benefits.

Food consumption in Sweden

Swedish schools increasingly offer climate-adapted meal options, as part of a broader trend toward plant-based eating. Food-related emissions in Sweden reached 1.45 tons CO₂e per person and year in 2021, showing improvement from previous years, with 2020 marking the lowest level at 1.42 tons CO₂e (Naturvårdsverket, 2022). This reduction corresponds with more people adopting flexitarian diets and greater acceptance of vegetarian foods (Patterson et al., 2021).

The national Riksmaten 2010-11 survey highlighted gender differences in eating habits. Men consumed more energy daily and ate significantly more meat (85 g daily versus 53 g for women) (Livsmedelsverket, 2012). For reference, Sweden's National Food Agency advises limiting weekly consumption of red meat, processed meats to 500 g or less (Livsmedelsverket, 2024a).

When analyzed against these recommendations, men's average weekly red and processed meat consumption reached 791 g, exceeding the guidelines, while women's intake averaged 476 g weekly, within the recommended limit. By comparison, the Riksmaten 2016-17 adolescent survey showed that girls in the 8th grade had a considerably lower intake of red and processed meat, averaging 350 g weekly, compared to boys who had an intake of 532 g weekly (Livsmedelsverket, 2018).

These dietary patterns reflect broader gender differences in food choices, not just in quantity consumed. Young women make up a notably larger proportion of those following vegetarian and vegan diets. Research in Sweden shows that environmental considerations strongly influence these choices, with 68% of women between 16–34 years old identifying climate concerns as their primary reason for selecting vegetarian foods (Eustachio Colombo et al., 2020).

The Swedish Food Agency's eco-smart food choices

The Swedish Food Agency now includes climate impact in its nutrition guidelines (Livsmedelsverket, 2018). This aligns with Sweden's commitment to national environmental goals as part of the Agenda 2030 sustainability framework (UN General Assembly, 2015). These environmental goals consist of an overarching generational goal, 16 specific objectives, and various milestone targets. Changes in food systems directly affect nine of these 16 objectives. The agency considers sustainability through three dimensions: economic, social, and ecological. Together, these environmental goals establish a vision for Sweden's desired future (Naturvårdsverket, n.d.).

The Swedish Food Agency recognizes that both consumers and food companies influence environmental outcomes. To help reduce climate impact, the agency provides regulations, advice, guidance, and information. This advice appears in the official recommendation for public meals and is relevant for procurement considerations. In 2017, the Swedish government established a goal that 60 percent of public food consumption by 2030 should consist of certified organic products. The Swedish Procurement Agency offers support for sustainable procurement (Upphandlingsmyndigheten, n.d.). The national guidelines for school meals (Livsmedelsverket, 2019) suggest schools purchase products with the “Keyhole” symbol, which indicates nutritious foods with less sugar and salt, more whole grains and fiber, and healthier fats (Amcoff et al., 2015).

Meat replacement products

To reduce the CO₂e emissions from food often involves increasing vegetarian options and decreasing meat dishes. This climate adaptation typically includes more legumes, vegetables, and grains, or using plant-based meat alternatives (PBMA). PBMA available in Sweden are generally made from plant-based protein concentrates or isolates, with varying nutritional profiles (Bryngelsson et al., 2022). Many have low iron bioavailability due to high phytate content (Mayer-Labba et al., 2022).

Some PBMA's contain iron oxide as a colorant to create a meat-like appearance. Iron oxide does not provide absorbable iron, which may result in misleading iron content information in the Swedish National Food Agency's database. This could lead to inaccurate iron calculations in menu planning if consumers are unaware of this distinction. While PBMA's are designed to ease the transition to plant-based diets by substituting or supplementing animal-based products, there has been a trend away from minimally processed plant foods toward these meat analogues. Research suggests these products may not always deliver the health benefits consumers expect (Brooker et al., 2022; Bryngelsson et al., 2022; Mayer-Labba et al., 2022; Wickramasinghe et al., 2021), and their marketing as healthy and sustainable options may sometimes be overstated (Oussalah et al., 2020).

Public School Meal

Today, school meals in Sweden are free of charge. Sweden, together with a few other countries: Finland, Estonia, Brazil, India and South Korea are the only countries that serve free school meals to all pupils (Cohen et al., 2023).

History of Public School Meals

School meals in Sweden originated with goodwill organizations providing food for children in need during the early 20th century (Gullberg, 2004). The 1920s saw advances in nutritional science, including the identification of vitamins and minerals, their chemical structures, and their role in preventing deficiency diseases like scurvy and rickets (Backstrand, 2002). Population decline in the 1930s prompted national and international discussions about public school lunches, with the League of Nations encouraging members to address undernutrition (Gullberg, 2004).

The Swedish state began providing grants for limited school meals in the 1930s, recognizing that nutritionally adequate diets could improve health and academic performance. A 1945 proposal established the foundation for modern school meal programs (Gullberg, 2006). Schools received financial support for serving cooked meals meeting specific nutritional requirements. In July 1946, the Swedish parliament introduced free public-school meals for all children (Gullberg, 2006; Lundmark, 2002). School meal coverage increased by 65 percent from 1947 to 1967, with more than half of pupils receiving free food, aiming to level educational conditions regardless of socioeconomic status. The 1997 school legislation

mandated that all municipalities in Sweden provide free school meals to primary school pupils (Gullberg, 2004).

During the 2000s, schools began offering multiple options, typically including a vegetarian choice. The 2010 school law mandated that school food should be nutritious (SFS 2010:800), while municipalities and independent schools retained authority over meal preparation and service locations (Livsmedelsverket, 2013).

Public School Meals Today

Today, the Swedish Food Agency provides information and guides (Livsmedelsverket, 2018a) to all municipalities based on the Nordic Nutrition Recommendations 2012 (Nordic Council of Ministers, 2014). Since the new law of 2010 stated that public school meals should be free of charge and nutritious, the guides calculate that 30% of the daily intake should be provided by school lunch (Livsmedelsverket, 2019). Although recommended intake varies depending on the age group, the age groups covering compulsory school are 6-9, 10-12, 13-15, and 16-18 years respectively (Livsmedelsverket, 2019). The national guidelines encourage schools to create meal experiences that students enjoy while also expanding their food preferences. These meals are viewed as valuable learning opportunities where children can discover new foods, develop more diverse tastes, and build healthy eating habits through direct experience with different foods (Persson Osowski & Fjellström, 2019).

School meal programs now look beyond nutrition to address climate impact through practical approaches. These include reducing food waste and creating more environmentally friendly menus with more plant-based options to lower CO₂e emissions (Persson Osowski & Fjellström, 2019). The Swedish Food Agency reports notable improvements in this area (Swedish Food Agency, 2022). Local governments have established specific targets for reducing food waste, and many have developed their own strategies to decrease the climate impact of school meals (Post et al. 2025, In manuscript). While schools are not required to serve vegetarian meals, such options are now commonly available in both primary and secondary schools, in line with national guidance (Post et al. 2025, In manuscript). However, these sustainability efforts can only succeed if students accept and enjoy the meals being served.

Opportunities and challenges with a shift to a climate-adapted diet

Opportunities

Swedish dietary patterns, as documented in the Riksmaten surveys, suggests that both adults and adolescents typically consume fewer fruits and vegetables than recommended (Livsmedelsverket, 2012, 2018b). These findings suggest opportunities for better alignment with the Nordic Nutrition Recommendations to support long-term health (Blomhoff & Nordic Council of Ministers, 2023). A diet more consistent with the NNR2023 could offer both health and climate benefits.

The EAT-Lancet diet underline eating whole grains, vegetables, fruits, legumes, nuts, and unsaturated oils, while recommending limited consumption of animal-based foods, dairy products, tubers, starchy vegetables, added fats, and sugars. This dietary approach aims to meet nutritional requirements for our growing global population while respecting planetary limits (Willett et al., 2019). A Swedish study by Zhang et al. (2023) examined how following the EAT-Lancet diet relates to heart disease risk. Following participants for nearly 25 years, they found that closer adherence to this diet was linked to a significantly lower risk of coronary events (Zhang et al., 2023). Other research indicates the EAT-Lancet diet may also help reduce risks of type 2 diabetes (Knuppel et al., 2019; Langmann et al., 2023), cancer, and death from all causes (Berthy et al., 2023; Karavasiloglou et al., 2023). These findings suggest potential benefits from aligning dietary patterns with both Nordic Nutrition Recommendations 2023 and EAT-Lancet guidelines, potentially improving both health outcomes and environmental sustainability. However, ensuring adequate micronutrient intake while minimizing climate impact remains an important challenge requiring further research.

Challenges

Providing adequate nutrition globally requires balancing varied human needs within environmental constraints (Richardson et al., 2023). Nutritional requirements differ according to biological factors including gender, age, genetics, existing nutritional status, and health history. Women and young children face higher malnutrition risks because they need more micronutrients, and nutritional deficiencies during key developmental stages can have lasting effects across

generations (Martorell, 2017). The scale of this problem is significant: more than half of all preschool-aged children (about 372 million) and over two-thirds of non-pregnant women of reproductive age (approximately 1.2 billion) lack at least one essential micronutrient (Stevens et al., 2022) with iron being one of the most common (Passarelli et al., 2024)

Although it is theoretically possible to meet nutritional needs using only plant foods and supplements, putting this into practice is often difficult. (Beal et al., 2023). Lack of information about micronutrient availability in foods and the widespread presence of deficiencies suggests that many people struggle to obtain sufficient nutrients without including some animal-based foods in their diets (Passarelli et al., 2022).

Reducing animal-source foods as suggested by the planetary-health diet would require significantly increased intake of nutrient-dense plant-source foods like dark green leafy vegetables, pulses, traditional whole grains, and seeds, necessitating dietary changes and education (Beal et al., 2023). Population groups with increased nutrient needs, women of reproductive age, pregnant and lactating women, adolescents, and young children, face higher risks of micronutrient deficiencies when animal-based foods are limited (Gernand et al., 2016; Passarelli et al., 2022). Achieving dietary micronutrient adequacy within planetary boundaries calls for a multifaceted approach including improved diet diversity (Salomé et al., 2020), sustainable food consumption practices (Hoek et al., 2021), and consideration of local contexts (Dawkins et al., 2023), balancing nutrient-dense foods with climate impact.

Animal-source foods provide essential nutrients including iron, zinc, folate, calcium, and vitamins A, B₁₂, and D, often at higher levels than plant-based alternatives (Moretti, 2017). Vulnerable populations such as children, pregnant women, the elderly, and those in low-income communities are particularly susceptible to micronutrient shortfalls (Bailey et al., 2015). For children, deficiencies in key nutrients can impair growth, cognitive development, and immune function (Morales et al., 2023), while in low-income communities with limited food access, these deficiencies can exacerbate inequalities, hindering economic productivity and perpetuating cycles of poverty and poor health (Morales et al., 2023).

Iron

Iron status and iron deficiency

Iron deficiency (ID) remains the most common nutritional deficit globally, affecting both high- and low-income countries (Kassebaum et al., 2014). According to the Swedish national survey Riksmaten 2010-2011, women's daily iron intake averaged 9.5 mg, falling below the Nordic Nutrition Recommendations (NNR) 2023 of 15 mg for women of childbearing age. In contrast, men's intake (11.5 mg) exceeds their recommended 9 mg daily requirement, suggesting women face a higher risk of (Livsmedelsverket, 2012).

Recent dietary surveys of Swedish adolescents indicate concerning iron status among girls. Blood plasma samples showed empty iron stores in girls from grade 5 (10%), grade 8 (30%), and upper secondary grade 2 (26%) (Livsmedelsverket, 2018b), with a study in the Gothenburg area finding even higher percentage of deficiency (Sjöberg & Hulthén, 2015). Research by Stubbendorff et al. (2025) further reveals that dietary choices significantly impact iron status, with omnivores showing substantially higher ferritin levels than pescatarians and particularly vegetarians/vegans, who exhibited the highest rates of iron deficiency. Their findings also link lower red meat consumption and higher intake of plant-based alternatives to increased ID risk (Stubbendorff et al., 2025). Women generally face higher vulnerability to ID due to menstrual losses, reduced storage capacity, and lower food intake (Domellöf & Sjöberg, 2024; Hoppe et al., 2008; Vandevijvere et al., 2013). This deficiency can impact physical health, cognitive development, and academic performance, potentially contributing to gender inequalities in health and education outcomes (McCann & Ames, 2007; Mesías et al., 2013).

Iron serves as an essential component of hemoglobin, enabling oxygen transport throughout the body (Shils, 2006). Since the body cannot synthesize iron, dietary sources are necessary. Iron contributes to numerous physiological functions, including oxygen transport, DNA synthesis, electron transport, and muscle metabolism, while supporting physical growth and neurological development (Filer & Ziegler, 1996). Hemoglobin production requires iron along with vitamin B₁₂ and folic acid, with iron being absorbed intestinally before transportation to the bone marrow for red blood cell formation (Koury & Ponka, 2004).

Iron is stored primarily in the liver, spleen, and bone marrow, with its absorption process beginning in the intestines where specialized enzymes convert insoluble ferric ions (Fe³⁺) to absorbable ferrous ions (Fe²⁺). Most iron turnover

occurs endogenously as the body recycles approximately 20-25 mg daily from aged red blood cells. Adults typically lose 1-2 mg daily, with higher losses in menstruating females (Domellöf & Sjöberg, 2024, Table 4). While many foods contain iron, absorption efficiency ranges from only 5-20% (Miller et al., 2011).

Iron deficiency and iron deficiency anemia

The most prevalent micronutrient deficiency globally is ID, with iron deficiency anemia (IDA) being its most severe manifestation (Engle-Stone et al., 2017; Petry et al., 2016; World Health Organization, 2017). The condition develops progressively, beginning with depleted iron stores and potentially advancing to anemia if left uncorrected (Pasricha et al., 2021). While the Nordic countries demonstrate lower prevalence rates compared to global statistics, certain population groups remain at significant risk, particularly infants, young children, adolescent girls, and women of reproductive age (Blomhoff & Nordic Council of Ministers, 2023; Hay et al., 2004; Milman et al., 2004).

The clinical manifestations of ID exist on a spectrum, ranging from subtle cognitive effects in mild cases to more pronounced symptoms in IDA, including fatigue, reduced physical capacity, and compromised cognitive function. Of particular concern is the association between IDA in early childhood and impaired neurodevelopment, with potential irreversible effects, underscoring the critical importance of prevention in young children. The etiology of ID varies across life stages, with risk factors including inadequate dietary intake, increased physiological demands during growth and pregnancy, menstrual blood losses, and malabsorption issues (Houston et al., 2018; Lozoff et al., 2006; Trotti et al., 2019).

Iron bioavailability

Dietary iron exists in two forms: heme and non-heme (Shils, 2006). Heme iron, found in animal tissues such as beef, poultry, and seafood, demonstrates consistently efficient absorption rates of approximately 25% regardless of other dietary components (Hallberg et al., 1997). In contrast, non-heme iron from plant sources and fortified foods shows more variable bioavailability.

Human iron homeostasis operates with remarkable efficiency, primarily through recycling mechanisms that break down and reuse iron from aging red blood cells (Sharp & Srai, 2007). Notably, humans lack a specific biological mechanism for eliminating excess iron, reflecting our evolutionary adaptation to prioritize iron retention. The body absorbs heme iron through specialized transport proteins that allow direct entry into the bloodstream, while non-heme

iron requires conversion from Fe^{3+} to Fe^{2+} before absorption, which reduces its bioavailability. While the molecular pathways of non-heme iron absorption have been extensively studied, the precise mechanisms of heme iron uptake remain less comprehensively understood. Research indicates that after cellular uptake by enterocytes, both iron forms converge into shared metabolic pathways. When the body's iron stores are full, absorption is downregulated, and when they are low, absorption is upregulated to maintain optimal iron homeostasis.

Although heme iron constitutes only 10-15% of dietary iron intake, it accounts for approximately 40% of absorbed iron in omnivorous diets, highlighting its nutritional significance (Bjorn Rasmussen et al., 1974).

Several dietary factors influence iron absorption. Vitamin C and peptides from meat and seafood enhance absorption, while calcium and phytates inhibit it. Phytates, commonly found in legumes and pulses, form insoluble complexes with minerals that reduce their bioavailability (Sharp & Srai, 2007). Despite legumes and pulses being rich sources of dietary fiber, protein, vitamins, and minerals including iron, their phytate content significantly impairs iron absorption (Mayer Labba et al., 2022; Sandberg, 2002; Vigouliouk et al., 2017). Therefore, when implementing more plant-based diets in public school meals, careful consideration of dietary iron bioavailability is necessary.

Requirements and recommendations

The Swedish National Food Agency follows iron intake guidelines established in NNR2012 (Nordic Council of Ministers, 2014), which were maintained in the recent update (Blomhoff et al., 2023). Research states that the chemical form of iron in food (such as heme vs. non-heme iron) may be as important as the total iron content, since bioavailability varies significantly (Bæch et al., 2003; Hallberg & Hulthén, 2000). Despite this knowledge, studies on climate-adapted and nutritious school meals often give insufficient attention to iron bioavailability (André et al., 2023; Colombo et al., 2019; Vieux et al., 2013). Therefore, simply increasing plant-based foods like legumes in school lunches without accounting for their lower iron absorption rates could potentially limit effective iron absorption. When selecting foods to reduce climate impact in school meals, careful consideration of iron availability alongside overall nutritional value appears necessary.

Iron requirements differ by age, gender, and life stage. For adolescents aged 11-14 years, girls need 13 mg/day, reflecting early menstruation onset, while boys require 11 mg/day. As adolescents reach 15-17 years, the recommended intake for

females rises to 15 mg/day due to established menstrual losses, with males continuing to need 11 mg/day (Blomhoff & Nordic Council of Ministers, 2023; Domellöf & Sjöberg, 2024).

In adults, physiological differences maintain this gender disparity in iron needs. Adult males require 9 mg/day, while premenopausal women need 15 mg/day due to regular iron losses through menstruation. This recommendation for premenopausal women corresponds to the 95th percentile of menstrual iron losses, approximately 1.32 mg/day. After menopause, women's iron requirements decrease to 7 mg/day, reflecting the cessation of monthly cycles (Blomhoff & Nordic Council of Ministers, 2023; Domellöf & Sjöberg, 2024).

Pregnancy significantly increases iron demands, with a recommended intake of 26 mg/day. This addresses fetal growth (270 mg), placental development (90 mg), expanded maternal blood volume, and anticipated delivery blood loss (175 mg). Meeting these needs through diet alone can be challenging, leading to recommendations for iron deficiency screening and potential supplementation during pregnancy (Blomhoff & Nordic Council of Ministers, 2023; Domellöf & Sjöberg, 2024).

Meal development, taste preferences and acceptance

School meals present a unique opportunity to shape eating habits, with food appeal being a key factor in what pupils choose to eat. The sensory qualities of food, how it looks, smells, and tastes, guide our food choices before we even take a bite and continue to influence our experience throughout the meal (McCrickerd & Forde, 2016; Sørensen et al., 2003).

Since school meals in Sweden have a great reach, there is significant potential to promote sustainable eating behaviors (Westling et al., 2022). Creating appealing meals requires balancing taste preferences with nutritional needs, including important nutrients like iron.

Research shows that both sensory properties and biological mechanisms influence food selection. Our bodies respond to foods through signals from our digestive system and fat tissue, affecting hunger and satisfaction levels. Plant-based foods often face acceptance challenges because they tend to have more sour and bitter notes than meat products (Pagliarini et al., 2021). To address this, food developers are trying various approaches, such as combining plant foods like lentils or soy with meat, or creating hybrid recipes (Pettersson et al., 2024). By introducing

plant ingredients gradually and using taste tests to guide improvements, schools can help expand pupils' food preferences toward low-CO₂e options.

For developing hybrid products or recipes, the “culinary funnel” approach offers a practical method, focusing on making specific ingredients or recipes as tasty and acceptable as possible through repeated cooking experiments and consumer feedback (Westling et al., 2021).

Physical Activity and Energy Requirements

The relationship between physical activity and nutrition is particularly significant as energy requirements scale with activity level (Pontzer et al., 2016; ten Haaf & Weijts, 2014). Higher activity levels necessitate increased energy intake, which can substantially impact both nutritional needs and CO₂e. For instance, highly-active individuals often require significantly more protein and overall calories compared to moderately-active individuals (Thomas et al., 2016), leading to distinct dietary patterns and challenges in maintaining sustainable food practices.

Research indicates that activity levels can influence not just the quantity of food consumed but also food choices and eating preferences (Kaufman et al., 2023). Athletes and highly-active individuals often structure their diets around performance goals, which can lead to specific dietary preferences and practices (Noll et al., 2017). This is particularly relevant when considering the climate impact of food choices, as higher activity levels typically correlate with increased CO₂e emissions through both greater overall consumption and reliance on protein-rich, often animal-based, food sources.

The World Health Organization (WHO) defines physical activity as “any bodily movement produced by skeletal muscles that require energy expenditure” (Bull et al., 2020). Physical activity is categorized based on intensity using metabolic equivalents (METs), where one MET represents the baseline energy expenditure at rest (1 kcal/kg/hour or oxygen uptake of 3.5 ml/kg/min). Activities are classified as moderate-intensity (3-5.9 METs) or vigorous-intensity (≥ 6.0 METs) (Bull et al., 2020). This classification system provides a quantitative basis for developing physical activity recommendations that aim to improve health outcomes across different population groups.

Current WHO guidelines recommend adults engage in either 150-300 minutes of moderate-intensity or 75-150 minutes of vigorous-intensity physical activity weekly (Bull et al., 2020; Piercy et al., 2018). However, many individuals, particularly recreational athletes, significantly exceed these baseline

recommendations. This increased activity level has important implications for both energy requirements and dietary choices.

Understanding these relationships between physical activity levels, dietary requirements, and CO_{2e} is important for developing sustainable nutrition strategies that can support both athletic performance and climate consciousness. This thesis includes participants from different sports which are described below.

CrossFit®

CrossFit sits at the intersection of intensive training and food culture. This trademarked training system integrates multiple athletic disciplines including endurance, bodyweight movements, gymnastics, powerlifting, and Olympic weightlifting (Glassman, 2002). The program has experienced remarkable growth, expanding to over 4 million participants and evolving from a specialized workout routine into a significant influence in contemporary fitness culture (Claudino et al., 2018).

Beyond physical training, CrossFit's impact extends through its community emphasis. Rather than the “cult-like” characterization some have applied (Herz, 2014), Dawson's (2017) analysis more fittingly describes it as a “reinventive institution.” This framework highlights voluntary participation and the integration of self-monitoring, peer support, and coached guidance. Notably, CrossFit participation shapes practitioners' identities, influencing not only their training regimens but also broader lifestyle choices including attire and eating habits (Dawson, 2017).

The nutritional approach endorsed by CrossFit (CrossFit, 2021) promotes a low-carbohydrate, paleolithic-style diet centered on meat, vegetables, nuts, seeds, and limited fruit consumption (Fraczek et al., 2021). This dietary framework, combined with practitioners' elevated energy requirements, presents challenges for low CO_{2e} emissions. The focus on high protein intake and animal-based foods, alongside increased energy expenditure, can result in substantial CO_{2e} emissions (Cambeses-Franco et al., 2021; O'Malley et al., 2019).

CrossFit athletes provide a valuable case study for examining relationships between intensive training, dietary practices, and CO_{2e} emissions. Their structured nutritional approach, paired with significant energy needs, exemplifies the challenges active individuals face when balancing performance goals with environmental considerations. The community's influence on dietary choices also offers insights into how social practices shape food consumption and their associated CO_{2e} emissions.

Running

Distance running requires careful nutrition planning for performance and recovery. Carbohydrates are the main fuel source, with muscle glycogen being essential for endurance. Research suggests strategic carbohydrate loading of 7-12 g/kg body weight daily before competitions to maximize glycogen stores. During events lasting over 90 minutes, consuming 30-60 g of carbohydrates per hour is recommended, with well-trained athletes potentially benefiting from up to 90 g/hour using multiple carbohydrate sources. Runners need more protein than sedentary individuals, with evidence supporting 1.2-2.0 g/kg body weight daily to support muscle adaptation and repair (Burke et al., 2019).

While carbohydrates fuel high-intensity efforts, fats are important for sustained, lower-intensity training. Athletes should include beneficial fatty acids from sources like avocados, olive oil, nuts, and seeds to support both performance and health (Burke et al., 2019).

For micronutrients, runners should focus on dietary variety, with special attention to iron due to its role in oxygen transport. Female athletes and those with restricted diets may need to monitor iron intake carefully (Burke et al., 2019). Research has identified concerning links between eating disorders and exercise addiction, particularly among young female runners who began training primarily for weight management (Di Lodovico et al., 2018).

Football/Soccer

Female soccer players require specific nutritional strategies for optimal health and performance. Research shows that energy intake should maintain a minimum of 30 kcal/kg fat-free mass daily to avoid negative health effects and performance declines (Thomas et al., 2016).

Carbohydrate intake should be adjusted based on training demands, 5-7 g/kg body weight daily during moderate to low-intensity training periods, increasing to 7-12 g/kg body mass daily during high-intensity training or match preparation. Protein needs for female soccer players range from 1.2-1.7 g/kg body weight daily. Dietary fat should be balanced carefully, making up less than 30% of total energy intake while maintaining at least 20% to ensure proper absorption of fat-soluble vitamins and essential fatty acids (Dobrowolski et al., 2020).

Several micronutrients deserve special attention for female soccer players, particularly iron, calcium, and vitamin D. These nutrients are essential for energy metabolism, bone health, and maintaining performance capacity (Dobrowolski et al., 2020).

Athletes as High-Energy Consumers

Athletes typically require significantly higher energy intake than the general population due to elevated activity levels, greater muscle mass, and increased energy expenditure. This higher energy requirement particularly affects protein needs, with international sporting bodies like the International Olympic Committee (IOC) recommending protein intakes between 1.2 and 2.0 g/kg body weight daily (Bakkman et al., 2016; Bytowski, 2018; Potgieter, 2013). These recommendations substantially exceed both WHO/FAO guidelines (0.8 g/kg/day) and Nordic Nutrition Recommendations (1.1g/kg/day) (Blomhoff & Nordic Council of Ministers, 2023; Joint WHO/FAO/UNU Expert Consultation, 2007), creating potential tension between nutritional needs and CO₂e when protein sources are primarily animal-based.

A prevalent strategy among athletes for meeting elevated protein requirements is whey protein supplementation. The production of whey protein, derived from cheese manufacturing, is resource-intensive, requiring 20-30 times the volume in processing resulting in 40.65 kg CO₂e/kg at 85% concentration (Bacenetti et al., 2018). This concentration is the standard in sports nutrition products and thus can whey protein consumption substantially contribute to athletes' overall CO₂e emissions. This is comparable to the CO₂e of beef and often goes unrecognized by athletes who view whey protein primarily through a performance lens.

Recent trends show increasing climate awareness among athletes, with growing adoption of vegetarian and vegan diets (Rogerson, 2017). Research demonstrates that plant-based diets can support athletic performance comparable to omnivorous diets (Craddock et al., 2016; Nebl et al., 2019; Rogerson, 2017), challenging traditional assumptions about protein requirements and sources. This evolution in athletic nutrition practices presents an opportunity to examine how high-energy consumers can balance performance needs with climate consciousness.

Athletes' influence can also serve positive role models, particularly among younger populations (Kershaw, 2017), positions them uniquely to promote sustainable dietary practices (Richert, 2019). However, traditional research on athletic nutrition has primarily focused on performance optimization rather than climate impact (Thomas et al., 2016). Understanding athletes' food choices requires moving beyond conventional dietary assessment methods to consider the multifaceted social and psychological factors influencing food practices.

Social practice theory offers a valuable framework for understanding athletes' and other consumers' food choices by examining eating habits as part of broader social structures rather than purely individual decisions (Shove et al., 2012; Warde, 2005). This approach helps capture the intricacy of food consumption and identify opportunities for promoting sustainable practices among high-energy consumers (M. Keller et al., 2016). Understanding these practices requires accurate assessment of physical activity levels and their relationship to dietary choices and CO₂e.

Theory

Social practice theory as a theoretical framework

Origins and Development of Social Practice Theory

Social practice theory represents a significant paradigm shift in sociological thinking, moving away from individualistic interpretations of human behavior toward understanding actions as embedded within larger social entities. This theoretical framework emerged as a response to the limitations of both purely structuralist and purely agency-focused approaches to social analysis. The development of social practice theory can be traced through distinct waves of theoretical advancement, each building upon and refining previous conceptualizations.

Pierre Bourdieu's work in the late 20th century established the first wave of practice theory. Bourdieu (1977) explored how people's perceptions of their social environment are shared among groups with similar experiences, challenging individualistic views of social behavior and positioning practices as fundamentally social phenomena.

Anthony Giddens' structuration theory (1984) further developed practice theory through his concept of the duality of structure. Giddens (1984) proposed that social systems simultaneously serve as both the medium and result of social practices, demonstrating how individual actions and social structures create each other. While structures influence behavior, they are also maintained and changed through the very practices they influence.

The second wave of practice theory saw significant theoretical refinement through the work of scholars such as Theodore Schatzki and Andreas Reckwitz. Schatzki et al. (2001) expanded the theoretical framework by emphasizing the role of material entities in practice formation, arguing that practices emerge through the interaction between human activities and material arrangements. This material turn in social practice theory opened new avenues for understanding how physical objects and infrastructure shape social practices.

Reckwitz's (2002) contribution was particularly significant in highlighting the routinized nature of social practices. His work demonstrated that practices are not random assemblages of action but structured, recurring patterns that integrate various elements including bodily activities, mental activities, objects, and forms of understanding (Reckwitz, 2002). This conceptualization helped bridge the gap between theoretical frameworks and empirical observation.

Alan Warde's application of social practice theory to consumption studies represents a significant advancement in the field. Warde (2005, 2017) developed a more empirically oriented framework that examines consumption through the lens of practical knowledge, established routines, emotional engagement, and material infrastructure. His approach demonstrates how consumption is not merely an individual act, but a social practice embedded within broader cultural and material contexts. This framework provides clear analytical categories while maintaining sensitivity to the interplay between different practice elements.

Social practice theory, as developed by Shove, Pantzar, and Watson (2012), offers a distinctive framework for understanding how social practices emerge, persist, and transform. Their approach simplifies previous practice theories by focusing on three key elements that constitute any practice: materials, competence, and meaning.

Their three-element model:

- Materials encompass objects, tools, infrastructure, and even the human body.
- Competence includes skills, know-how, and practical understanding required to perform a practice.
- Meaning represents the social and symbolic significance that makes the practice meaningful to practitioners.

Figure 1 illustrates the dynamic relationship between these elements, showing how they interact to create and sustain social practices.

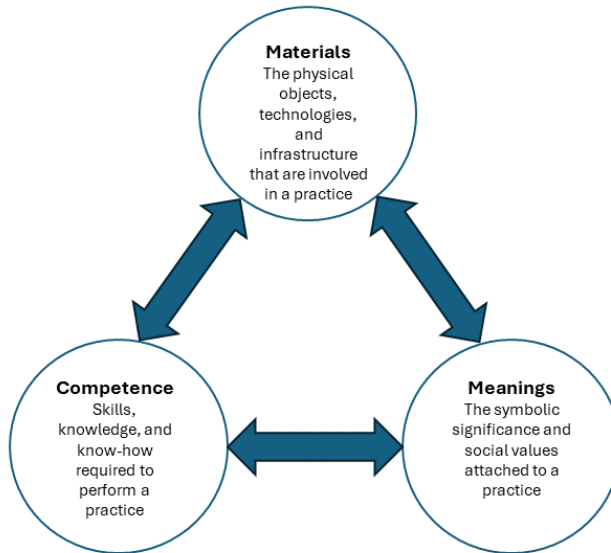


Figure 1. Inspired by Shove et al. (2012), p 14, Competence, material, and meaning that together interact to shape and sustain social practices.

This model offers analytical clarity alongside theoretical depth. Unlike earlier abstract approaches, Shove et al.'s (2012) framework provides researchers with tangible categories for empirical study while recognizing practices' dynamic nature. The model illustrates how practices emerge, persist, and transform through ongoing interactions between these three elements.

According to Shove et al. (2012), practices exist only when these elements are actively integrated through performance. A practice forms when connections between elements are established, continues when these connections are regularly renewed, and disappears when links dissolve. This perspective emphasizes the evolving nature of practices through the continuous formation and dissolution of connections between elements.

A key insight from Shove et al.'s framework is that while practices themselves do not travel, their individual elements can move independently across contexts

and time periods. Materials can be physically transported, competencies shared through documentation, and meanings spread through social networks, enabling practices to diffuse and evolve in new settings (Shove et al., 2012). This mobility of elements explains how practices spread and transform across different environments.

Social practice theory effectively illuminates food consumption and sustainability patterns. Marshall (2016) shows how cultural conditions shape sustainable practices, revealing activities like shopping, cooking, and eating form an interconnected network rather than standalone actions. Both material infrastructure and shared understanding significantly influence these practices.

This aligns with Warde's view (2005, 2016) that consumption involves adaptable understandings, procedures, engagements, and materiality. Marshall's (2016) analysis demonstrated how, within collectively established sustainable practices, individual practitioners negotiated the tension between adherence to sustainability ideals and the making compromises in their day-to-day choices.

Recent research demonstrates the theory's versatility. Fuentes & Fuentes (2021) explored plant-based practices in meat-centric cultures, while Biermann & Rau (2020) compared sustainability approaches in home versus restaurant settings. Dubuisson-Quellier & Gojard (2016) mapped sustainable food practices across French social groups, showing their connection to wider social structures.

The theory excels by capturing everyday eating practices as an integrated whole (Warde, 2014; Hargreaves, 2011; Keller et al., 2016), revealing how social, cultural, and material factors shape our food practices. For climate-conscious consumption, this suggests successful dietary transitions require reshaping collective routines rather than focusing solely on individual change.

Effective research must consider both structural elements and evolving dynamics (M. Keller et al., 2016; Warde, 2016), examining how practices attract participants and how configurations influence behavior (Shove et al., 2012).

Mixed-methods design

This thesis employed a pragmatic mixed methods approach to investigate how recreational athletes and physically active young adults make food choices in relation to climate considerations. Papers III and IV utilized a convergent parallel design, collecting quantitative and qualitative data simultaneously.

Food records provided quantitative measurements of consumption and CO₂e, while interviews yielded qualitative insights into motivations and perceptions. This methodological integration delivered a more comprehensive understanding than either approach could have achieved independently.

Pragmatism in Mixed Method Research

Pragmatism provides a philosophical foundation emphasizing practical outcomes and utility. In mixed-method research contexts, pragmatism enables methodological flexibility, allowing researchers to select approaches that best address research questions, whether qualitative, quantitative, or combined (Styhre, 2024). With its problem-solving orientation, pragmatism advocates method selection based on effectiveness in answering research questions and addressing real-world issues. This permits researchers to integrate qualitative and quantitative approaches within single studies to develop more comprehensive understandings of research problems (Onwuegbuzie et al., 2009).

Pragmatism supports combining qualitative and quantitative approaches to utilize their complementary strengths. Qualitative methods enable exploration and understanding of phenomena, while quantitative methods provide measurement and quantification. Method integration allows researchers to triangulate findings, comparing results across different methodological approaches to enhance the credibility and validity of research conclusions (Foss & Ellefsen, 2002; Onwuegbuzie et al., 2009).

Pragmatism views knowledge as both constructed and based on real-world experience. This allows researchers to blend subjective and objective methods when collecting and analyzing data. Knowledge claims gain validity through “warranted assertability,” meaning research findings earn credibility through appropriate methods and quality data (Styhre, 2024). This adaptability and practical focus make pragmatism valuable for mixed-methods research. The pragmatic approach does not require specific methods or combinations, nor does it reject any approach. Rather than seeking unchanging truths, pragmatism focuses on addressing specific research questions with the most suitable methods. Validity is

understood as the alignment between theory and method, which differs from the traditional scientific view of truth as correspondence to reality (Feilzer, 2010).

This research uses pragmatism as the philosophical foundation for methodological decisions in both papers. Paper III applies a pragmatic approach to examine the relationship between athletic performance and climate considerations, combining objective CO_{2e} measurements with subjective perspectives on food practices. This approach helped address the research question by considering both CO_{2e} and the socially constructed meanings of food choices.

Paper IV similarly employs pragmatism to integrate diverse data sources when investigating sustainable food consumption. The research demonstrates “warranted assertability” by basing CO_{2e} claims on quantitative measurements while validating interpretations of motivations through thorough qualitative analysis. This philosophical framework offers the flexibility to study both the measurable climate impact of food practices and their influencing social dynamics, yielding findings that have practical applications for understanding sustainable food consumption.

The convergent parallel design

The convergent parallel design represents a common mixed-methods approach where quantitative and qualitative data are collected simultaneously but analyzed separately. Findings from both methodological strands are then compared or integrated to develop comprehensive understanding of the research question (Creswell, 2007). This design proves valuable when addressing issues requiring both generalizable numerical data and contextual insights into underlying behaviors or perceptions (Onwuegbuzie et al., 2009).

In food and nutrition research, the convergent parallel design connects empirical food practice data with sociocultural, behavioral, and institutional factors influencing dietary decisions. Quantitative methods like surveys and dietary intake measurements reveal knowledge and behaviors, while qualitative approaches such as interviews and focus groups uncover values, motivations, and structural barriers shaping these practices (Creswell, 2017).

Simultaneous data collection ensures both datasets share the same temporal context, particularly important when studying dynamic phenomena like shifting dietary perceptions or behaviors. Separate analysis maintains the integrity of

quantitative rigor and qualitative depth, while subsequent integration enables nuanced interpretation of findings (Creswell, 2017; Onwuegbuzie et al., 2009).

For example, in Paper III-IV the convergent parallel design was employed to investigate food practices through complementary data streams. Quantitative measurements captured objective consumption while qualitative interviews revealed the underlying social dynamics and motivations. Social practice theory provided the analytical framework for understanding how performance-centered goals interacted with climate awareness.

In Paper IV, the research design compared different demographic groups while maintaining the methodological integration of quantitative CO₂e assessments with qualitative explorations of meaning-making. This approach enabled examination of how various factors influenced sustainable food practices across populations with different activity levels.

Both studies utilized the theoretical elements of competence, material, and meaning to analyze food consumption beyond individual choice, revealing how shared understandings and contexts shaped eating practices.

Aims

Overall aim

This thesis aims to explore sustainable food consumption in public and private meals, including nutritional, carbon footprint and sensory perspectives, and to suggest a model for meal development that can be used in the recipe and meal planning for groups and individuals to optimize sustainable meals.

Three Specific objectives

To evaluate and optimize public meal programs and recipes for effective balance between CO₂e reduction and nutritional adequacy, with specific focus on iron bioavailability and consumer acceptance.

Papers I and II

To identify gender-specific differences in dietary patterns and possible nutritional shortfalls and when shifting to climate-adapted diets.

Papers I, II, III, and IV

To examine the relationship between physical activity level and dietary CO₂e, and to identify strategies that enable active individuals to maintain their energy needs while reducing CO₂e emissions.

Papers III and IV

Figure 2 provides an overview of the thesis framework and how public and private meals through the objectives are used to identify opportunities and challenges in climate-adapted.

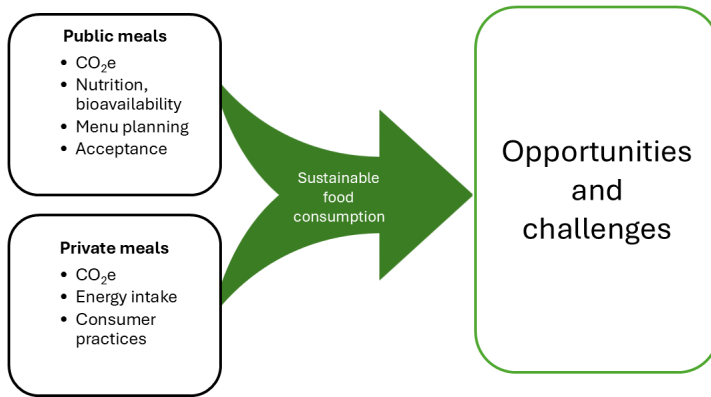


Figure 2: Thesis framework

Overview of thesis framework of public meals research (Papers I-II: CO₂e, nutrition, bioavailability, strategies) and private meals research (Papers III-IV: CO₂e, consumer perspectives) to identify opportunities and challenges for climate-adapted food systems.

Aims in the included papers

Paper I

Aims to assess climate-adapted practices, how this is mirrored in school lunch menus and recipes, nutritional aspects and carbon footprint of school lunches in different Swedish municipalities as well as if total and absorbable iron content can meet requirements for adolescent girls aged 12-16 years. Further, assess how total iron, absorbable iron and CO₂e varied between meal types.

Paper II

Aims to develop recipes that ensure that teenage girls meet their absorbable iron needs, while also considering carbon footprint and taste preferences. By focusing on both total and absorbable iron in our nutritional assessment, we strive to create recipes that are tasty, nutritionally beneficial, and sustainable.

Paper III

Aims to gain an in-depth understanding of recreational CrossFit athletes' food consumption practices and the possible role of climate consideration

Paper IV

Aims to explore climate consciousness in relation to food consumption in a sample of young Swedish adults, examining its relationship with physical activity level and gender.

Methods

Data collection

Table 1 provides an overview of the included papers' study design, objectives, focus area, participants and methods.

Paper I

The study collected data through a national survey of Swedish municipalities' food service departments. Out of all 290 municipalities contacted, 167 responded to the electronic survey. Additionally, 76 municipalities shared their school lunch menus, and six provided detailed recipes. The menu data covered a four-week period (weeks 3-6) in 2023.

The survey investigated meal composition and planning practices, including the balance between omnivorous and vegetarian meals, plant-based versus animal-based foods, and menu planning approaches. Municipalities were classified according to the Swedish Association of Local Authorities and Regions (SALAR) system into three categories based on population size and urbanity: (A) large cities and nearby municipalities, (B) medium-sized cities and surrounding areas, and (C) small towns and rural municipalities.

The analysis encompassed 1465 menu days, providing substantial data to examine school meal approaches across municipality types. Six municipalities supplied complete recipe documentation for the four-week period, yielding 120 days of detailed nutritional and preparation data that allowed for in-depth analysis of both nutritional adequacy and climate impact.

Paper II

The study employed a systematic dual-phase data collection approach incorporating both recipe development and consumer evaluation components. The study began by identifying a chili con carne recipe from a municipality participating in the national survey, which provided the baseline for recipe development. Various meat and plant-based ingredient combinations were then explored. Newly formulated recipes were then evaluated through a two-round

testing process, with four recipes assessed in the first round and three in the subsequent round.

Round 1 was performed in Spring 2023 with 48 participants (32 women, 15 men, 1 gender-undisclosed) aged 21-65 years, while Round 2 was conducted in Spring 2024 with 54 participants (32 women, 21 men, 1 gender-undisclosed) aged 19-66 years. Ten participants attended both rounds, resulting in 92 unique participants and 102 total evaluations. Participants were recruited from students and staff at the University of Gothenburg.

The consumer evaluation followed a standardized sensory testing methodology. Testing sessions, lasting 15-25 minutes, were conducted in groups of 7-12 participants in Round 1 and 11-21 participants in Round 2. Samples were prepared in an adjacent kitchen facility and maintained at serving temperature for 30-60 minutes before presentation. Each sample was served in clear 0.15 L plastic cups to enable visual examination and presented in randomized order with dual identification numbers to ensure double-blind conditions.

The participants filled out, a taste test protocol, including a 9-point hedonic scale to assess overall liking and a 5-point JAR (Just-About-Right) scale for evaluating specific attributes. The results in round 1 was evaluated and two recipe variants was selected for round two of cooking elaborations, modifications and consumer testing.

Paper III

The study followed a mixed-methods approach to investigate dietary practices among recreational CrossFit athletes. Data collection occurred between July and September 2020. The study recruited nine participants (five females, four males, ages 23-30 years) from a single CrossFit facility, with participation requiring at least ten hours of weekly training at various intensity levels.

Data collection comprised two primary elements. Participants maintained a seven-day weighed food record using an online tool, strategically split across two weeks (4+3 days) to capture representative consumption patterns. To support accuracy, participants were provided portable scales and received standardized reminders to enhance compliance. These records were used to assess energy and nutrient intake, and CO₂e.

Semi-structured interviews (20-30 minutes) were conducted within five weeks of food record completion. These explored training routines, daily activities, food procurement, cooking abilities, nutritional understanding, and climate impact

awareness. Participants also submitted photographic documentation of their meals. All interviews underwent verbatim transcription for analysis within a social practice theory framework (Shove et al., 2012). The sample size was deemed sufficient through data saturation.

Paper IV

The study used the same mixed-methods approach to data collection as in Paper III, integrating both qualitative and quantitative methodologies. Semi-structured interviews were conducted with all 47 participants, ranging from 20 to 60 minutes in duration and consisting of 12 open-ended, non-leading questions. These interviews examined participants' food procurement habits, dietary preferences, patterns of dietary change, diet-health relationships, and food choice considerations. To reduce social desirability bias, the study's focus on climate considerations remained undisclosed to participants.

Alongside interviews, participants maintained a seven-day food record using a digital application. To enhance reporting accuracy, portable scales were provided for food weighing, with the option to include photographic documentation. Participant engagement was supported through standardized encouraging messages sent on days three and six to promote compliance. Energy intake reporting validity was evaluated by comparison with participants' resting metabolic rate.

The study included 47 participants (25 women, 22 men), aged 18-40 years, recruited between October 2020 and April 2021 through university bulletin boards, email communications, social media platforms, and sports club networks. Participants were categorized into two groups based on physical activity: a moderately-active group (n=22) engaging in up to 150 minutes of moderate-to-vigorous physical activity weekly, and a highly-active group (n=25) performing at least 300 minutes weekly.

Dietary data underwent analysis for CO₂e, nutritional content, and protein source categorization (animal versus plant-based). All interviews were transcribed verbatim for analysis within a social practice theory framework (Shove et al., 2012). This multifaceted approach facilitated both qualitative insights into dietary decision-making and quantitative measurements of food consumption and CO₂e emissions.

Table 1. Overview of studies related to climate-adapted food consumption in public and private meals

Paper	Design	Objective	Focus	Data collection	Participants	Data analysis method
I	Explorative study	Public meals, Nutritional adequacy, Gender	Climate-adaptation in public school meals, general and iron nutrition	National survey, menu and recipe collection, nutrition calculations	76 municipalities provided menus, 6 provided recipes, total of 120 meals	Nutritional calculations, CO ₂ e assessment, parametric and non-parametric statistics
II	Methodological	Public meals, Nutritional adequacy, Gender	Recipe development climate-adapted school meals nutrition, iron and acceptability.	Recipe selection, cooking elaborations, consumer evaluations, nutrition calculations	102 consumer evaluations. (Round 1, 48 participants. Round 2, 54 participants)	Nutritional calculations, CO ₂ e assessment, statistical analysis of consumer preferences and sensory attributes
III	Mixed-method	Private meals, Gender, Physical activity	Food consumption, climate impact, activity level	Semi-structured interviews, 7-day food records	5 female, 4 male CrossFit athletes, minimum of 10 h training per week	Social practice theory, descriptive statistics, CO ₂ e assessment
IV	Mixed-method	Private meals, Gender, Physical activity	Food consumption, climate impact high activity level	Semi-structured interviews, 7-day food records	25 women, 22 men with different activity level, 22 moderately active, 25 highly active (runners, CrossFit, soccer)	Social practice theory, descriptive statistics, CO ₂ e assessment

In the following section, all the methods applied in the various studies included in this thesis will be described. While some methods are consistently used across all four articles, others are specific to individual studies. I will present these methods based on their frequency of use, starting with those applied most often.

Swedish food agency's food database (Papers I-IV)

The Swedish Food Agency's food composition database was used in all in all calculations of nutritional value in all the included papers. The database provides the foundational nutritional data for this study, offering comprehensive analysis of foods commonly consumed in Sweden. The database builds on a systematic approach to data collection, integrating information from multiple validated sources: direct laboratory analyses, national dietary surveys, and carefully vetted data from established international food composition databases (Livsmedelsverket, 2022). Its comprehensive coverage of Swedish dietary food products and composite dishes and methodological framework made it particularly suitable for this research.

The database development follows a strategic prioritization framework, focusing particularly on foods that contribute significantly to the Swedish population's nutrient and energy intake. These key foods undergo thorough analysis for more than 50 nutrients and components. The analytical scope includes macronutrients (proteins, carbohydrates, fats), micronutrients (vitamins and minerals), and other dietary components such as fiber and water content. All laboratory analyses adhere to standardized protocols with integrated quality control measures and uncertainty assessments for each nutrient determination (Livsmedelsverket, 2024b).

RISE Food Climate Database (Papers I-IV)

The RISE Food Climate Database was used to calculate the CO_{2e} emissions in all the included papers. The database offers a comprehensive coverage of Swedish food products through regularly updated life cycle assessments (LCA). Selected for its specific focus on Swedish food systems and transparent methodology, the database encompasses more than 800 food products that reflect typical Swedish consumption patterns, making it particularly suitable for analyzing school meals (Florén et al., 2017; RISE Food Climate Database | RISE, n.d.).

The database employs rigorous methodological standards, conducting LCAs in accordance with ISO 14040 and 14044 protocols (Arvanitoyannis et al., 2014). These assessments follow a cradle-to-gate approach, capturing CO₂e emissions across the entire production chain from primary production through processing and transportation to Swedish retailers (Florén et al., 2017). The climate impact calculations integrate multiple greenhouse gases - including carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) - expressing them as carbon dioxide equivalents (CO₂e) using IPCC AR5 conversion factors. Each food item is measured in kilograms of CO₂e per kilogram of food, with typical uncertainty ranges maintained within $\pm 20\%$ (Cucurachi et al., 2019).

The assessment boundaries include agricultural production (including feed for animal products), food processing, packaging materials, and transportation. For imported products, direct land-use change impacts are included where applicable. The database does not account for indirect land-use change or consumer-phase impacts like household storage and cooking, as these vary considerably depending on end-use practices.

The database is updated annually through a systematic process that includes new primary data from Swedish producers and suppliers, refined assessment methods based on recent LCA research developments, addition of new food products reflecting changing consumption patterns, and validation against other international food LCA databases. While other databases such as Agribalyse (Colomb et al., 2015) and World Food LCA Database (Nemecek et al., 2019) exist, the RISE database was selected for this research due to its focus on Swedish food systems and methodological transparency, despite limitations in capturing regional production variations and seasonal impacts (RISE Food Climate Database | RISE, n.d.).

Absorbable iron equation by Hallberg & Hulthén (2000) (Paper I-II)

The iron absorption algorithm is a sophisticated mathematical model designed to predict the amount of iron the human body absorbs from a meal. It considers several dietary factors that can either enhance or inhibit iron uptake. The algorithm was used as a part of the nutrition calculations in Papers I and II.

Key factors influencing iron absorption

The algorithm considers eight critical factors that interact to determine the final iron absorption:

Phytates, found in whole grains and legumes, nuts and seeds significantly reduce iron absorption by binding to iron molecules and preventing their absorption in the intestinal tract. This can decrease iron absorption by 50-90%.

Ascorbic acid (Vitamin C), present in citrus fruits and vegetables, dramatically increases iron absorption. It converts iron to a more easily absorbed form and breaks down iron-binding complexes and potentially increasing absorption by up to 67%.

Polyphenols, found in tea, coffee, and some fruits, block iron absorption by forming stable complexes with iron that prevent intestinal absorption. This can reduce absorption by 25-75%.

Calcium, present in dairy products and fortified foods, competes with iron for absorption by interfering with iron uptake at cellular absorption sites in the intestine. This can decrease iron absorption by 30-50%.

Meat factor, an active substance, or substances, contained within animal muscle tissue, which has been shown to increase overall absorption of iron. It enhances the absorption of iron from plant-based foods when consumed together in the same meal, potentially increasing absorption by 15-25%.

Soy protein, found in soy-based products, may reduce iron absorption as protein complexes potentially interfere with iron uptake.

Algorithmic calculation process

The algorithm works through a multi-step process. First, it analyzes the meal composition by identifying all food components and quantifying the amount of each iron-affecting factor. Next, it calculates the interactions between these factors by applying specific weight and reduction/enhancement coefficients to each factor and accounting for multiple interactions. Finally, it incorporates individual factors such as current iron status, serum ferritin levels, to adjust the final calculation.

Factor estimations

Iron, total iron content for all recipes in papers II and IV was derived from the Swedish Food Agency's food composition database (Swedish Food Agency, 2024) using mean values. The distribution between heme and non-heme iron, by

difference; in animal products was determined based on published literature (Archundia-Herrera et al., 2024; Hallberg & Hulthén, 2000).

Phytate values were obtained from several established sources in the literature. The majority of product references were sourced from Hallberg & Hulthén (2000), complemented by data from the Global Food Composition Database for Phytate (Dahdouh et al., 2019) and “Food Phytates” (Reddy & Sathe, 2001). For contemporary plant-based meat alternatives, phytate data were extracted from Mayer-Labba et al. (2022), while bulgur values were referenced from Ertaş (2017). In the algorithm phytate values were capped at 270 mg as instructed by Hallberg & Hulthén (2000).

Ascorbic acid, mean vitamin C content was obtained from the Swedish Food Agency’s food composition database (Swedish Food Agency, 2024). To account for thermal degradation during cooking and avoid overestimation, a 50% reduction in vitamin C content was applied in the algorithm calculations.

Calcium content was derived from the Swedish Food Agency’s food composition database (Swedish Food Agency, 2024) and content was capped at 600 mg in the calculations as instructed by Hallberg & Hulthén (2000).

Meat and fish proteins, the values reported in the original recipes were used. Breaded products underwent additional analysis to determine their actual meat or fish content. Similarly, processed products such as meatballs and sausages were evaluated to establish their precise meat percentage content.

Soy protein, for all soy products, calculations were based on the manufacturer-declared soy protein content. In accordance with the validation limits established by Hallberg & Hulthén (2000), soy protein content was capped at 20 g in the calculations.

Food records (Paper III-IV)

In Paper III-IV weighted food records was used to collect information regarding the participants food consumption and to calculate CO₂e. Weighed food records represent the most precise method for estimating individual food and nutrient intakes, particularly common in European dietary assessment (Bingham et al., 1994; Gibson, 2024). In this method, participants weigh and record all consumed foods and beverages during a specified period, including detailed information about food preparation methods, and brand names (Gibson, 2024). This approach involves thoughtful selection of recording timeframes, incorporating balanced weekday and weekend sampling to reflect intake variability.

In this thesis Paper III-IV dietary intake was assessed using a seven-day weighed food record, divided into two recording periods (4 + 3 days) in Paper III to reduce participant burden while maintaining data quality and 7 consecutive days in Paper IV. Participants used an online dietary assessment tool (Nutrition Data, Nutrition Data Sweden AB, Norsjö, Sweden, version 20.11.11) to record their food and beverage consumption. Each participant was offered a portable digital scale to accurately weigh their intake. To enhance the precision of the dietary records, participants were instructed to document all consumed foods and beverages, including preparation methods and brand names where applicable. The Nutrition Data app's built-in photography feature allowed participants to provide visual documentation of their meals, offering additional verification of portion sizes and food items.

To maintain participant engagement and ensure data quality throughout the recording period, standardized encouraging text messages were sent to participants on days three and six. The Nutrition Data app's messaging function facilitated ongoing communication between researcher and participants. To evaluate the reliability of reported intake, energy intake was assessed relative to resting metabolic rate (EI/RMR), with values below 1.2 indicating potential underreporting.

The collected dietary data provided comprehensive information about participants' food consumption, including total energy intake, macronutrient distribution, and the balance between animal and plant-based protein sources. Additionally, the climate impact of dietary choices was evaluated using CO₂e calculations through the RISE climate database as a plug-in in DietistNet software (version 1.6). This method was selected for its ability to provide detailed quantitative dietary data while enabling analysis of both nutritional adequacy and CO₂e of food choices.

Interview methodology (Papers III-IV)

Semi-structured interviews

Semi-structured interviews were conducted to explore food habits and consumption patterns among young adults with varying levels of physical activity. The interviews were designed to understand how participants chose, prepared, and consumed food within the context of their daily lives and activity levels. Participants were recruited through university settings, sports clubs, and social

media channels to ensure representation of both moderately active and highly active young adults.

The interview guide focused primarily on understanding food-related behaviors and choices. Key areas of exploration included food shopping habits, dietary preferences, meal planning and preparation, and how these aspects interacted with participants' varying activity levels. Questions progressed from general inquiries about daily food routines to more specific explorations of food choices and consumption.

The semi-structured format allowed for systematic investigation while maintaining flexibility to explore emerging themes. When discussing food habits, the interviewers considered participants' activity levels as an important contextual factor, exploring how different levels of physical activity influenced food choices and consumption patterns. This approach helped illuminate how participants adapted their food practices to support their varying activity levels.

To capture comprehensive data about food consumption within the context of different activity levels, interviewers used a combination of open-ended questions and specific prompts about meals, food preferences, and dietary adaptations. Participants were encouraged to describe their food practices in detail, including how these practices aligned with or were influenced by their physical activity.

The interviews were in Paper III conducted on Zoom or at the gym and in Paper IV at the research facilities, with sessions lasting between twenty minutes to an hour. Each interview was audio-recorded and transcribed verbatim to ensure accurate data capture. Analysis focused on understanding food consumption and how it related to participants' different activity levels, with transcripts examined systematically for recurring themes and patterns in food practices.

Throughout the interview process, careful attention was paid to understanding both the practical and personal aspects of food choices. The interview structure encouraged participants to reflect on their food practices and articulate how these practices were shaped by their activity levels and lifestyle.

Physical activity (Paper III-IV)

In Paper III, employed a structured methodology to estimate Physical Activity Level (PAL) through a combination of qualitative interviews and established metabolic equivalent (MET) calculations. During 20–30-minute interviews, participants provided detailed information about their training regimens and daily activities. The standardized metabolic equivalents framework from Ainsworth et

al. (2011) Compendium of Physical Activities to quantify activity intensity was utilized. PAL values were derived through a compiled estimation that specifically accounted for the various sports disciplines incorporated within CrossFit training, with participants maintaining a minimum threshold of ten hours of weekly training across varying intensity levels. The energy requirement was estimated by multiplying PAL with the basal metabolic rate (BMR) calculated by the Harris and Benedict equation as it is found suitable for a CrossFit population (Souza et al., 2020).

In Paper IV, basic metabolic rate was estimated using the Harris and Benedict equation (Bendavid et al., 2021). The physical activity level (PAL) was assigned based on the activity group to which the participants were recruited: a PAL of 1.6 for the moderately active group and 2.0 for the highly active group. The estimated energy requirements were subsequently calculated by multiplying the BMR by the respective PAL.

Recipe development and consumer evaluations (Paper II)

Paper II used a modified culinary funnel approach (Westling et al., 2020), beginning with an established base recipe rather than a specific crop variety. This adaptation preserved the methodological framework's systematic nature while repositioning the entry point. The process commenced with selection of the foundational recipe, followed by controlled variation of ingredients, preparation techniques, and cooking parameters.

A methodical consumer evaluation approach was employed to assess recipe variants of chili con carne, balancing nutritional quality, sustainability, and taste preferences. The methodology utilized both hedonic scaling and the Just-About-Right (JAR) technique in a systematic two-round evaluation process. For consumer acceptance, a 9-point hedonic scale (Peryam & Pilgrim, 1957; Ares, Bruzzone, et al., 2014) was implemented to measure participants' overall liking of samples. Participants were also asked to indicate their preferred products through ranking methods and direct questioning approaches as suggested by Lawless & Heymann (1999).

The hedonic evaluation was complemented with a 5-point JAR scale (Li et al., 2014) for specific sensory attributes including "amount of beans," "richness," "spiciness," "seasoning," and "saltiness." Attributes that deviated from ideal intensity levels were identified through this method. When attributes were scored

below the JAR threshold, these insights were incorporated into recipe refinements for the second round of testing, such as sun-dried tomato paste being added and cumin being doubled to enhance richness.

For data analysis, non-parametric tests (Friedman's ANOVA) were employed after non-normal distribution of hedonic data was determined. A modified penalty analysis (Ares, Dauber, et al., 2014; Li et al., 2014) was also conducted to identify which attributes contributed to decreased overall liking, with these results being effectively visualized in radar plots to show variation between samples.

Each iteration underwent sensory evaluation to identify possible modifications. The recipe was tested using different ingredients and repeatedly improved based on consumer feedback. This ongoing process helped make the recipe versatile while preserving its core qualities. Quantitative assessments were integrated with sensory evaluations across multiple iterations, with recipe options being systematically narrowed down while multiple factors were simultaneously optimized.

Through this comprehensive sensory evaluation framework, recipes were developed that balanced nutritional adequacy, reduced environmental impact, and maintained consumer acceptance, demonstrating how sustainable food system transformation can be supported by systematic consumer testing. The methodology prioritized both sensory quality and functional adaptability throughout the development cycle.

Statistical analysis

Paper I

Statistical analyses in Paper I were conducted using R statistical software (version 4.1.2; R Core Team, 2024). Chi-square tests assessed meal type distributions, while independent t-tests compared iron content between vegetarian and animal-based meals. Given heterogeneous variances, Welch's ANOVA with Games-Howell post-hoc tests evaluated iron content differences across meal categories. The relationship between absorbable iron and CO_{2e} emissions was examined via Pearson correlation. Significance was set at $p < 0.05$. Welch's ANOVA was chosen because it remains accurate when groups have different variances and sample sizes. The Games-Howell post-hoc test complements this approach by maintaining reliable comparisons between specific groups under these same conditions.

Paper II

In Paper II, the Shapiro-Wilk test assessed the normality of hedonic data collected using the 9-point hedonic scale. Due to the non-normal distribution of hedonic data, non-parametric tests were employed with significance set at $p < 0.05$.

Friedman's ANOVA identified significant differences in liking between chili con carne variants. This non-parametric test was selected for analyzing related samples data where parametric assumptions were not met with ordinal data (Friedman, 1937). By transforming raw data into ranks within each subject, the test assessed whether repeated measurements showed significant differences while accounting for their dependent nature.

Penalty analysis quantified the relationship between product attribute deviations and consumer acceptance. This method utilized two fundamental measurements: Just About Right (JAR) scales and overall hedonic assessment. JAR scales measured consumer perception of specific attributes relative to ideal levels, typically on 5 or 7-point scales ranging from "much too little" to "much too much" (Rothman & Parker, 2009). The 9-point hedonic scale measured food acceptability from "dislike extremely" (1) to "like extremely" (9) (Song et al., 2021).

The analysis produced two metrics: frequency (proportion of consumers perceiving an attribute as deviating from optimal) and penalty score (difference in mean hedonic scores between consumers who rated an attribute as JAR versus those indicating deviation). Results were presented via scatter plots showing frequency of ratings outside the JAR range (x-axis) and associated penalty scores (y-axis). Attributes were considered meaningful when at least 20% of consumers rated them outside the JAR range (Meullenet et al., 2008).

This methodology translated subjective consumer assessments into quantifiable metrics that directly informed product development strategies. By identifying attributes with both frequent deviation from optimal levels and significant impact on consumer acceptance, targeted improvements could be implemented efficiently (Pagès et al., 2014).

Paper III

In Paper III due to the limited sample size ($n=9$), median and interquartile ranges were selected as the primary measures of central tendency and dispersion, providing statistical representations less sensitive to outliers and non-normal distributions. Sample characteristics were comprehensively analyzed using descriptive statistics to establish baseline demographic and contextual parameters. Power calculations were conducted for key outcome variables including energy intake, macronutrient composition, and daily CO₂e emissions (CO₂e /day) to assess the statistical robustness of the findings and determine the study's ability to detect meaningful differences in these primary endpoints.

Paper IV

Statistical analyses included descriptive statistics using means and standard deviations for participant characteristics and dietary patterns, with data stratified by activity level and gender. The Shapiro-Wilks test was employed to assess normality of variables. Relationships between variables were examined using Pearson's correlation coefficient. Between-group comparisons were conducted using Student's t-test for binary comparisons, while one-way ANOVA with Bonferroni post-hoc tests was utilized for multiple group analyses. Statistical significance was established at $p \leq 0.05$.

Software

Statistical analyses were conducted using multiple specialized software packages. IBM SPSS Statistics (Version 29.0.0.0, IBM Corporation, Armonk, NY, USA) was employed for statistical analyses in Papers III and IV. For Papers I and II, analyses were performed using R Statistical Software (Version 4.1.2, R Foundation for Statistical Computing, Vienna, Austria). Radar charts were created using the ggradar package (Bion, 2024), data were processed using the tidyverse suite of R packages (Wickham et al., 2019).

Sensory data analysis, specifically the modified penalty analysis, was executed using XLStat (Version 2024.1, Addinsoft, Paris, France). These software packages were selected to ensure robust and appropriate statistical processing aligned with the specific analytical requirements of each study component.

Ethical considerations

Most important when conducting research is that the benefits outweigh the risks (Swedish Research Council, 2017). These risks can be of both physical characteristics and integrity aspects. Thus, it is essential to thoroughly plan the studies and use methods with as low a risk as possible. Dietary assessment can be time-consuming and expensive, so data concerning other parameters should be collected simultaneously. Additional parameters include socio-economic status, health parameters, anthropometrical measurements, physical activity, and biomarkers if possible. These variables are addressed to gain valuable information with as little intrusion as possible into the lives of the participants (Gibson, 2024). It is avoided as much as possible to collect names, social security numbers, or other personal data during data collection. Names of subjects and schools are anonymized by code (Deac, 2018). Data collection, storage, and handling follow research practice and Gothenburg University's guidelines (Göteborgs Universitet, 2015).

Paper I utilized national survey data containing no sensitive or personal information and adhered to Helsinki Declaration regulations (World Medical Association, 1964).

Paper II received approval from the Swedish ethical review authority (No. 2022-04834-01) and included a taste panel without sensitive variable collection. All taste panel participants provided informed written consent and maintained withdrawal rights without explanation. Project risks were minimal and managed through communication and secure data handling. Participants sampled meals prepared in approved kitchens with established hygiene and safety protocols according to the regulation of the European Parliament and of the Council on the hygiene of foodstuffs. ((EC) No 852/2004, 2004). Study objectives were clearly communicated to participants across all project phases.

Papers III and IV included only consenting adults and received approval from the Gothenburg regional ethics committee No. 2019-05316. All participants provided informed written consent at screening and were notified of any deviant test values post-trial. Participants could withdraw without explanation. The study collected sensitive health variables that were handled in compliance with European

General Data Protection Regulation (GDPR) confidentiality requirements (Deac, 2018).

For qualitative interviews, I established conversational environments while acknowledging interviewer-established agendas. I emphasized value in all participant contributions while guiding discussions according to interview protocols. When potential health risks were identified, participants were helped in contacting appropriate healthcare providers. In cases where restrictive eating behaviors were observed, participants were encouraged to seek professional support and were provided with relevant contact information.

Results and discussion

This section presents a synthesis of findings across all four studies (Papers I-IV), addressing the three themes outlined in the specific objectives. By integrating evidence from both public meal systems and individual dietary practices, the discussion offers insights into climate-adapted food consumption. The analysis examines school meal programs as potential climate champions, revealing both opportunities and challenges in balancing nutritional adequacy with CO₂e reduction. It then explores how gender shapes nutritional needs and dietary behaviors, with particular focus on iron bioavailability challenges in climate-friendly diets. Finally, the section investigates the relationship between physical activity levels and CO₂e, identifying pathways to reconcile active lifestyles with environmental sustainability.

Theme 1: School meals as climate champions

The implementation of climate-adapted school meals presents an intersection of nutrition, climate impact, taste, and ethical considerations. While school meal programs demonstrate significant potential (20-40%) for CO₂e reduction (André et al., 2023; Colombo et al., 2019, 2020), the transition raises important questions about both nutritional adequacy and the fairness of placing substantial climate action responsibility on children and adolescents.

Current implementation (Paper I)

In the analysis of 76 Swedish municipalities serving 538,750 daily school lunches, clear patterns emerged in the implementation of climate-adapted meals across the established municipality categories. Category A provided 40.5% of lunches, Category B served 42.3%, and Category C delivered 17.2% of the total.

Serving on vegetarian option daily alongside the omnivore alternative were almost a standard, with 92.1% of municipalities offering daily vegetarian alternatives. Category B led this trend at 94.4%, followed by Category C (88.5%) and Category A (86.7%). Additionally, 64 municipalities served one fully vegetarian lunch day per week. While only four municipalities (all from Category A) reported

in the survey that they serve two fully vegetarian days weekly, actual implementation was higher. When analyzing the provided menus eight municipalities were found to implement two vegetarian days per week, with six in Category A and one each in Categories B and C.

Analysis of 1,465 menu days showed meat-based meals dominated at 53.9%, while fish and vegetarian options each represented about one-fifth (20.0% and 21.9% respectively). Category A showed the most progressive approach with the lowest proportion of meat meals (47.7%) and highest proportion of vegetarian options (29.0%), including greater use of plant-based meat alternatives (9.7%). This pattern suggests a more ambitious climate-adapted approach, supported by CO₂e emission targets in their meal planning strategies (Post et al., 2025).

Fish appeared consistently across all municipality categories at approximately 20%, suggesting standardized practices aligned with nutritional guidelines. Among meat options, poultry was most common (15.2%), followed by pork/sausage (13.4%), beef (11.5%), and ground meat (10.6%), with game meat rarely appearing (less than 1.6%).

Nutritional analysis and CO₂e

In an in-depth recipe analysis from six municipalities (two each from Categories A, B, and C), 120 school lunch recipes were examined over four-week periods. All recipes were energy-adjusted to 735 kcal to enable fair comparison. This analysis revealed important relationships between iron content, its bioavailability, and CO₂e emissions across different meal types.

Vegetarian options showed the highest total iron content (3.86 ± 1.75 mg/100g), followed by red meat (3.55 ± 0.97 mg/100g) and poultry (3.45 ± 0.77 mg/100g), with fish showing significantly lower levels (2.29 ± 0.66 mg/100g). However, when examining absorbable iron, a different picture appeared: red meat and poultry demonstrated the highest amount (0.42 ± 0.21 and 0.41 ± 0.15 mg/100g respectively), while vegetarian meals showed significantly lower absorbable iron (0.22 ± 0.14 mg/100g). Fish meals showed intermediate numbers (0.33 ± 0.14 mg/100g). Further details regarding total iron, absorbable iron, iron bioavailability and CO₂e can be found in Table 2.

Table 2. Total iron, absorbable iron, iron bioavailability and CO₂e across meal types

Meal type	n	Total iron mg	Absorbable iron mg	Bioavailability %	Kg CO ₂ e/meal
Type of meat					
Beef	11	4.13 (3.0-6.4)	0.57 (0.29-1.38)	14	2.98 (1.8-5.4)
Fish	25	2.28 (1.5-4.1)	0.34 (0.18-0.65)	15	0.73 (0.4-2.4)
Ground meat [†]	8	3.38 (2.6-4.6)	0.40 (0.13-0.66)	12	1.90 (1.2-3.5)
Pork/sausage	17	3.26 (2.0-6.2)	0.33 (0.13-0.66)	10	0.75 (0.4-1.6)
Poultry	23	3.25 (2.3-5.5)	0.39 (0.18-0.69)	12	0.63 (0.3-1.3)
Type of vegetarian					
Vegetarian (non-soy)	21	3.48 (1.2-6.8)	0.21 (0.07-0.52)	6	0.56 (0.3-0.8)
Soy-based	10	4.47 (1.9-6.8)	0.15 (0.09-0.26)	3	0.50 (0.3-0.7)

For each meal category, the following parameters are reported: sample size (n), total iron content (mg), absorbable iron (mg), iron bioavailability (%), and CO₂e (kg CO₂e/meal). Meals are categorized into main groups (meat, fish, vegetarian) with further subdivision of meat into poultry, beef, ground meat, and pork/sausage, and vegetarian meals into non-soy and soy-based options. Values are presented as means with (min-max) in parentheses.

[†]Ground meat made of a mix of beef and pork

* The max values of total and absorbable iron are from black pudding

Analysis of CO₂e emissions revealed that red meat meals generated significantly higher CO₂e (1.69 ± 1.19 kg CO₂e/kg) compared to all other meal categories. Poultry, fish, and vegetarian options demonstrated similar, lower environmental impacts (0.63 ± 0.18 , 0.76 ± 0.47 , and 0.53 ± 0.17 kg CO₂e/kg, respectively). This finding aligns with previous research showing that plant foods consistently generate the lowest CO₂e compared to meat, fish, and dairy products (Röös, 2013).

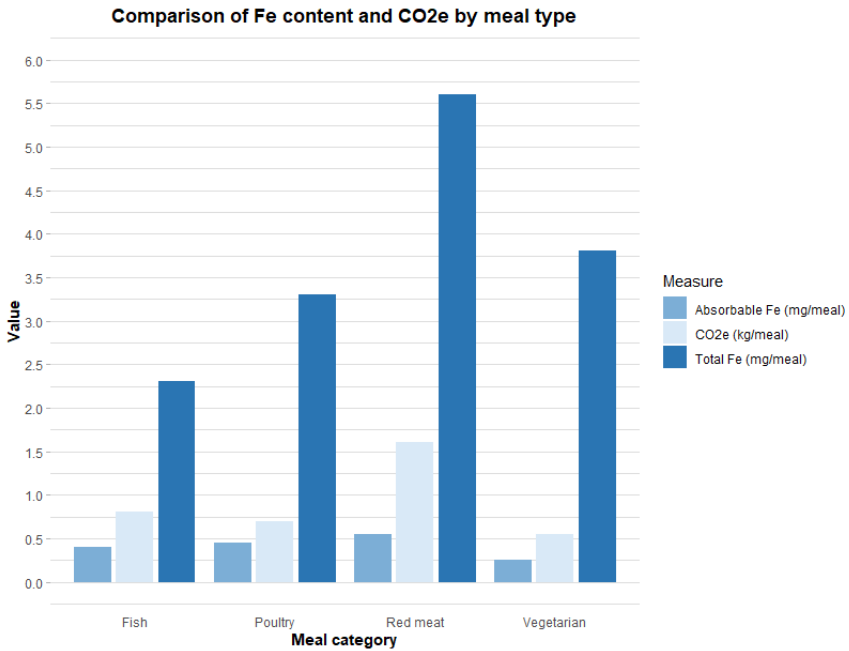


Figure 1. Comparison of Iron (Fe) content in mg per meal and kg CO₂e per meal across meal types.

The graph shows three measures - Absorbable Fe, CO₂e emissions, and Total Fe - for fish, poultry, red meat, and vegetarian food categories. Values are presented in standardized units, with Fe content measured in milligrams and CO₂e in kilograms per serving.

These findings reveal a key conflict between nutritional adequacy and climate goals, especially for populations with higher iron needs, such as women (Barre et al., 2018; Beal et al., 2023; Leonard et al., 2024). Barré et al. (2018) support this observation, showing through diet modeling that iron bioavailability substantially limits potential meat reduction, particularly when ensuring sufficient iron status in women.

Hybrid recipe solutions (Paper II)

Paper II explored potential solutions through meal optimization, beginning with seven variations of chili con carne developed from a base recipe containing 50g of ground beef per portion. All variations incorporated finely chopped carrot and celeriac to enhance palatability. Four variants were selected based on taste, iron content and CO₂e for Round 1 of consumer evaluations: one soy-based (Soy1),

two hybrids combining ground beef with either soy mince (Beef/Soy1) or lentils (Beef/Lentils1), and a beef-and-beans variation (Beef/Beans1).

The optimization process revealed varying success in balancing nutritional and CO₂e goals. Among optimized recipes, only Beef/Lentils1 exceeded the recommended absorbable iron threshold for median girls (0.44 mg) when served without milk. CO₂e reductions varied significantly: Soy1 achieved 84% reduction, hybrid recipes approximately 39%, and the Beef/Beans1 16%. These findings demonstrate that strategic recipe optimization, particularly through hybrid formulations, can achieve significant climate benefits while maintaining nutritional value.

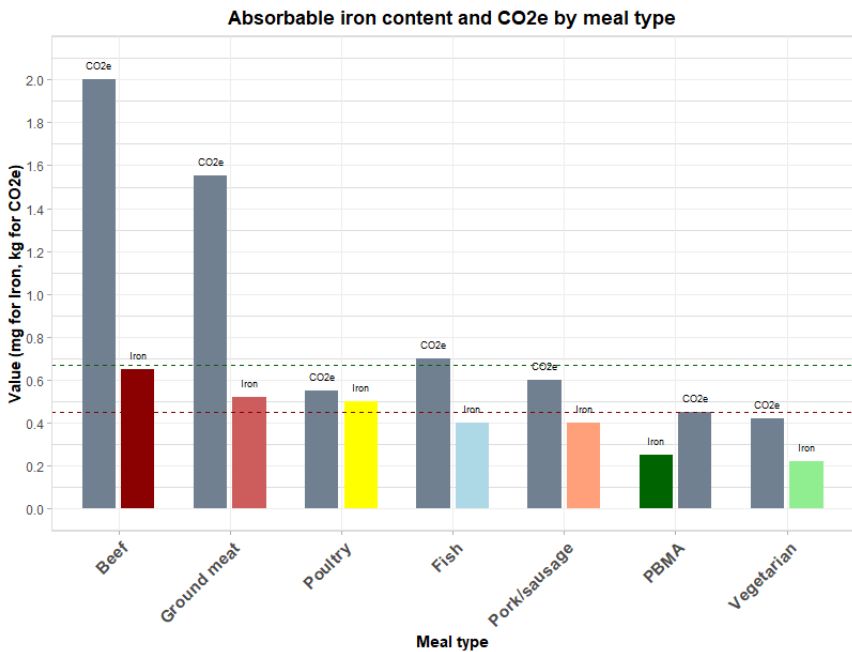


Figure 4. Absorbable iron content and CO₂e per meal type

The bar chart compares absorbable iron content (measured in mg) and kg CO₂e across more detailed type of meals. Dotted lines represent absorbable iron requirements for the median girl 0.44 mg and 95th percentile 0.66mg (Domellöf & Sjöberg, 2024).

Consumer acceptance and recipe development

Round 1 of consumer evaluation showed positive acceptance across all recipes in (scores 6.5-7.1), with the Beef/Soy1 combination emerging as most preferred. While penalty analysis identified concerns with richness and saltiness in the Beef/Soy1 variant ($p=0.03$ and $p=0.04$), these did not significantly affect overall acceptance (Friedman's ANOVA, $p=0.066$).

For the second round of recipe development, the two hybrid formulations from round 1 were selected for further improvements (Beef/Soy2 and Beef/Lentils2) based on a balanced compromise between taste, iron absorption and CO₂e. The improvements included using leaner beef (10% fat) and rapeseed oil to reach the same fat content in the hybrid recipes and enhanced seasoning. We also tested a third variant—the original recipe modified with the same vegetable base and seasoning profile (Beef2). The JAR scores for richness showed notable improvements: Beef/Soy2 increased from 52% to 61%, while Beef/Lentils2 rose from 38% to 56%. In the second round of consumer evaluations, Beef/Soy2 emerged as the preferred option (40.4%, $n=21$), followed by Beef2 (34.6%, $n=18$) and Beef/Lentils2 (25%, $n=13$).

These improvements in consumer acceptance can be attributed to our focus on enhancing flavor complexity, particularly through umami components. Umami plays a critical role in hybrid recipe development, as research has shown that this “fifth taste” significantly influences meat-like flavor perception, making it essential for optimizing hybrid formulations (Lang, 2020). The addition of naturally umami-rich ingredients like sun-dried tomatoes, containing glutamine (Paolo et al., 2019), improved sensory scores. Recent advances in plant-based proteins, particularly the success with pea protein (Baune et al., 2023) combined with improved techniques for reducing antinutritional factors (Chigwedere et al., 2023), suggest promising development pathways.

The combined findings from both papers demonstrate that recipe development can successfully reduce CO₂e while maintaining nutritional adequacy and consumer acceptance. This challenges the assumption that climate adaptation inherently reduces consumer acceptance, as evidenced by a French study where hybrid approaches combining vegetarian meals with fish and non-ruminant proteins reduced CO₂e by 50% while maintaining nutritional adequacy (Poinsot et al., 2022).

However, acceptance vary significantly across consumer groups and countries, influenced by factors such as appeal, taste, and cultural preferences (Szenderák et

al., 2022). Implementation requires careful consideration of contextual factors and fairness concerns, particularly for children in critical developmental stages who depend on school meals as a primary source of nutrition (Beal et al., 2024; Eustachio Colombo et al., 2020).

These findings suggest that school meal programs can serve as catalysts for sustainable food systems, but success requires carefully balanced approaches that prioritize children's nutritional needs alongside climate goals. The tension between climate ambitions and nutritional adequacy is particularly concerning since climate action responsibility falls on children with limited agency in their meal choices. School meal programs can drive sustainability, but effective implementation demands balanced strategies that address both iron bioavailability and CO₂e emissions. This is especially important for municipalities with ambitious climate goals, to ensure this ambition does not compromise children's and adolescents' nutritional wellbeing.

The concept of “climate champions” arises in school meal contexts where students and meal planners are tasked with significant climate action responsibility through dietary modifications. This framework positions young people as both beneficiaries and agents of sustainable food transitions, creating a dual burden: advancing climate mitigation objectives while potentially compromising nutritional adequacy, particularly regarding bioavailable iron. School meal systems thus become experimental grounds for long-term dietary change initiatives, assigning climate responsibility to populations with limited agency in food selection during critical developmental stages.

Theme 2: Gender nutrition gaps in low-carbon diets

This analysis explores how gender, nutrition, and climate adaptation intersect within food systems across four research papers (Papers I-IV). Papers I and II examine nutritional challenges in climate-adapted school meal programs, particularly focusing on iron bioavailability and gender-specific nutritional needs. Papers III and IV complement these findings by investigating how gender influences dietary practices among private consumers, specifically CrossFit athletes and young active adults.

Across all studies, a consistent pattern emerges, efforts to reduce climate impact in food systems frequently intersect with gender-specific nutritional challenges, especially regarding iron intake and energy requirements.

The research progresses systematically from public to private food consumption, offering a comprehensive view of sustainable food system transformation. While Papers I and II highlight the challenges of balancing CO₂e emissions with nutritional adequacy in public meal services, Papers III and IV show related challenges and opportunities in personal dietary choices and behaviors.

A key finding across all four papers is the ongoing tension between reducing CO₂e emissions and maintaining adequate iron bioavailability, particularly for women and adolescent girls. This challenge appears in both public settings, where school meals struggle to meet iron requirements while reducing climate impact, and in private dietary practices, where female athletes and young adults face similar nutritional challenges when adopting climate-friendly diets.

School meal programs: gender and nutrition

Paper I's analysis of Swedish school lunch programs found important gender-related nutritional challenges in climate-adapted meals, especially regarding iron availability for adolescent girls. With iron deficiency affecting around 30% of Swedish adolescent girls (Hallström, et al., 2025; Livsmedelsverket, 2018b), this issue deserves special attention. This is especially important because school meals serve two key purposes: they provide one-third of pupils' daily nutrition and they are specifically designed to reduce nutritional inequalities among children (Livsmedelsverket, 2019; Swedish Parliament, 2010).

Statistical analysis showed clear differences across meal types. Red meat-based meals provided the highest absorbable iron (0.42 mg), followed by poultry (0.41 mg) and fish (0.33 mg), while vegetarian meals lagged significantly (0.22 mg). Most concerning were soy-based meals which, despite containing the highest total iron (mean 4.47 mg), had the lowest bioavailability at just 3%. Only one of the analyzed menus met the recommended daily iron provision of 4.5 mg, with vegetarian meals providing only 48% of median requirements of absorbable iron and less than 32% for teenage girls with higher iron needs.

A negative relationship between CO₂e reduction and absorbable iron was found ($r = -0.337$, $p < 0.001$), showing that meals with higher absorbable iron consistently had greater CO₂e emissions. Conversely, meals designed for low CO₂e emissions often had reduced levels of absorbable iron. The widespread use of soy-based protein alternatives which, while reducing CO₂e (Herrmann et al., 2024), significantly inhibit iron absorption (Hallberg & Hulthén, 2000; R. N. Reddy et al., 1996) serves as a perfect example of the risks of changing meal composition solely based on CO₂e metrics.

Plant-based meat alternatives (PBMA) pose significant nutritional challenges, particularly in certain municipalities. Our analysis of 1,465 school meal days revealed that 79 days (5.4%) featured PBMA, with soy-based products accounting for 74.7% of these meals. Usage varied by municipality category: Category A municipalities incorporated PBMA in 9.7% of meals, compared to just 3.6% in Category B and 4.6% in Category C municipalities.

This trend raises concerns about iron adequacy, especially for female students. Research by Hallström et al. (2025) demonstrates that girls consuming low-climate-impact diets face more than twice the risk of iron deficiency compared to those with higher-impact diets. These findings suggest that current climate-focused meal planning may inadvertently overlook critical gender-specific nutritional requirements while prioritizing CO₂e reductions.

The data shows clear differences in how well school meals cover iron requirements between boys and girls. School meals provide more of the needed iron for boys than for girls. For the average boy (median), school meals cover about 95% of their iron requirements, while for average girls, meals only cover about 73%. Even when looking at the higher coverage level (95th percentile), boys' school meals reach about 85% of their requirements, but girls' meals only cover 58%. The dotted line at 100% shows the target for complete iron coverage, which no group fully achieves through school meals, though average boys come closest. This pattern reveals an important nutrition gap between genders, with school

meals consistently covering less of the required iron for girls than for boys. Mean coverage for the median girl and boy and the 95th percentile is displayed in Figure 5.

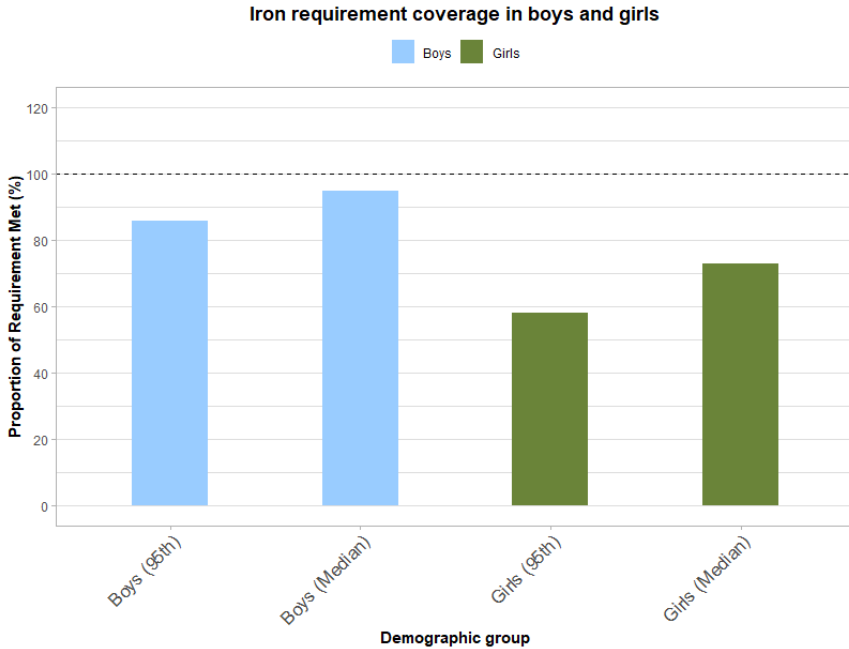


Figure 5. Iron requirement coverage

Visualization of iron requirement coverage (%) for boys and girls across median and high-need (95th percentile) groups. The dashed line indicates 100% coverage of recommended values.

Regarding other vitamins and minerals, Vitamin C levels were higher than the reference value (23 mg) in all municipalities, ranging from 29-71 mg. Folate levels also exceeded the reference value (90 µg) in all municipalities, ranging from 111-170 µg. Similarly, calcium levels were above the reference value (240 mg) across all municipalities, ranging from 264-558 mg. Vitamin D levels varied around the reference value (3.0 µg), with Municipality 4 and 6 having higher levels (4.7 µg and 3.8 µg respectively), while the other municipalities ranged from 2.6-3.3 µg.

Previous research on climate-adapted school meals designed to reduce CO₂e emissions while maintaining nutritional value (André et al., 2023; Colombo et al., 2020) may not have fully considered the challenges of low iron bioavailability in plant-based alternatives. This is especially important since school meals provide

more than 30% of Swedish adolescents' daily iron intake (Eustachio Colombo et al., 2020).

To address this challenge, Paper II explored potential solutions through meal development, using chili con carne as a test case. The recipe development findings suggest a promising approach through hybrid formulations that effectively balance climate impact, nutritional requirements, and taste preferences. By combining plant-based ingredients with smaller amounts of meat, significant CO₂e reductions of 16-84% were achieved while maintaining adequate levels of absorbable iron. The Beef/Lentils² hybrid recipe was particularly successful, as it was the only optimized recipe that provided more than the recommended 0.66 mg of absorbable iron per meal while still reducing CO₂e emissions by 38% compared to the original recipe. Consumer testing showed that these hybrid recipes were well-received, with no significant difference in taste preference compared to traditional versions. The Beef/Soy² variant received the highest preference ranking (40.4%) among participants while reducing CO₂e by 37%. This suggests that hybrid recipes can effectively balance CO₂e reduction and nutritional goals without compromising taste, offering a practical solution that does not sacrifice either climate objectives or nutritional adequacy.

Women leading the climate-adaptation

The analysis of food practices among Swedish recreational CrossFit athletes and young Swedish adults in Papers III and IV showed clear gender differences across several areas. These differences appeared in how much energy they consumed, their approaches to food, and their broader nutrition and climate-related food choices. Some of the results presented here are compiled from Papers III and IV combined.

Gender differences in energy and nutritional intake

In Paper III, a notable gender disparity in energy consumption was observed. Female CrossFit athletes met only 58-86% of their estimated energy requirements, while males achieved 94.5% of theirs. This gender disparity in energy consumption was also seen in the moderately-active population examined in Paper IV, where women averaged 9.2 MJ/d compared to men's significantly higher 13.1 MJ/d. When results were weighted for female CrossFit athletes and highly active young females, there was a concerning average deficit of 497 kcal below estimated requirements, Figure 6.

Low energy intake is a common finding among female athletes and has been well-documented in research (Kuch, 2021; Mathisen et al., 2020; Melin et al., 2016; Sundgot-Borgen & Torstveit, 2010). However, there is a methodological challenge in accurately determining the true extent of this energy deficit. It remains difficult to establish whether the reported low intake reflects actual consumption or might partially result from underreporting, both phenomena frequently observed in dietary assessments, particularly among female participants (Goris & Westerterp, 1999).

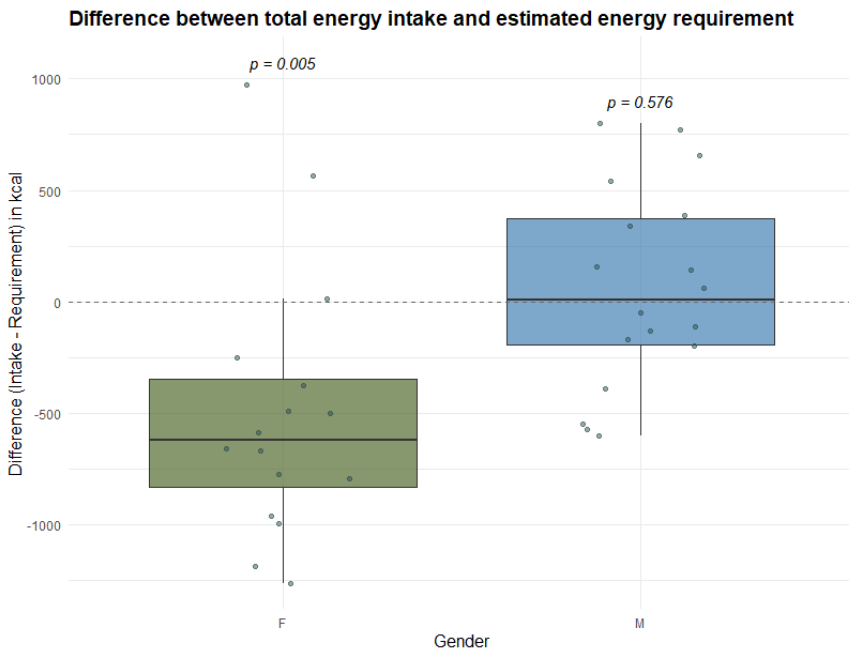


Figure 6. Weighted figure for CrossFit athletes and highly active young adults' reported energy intake compared to estimated energy needs.

Each point represents an individual participant, while boxes display the interquartile range and median. The dashed line at zero indicates where intake equals requirement; positive values show intake exceeding requirement. P-values indicate the statistical significance of differences between intake and requirement within each gender group, analyzed using paired t-tests.

Iron intake challenges across gender and dietary preferences

The insufficient energy intake has broad implications for micronutrient consumption, particularly concerning iron intake across genders. As shown in Figure 7, total iron intake varies significantly across gender and dietary preferences, with all female groups consistently falling below recommended intake levels regardless of their dietary approach. While omnivorous diets provide more iron compared to vegetarian or flexitarian diets, these figures represent total iron content rather than bioavailable iron. This distinction is crucial, as female vegetarians may only achieve approximately 50% of their daily iron requirements due to the predominance of non-heme iron sources and the presence of absorption inhibitors common in plant-based foods (Hunt, 2003). This concern aligns with the findings from Papers I and II regarding bioavailable iron in vegetarian and soy-based meals, suggesting that the risk of inadequate iron intake is likely substantial for the vegetarian and flexitarian participants studied in Papers III and IV.

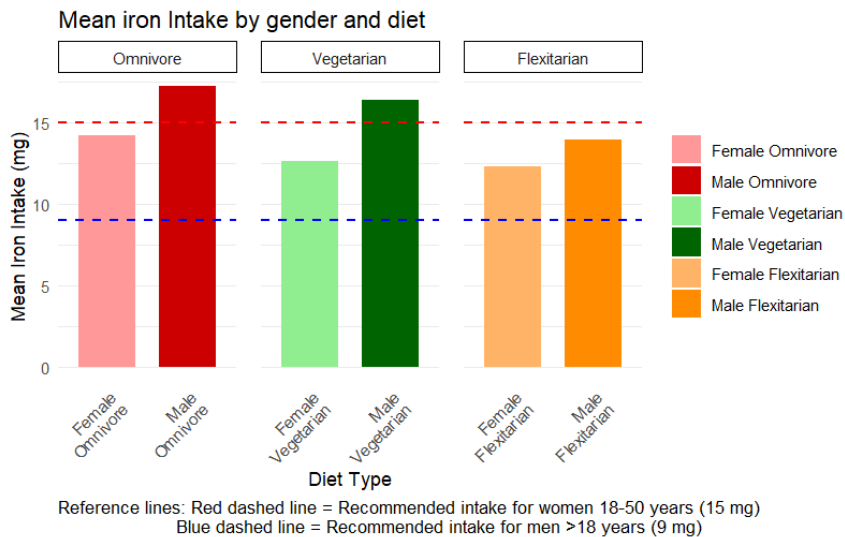


Figure 7. Summarized mean iron intake (mg), for Paper III and highly-active participants in Paper IV.

Visualization of mean iron intake based on dietary preference (omnivore, vegetarian, and flexitarian) and gender. Red dashed line indicates recommended intake for women (15 mg), blue dashed line for men (9 mg).

This is particularly concerning for female athletes, whose iron needs can be up to 70% higher than the estimated average requirement (Dobrowolski et al., 2020). Exercise reduces iron absorption because it triggers inflammation markers that increase hepcidin, a hormone that blocks iron absorption (Barney et al., 2022; Hennigar et al., 2021). As a result, women with high training loads should aim to consume more than 18 mg of iron daily (Thomas et al., 2016), a target that is especially difficult for vegetarian athletes to reach. Iron deficiency can harm athletic performance, reduce training adaptation, and increase muscle fatigue (Keller et al., 2024; Thomas et al., 2016)—negative effects that both elite and recreational athletes want to avoid.

Gender differences in protein consumption

Protein intake, based on weighted data from Papers III and IV, shows almost the opposite pattern when examining both absolute amounts and amounts adjusted for body weight. In absolute terms, male participants consumed a slightly higher median amount of protein in grams per day compared to females. The male group showed greater variation in their protein intake, with a wider interquartile range and absolute values ranging from 100 to 200 grams per day. Female participants had a narrower distribution, with intake values ranging from 75 to 170 grams per day (Figure 8).

Nonetheless, when protein intake was calculated relative to body weight, a notable difference emerged. Protein consumption shows interesting gender differences when viewed from both absolute and relative perspectives, as shown in Figure 8. Women had higher relative protein consumption, with a median intake of approximately 1.9 g/kg body weight, while men consumed approximately 1.7 g/kg body weight.

These findings highlight the importance of considering body weight when evaluating intake patterns between genders. While men consume greater absolute amounts of protein, women show higher relative protein intake when accounting for body mass, suggesting that simple absolute comparisons may not fully capture gender-specific consumption.

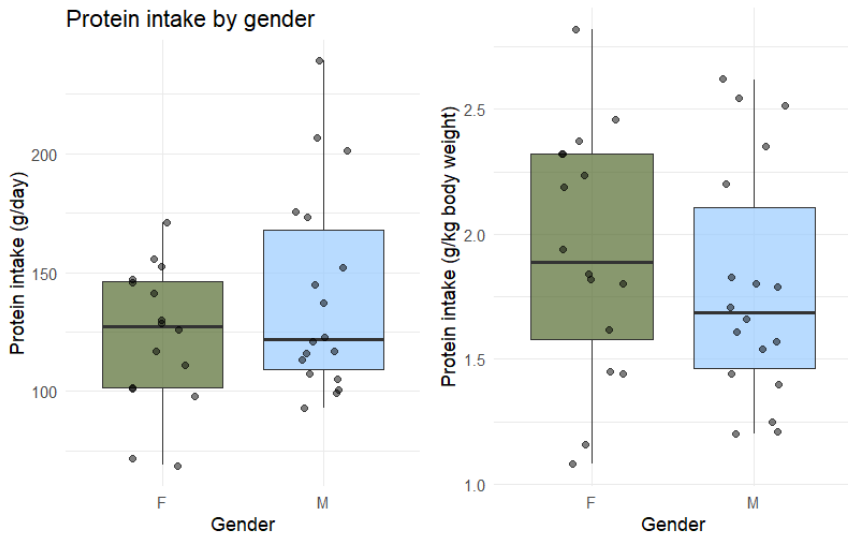


Figure 8. Protein intake comparison between genders

Visualized using box plots, presented in both absolute (g/day, left panel) and body weight-normalized (g/kg body weight, right panel) values. Individual data points are overlaid on the box plots to show the distribution of observations.

Still, CO₂e only considers absolute values, and the higher protein intake per kg body weight rather reflects different dietary approaches (Birkenhead & Slater, 2015; Smart & Bisogni, 2001; Thurecht & Pelly, 2020). As the highly-active women in Papers III and IV have a low total energy intake, it is their fat and carbohydrate intake that falls below recommendations. This is not favorable from a climate perspective. The material elements of these practices, particularly protein-rich foods like meat and dairy, carry different meanings for male and female athletes. Women’s practices often reflect a negotiation between performance goals and psychological well-being. As one female participant articulated:

“Sometimes, I think I let it take over my life too much. I analyze what I eat, whether it is good or not. I do not think analyzing everything is healthy in the long run.”

This quote illustrates the psychological complications in women’s meaning-making around food, contrasting with men’s more straightforward performance-oriented approach. The tension between performance optimization and

environmental impact creates what Shove et al. (2012) would describe as competing elements of practice, where athletes must navigate between sometimes contradictory competencies, materials, and meanings in their daily food routines. These findings align with previous research (Franca et al., 2022; Garnett, 2016; Meyer et al., 2020) on the relationship between athletic performance and environmental sustainability in food choices, while also highlighting the need for gender-sensitive approaches in promoting sustainable athletic nutrition practices.

Gender perspectives on food consumption and CO₂e

Analysis of CO₂e revealed further gender differences, with women showing stronger tendencies toward climate-conscious dietary choices (3.0 kg CO₂e/day) compared to men's (4.7 kg CO₂e/day). This was particularly evident among moderately-active women in Paper IV, who had the lowest emissions with 15.4 kg CO₂e weekly.

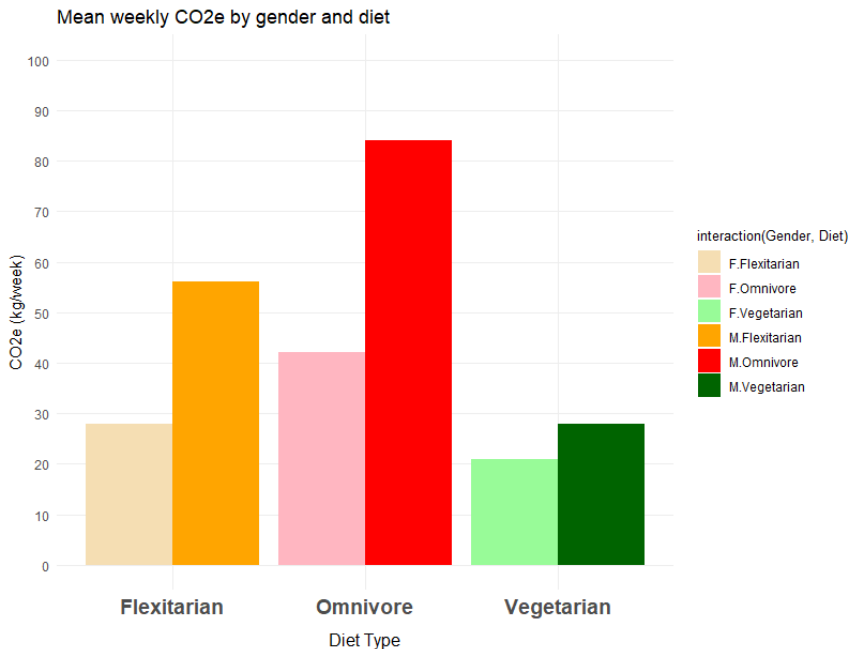


Figure 9. Mean CO₂e (kg/week) across dietary preferences and gender.

Visualization of mean CO₂e emissions across dietary preferences (omnivore, vegetarian, and flexitarian) stratified by gender (F=female, M=male), demonstrating the interaction between gender and diet type on dietary CO₂e.

When comparing these dietary CO₂e emissions to planetary boundaries for food-related climate impact, which suggest a weekly limit of 11 kg CO₂e per person (IPCC, 2022; Akenji et al., 2019), all observed dietary preferences exceed this threshold, though to vastly different degrees. Male omnivores show the highest exceedance, generating nearly 84 kg CO₂e weekly, while female omnivores produce about 42 kg CO₂e weekly. Even vegetarian diets, despite having the lowest CO₂e emissions, still exceed the recommended boundary with men and women generating approximately 28 kg and 21 kg CO₂e weekly, Figure 9. Flexitarian diets fall between these extremes, though gender differences remain pronounced, with flexitarian women at 28 kg weekly and flexitarian men 56 kg weekly.

These findings suggest that while both diet type and energy intake significantly influence individual climate impact, achieving CO₂e emissions within true planetary boundaries remains a substantial challenge that may require more dramatic dietary shifts than those observed in this study. This challenge is particularly acute for physically active individuals with high energy requirements, who need to consume larger quantities of food to meet their nutritional needs, making it even more difficult to stay within the recommended CO₂e emissions threshold while maintaining adequate caloric intake.

Gendered elements of climate-conscious food practices

The research findings reveal how gender fundamentally shapes household food practices through material, competence, and meaning elements of social practice. The material dimension, including plant-based alternatives, shopping spaces, and household kitchens, is distinctly filtered through gendered decision-making processes. Women's role as primary initiators of sustainable food choices demonstrates how deeply gender is embedded in the material infrastructure of household consumption. As Shove et al. (2012) argue, practices are shaped not just by individual choices but by the configuration of these material elements within specific social contexts.

The competence element of sustainable food practices emerges through gendered forms of knowledge and skills, particularly visible in educational settings and urban environments. These contexts facilitate new competencies around climate-conscious food practices, aligning with Shove and Pantzar's (2005) observation that practices evolve as practitioners acquire new understanding. Higher education contexts especially influence male participants' competencies,

enabling novel engagements with sustainable food practices that diverge from traditional patterns.

The meanings associated with food practices reveal obvious gender dynamics. While traditional roles position women as “gatekeepers” of household consumption (Tanner & Wölfing Kast, 2003), these meanings shift within educational and urban settings, particularly among male participants. As Hargreaves (2011) describes, this demonstrates the dynamic nature of social practices, where meanings evolve through interaction with new competencies and materials.

The intersection of athletic performance with sustainable food practices reveals how different practice domains - athletics, environmental consciousness, and gender performance interconnect in daily life. This reflects Warde’s (2005) understanding of how practices overlap and influence each other, creating both opportunities and challenges for sustainable transitions.

The findings illustrate what Shove terms the “co-evolution of practice elements.” As plant-based alternatives enter households, they necessitate new competencies in cooking and nutrition while generating new meanings around environmental responsibility and modern gender roles. This co-evolution varies across gender, education, and urban contexts, highlighting how sustainable transitions depend on reconfiguring entire practice systems rather than individual behavior change (Mylan, 2015).

This analysis suggests that transitioning to sustainable food practices requires attention to all practice elements and their gendered dimensions. Understanding these interactions can inform approaches when promoting sustainable food transitions. Effective strategies work with, rather than against, existing practice configurations. Additionally, it is important to acknowledge how institutional structures, educational contexts, and urban environments shape these processes.

The research uncovered distinct gendered differences in climate-adapted food systems. Women consistently showed stronger environmental consciousness in their dietary choices yet faced greater nutritional challenges when adopting climate-friendly diets. Female athletes and adolescent girls particularly struggled with iron intake when consuming plant-based meals, highlighting a tension between environmental and nutritional goals. Women also approached food differently than men, displaying more intricate relationships with their dietary choices, while men typically took a more straightforward, performance-focused approach. These gender differences extended to household practices, where women often acted as primary initiators of sustainable food choices.

In educational and urban settings, traditional gender roles began to shift, especially among male participants who developed new competencies around sustainable food practices. A summary of opportunities and challenges found across the synthesis of all included papers is found in Figure 10.

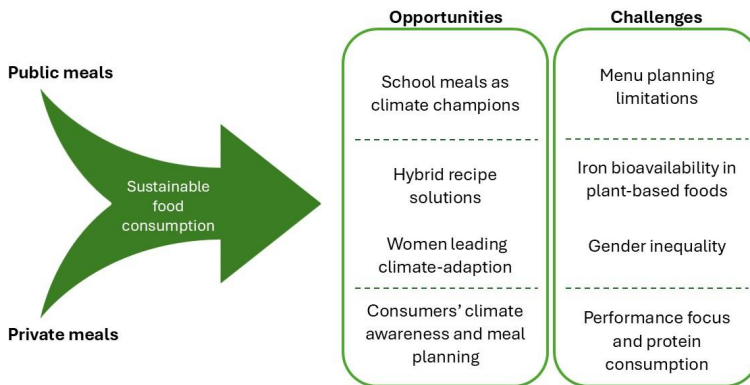


Figure 10: Summary of research findings on sustainable food consumption transitions across public and private meal contexts.

Visualization of key opportunities (school meal reach, hybrid recipe solutions, women driving change, and consumers' awareness and meal planning) and challenges (menu planning limitations, iron bioavailability concerns, gender inequality/iniquity issues, and athletes' CO₂e emission considerations).

Theme 3. Balancing activity and CO₂e among young adult consumers

Higher activity levels and increased CO₂e

The relationship between physical activity and CO₂e emissions presents a challenge in sustainable food consumption. Papers III and IV demonstrate that higher activity levels correlate with increased CO₂e, primarily driven by both elevated energy requirements and reliance on animal-based proteins. The findings identify successful strategies for mitigating CO₂e emissions across activity levels, while also revealing important nuances in how different groups navigate this balance.

The research established a clear progression in dietary CO₂e corresponding to activity intensity. CrossFit athletes exhibited the highest emissions at 40.8 kg CO₂e weekly, while highly-active individuals in Paper IV generated 29.4 kg CO₂e weekly, yielding a mean value of 35.1 kg CO₂e weekly remarkably close to Franca et al.'s (2022) findings of approximately 35.0 kg CO₂e weekly among adolescent athletes. Both significantly exceeded the Swedish national average of 27.3 kg CO₂e weekly (Naturvårdsverket, 2022). Moderately-active participants produced the lowest emissions at 23.1 kg CO₂e/week. This agreement in results across different groups of highly active participants reveals a consistent finding: athletic diets consistently cause higher environmental impacts (Heydenreich & Carlsohn, 2024).

Protein sources: a key factor in climate impact

Analysis of dietary composition revealed that protein source selection substantially influenced CO₂e across activity levels. CrossFit athletes derived 70% of their protein from animal sources, with dairy products and whey supplements constituting 21% and 19% of protein intake respectively. This pattern was mirrored among recreational athletes, where highly-active participants consumed significantly higher protein levels (1.8g/kg body weight/day) compared to moderately-active participants (1.1g/kg body weight/day, $p < 0.001$). The data suggest that performance-oriented mindsets strongly influenced protein source selection, particularly among highly-active participants who often followed professional athletes' nutrition practices.

The underlying mechanism for these elevated CO₂e emissions appears to be consistent across studies. Our observation that the CO₂e emissions stems largely

from high protein consumption, particularly dairy and whey sources, is strongly supported by Franca et al.'s (2022) finding that 85.9% of athletes' CO₂e was attributable to animal protein consumption, with athletes consuming almost four times more animal than plant-based protein. In Paper IV, the highly-active participants had a 65% higher intake of animal-based protein sources compared to the moderately active group. In Paper III, 70% of the protein intake came from animal-based protein sources. This reflects a persistent performance-focused mindset in athletic communities, exemplified in Paper IV by one participant's approach to training "as if I was a pro."

Balancing performance focus and CO₂e

The tension between athletic performance and climate impact may not be inevitable, studies suggests viable pathways toward more sustainable athletic practices. Franca et al.'s (2022) research demonstrates that athletes can meet their protein requirements while maintaining a reduced CO₂e through strategic protein sourcing. This theoretical possibility is supported by empirical findings in Paper III-IV, where 29 % of all highly active participants maintained high performance levels with CO₂e below the Swedish average. Among those 29%, dietary preferences were predominantly vegetarian and flexitarian. Interestingly, only one highly active participant was able to achieve a weekly CO₂e emission in line with the 11 kg target, a small female runner following a vegan diet (11.5 kg CO₂e/week), suggesting this target might be difficult for many highly-active individuals.

Still, these examples demonstrate that the integration of climate consciousness and athletic performance is possible. Research exhibits that athletes can maintain high performance levels while reducing their CO₂e emissions through dietary choices. Multiple studies have demonstrated that vegetarian diets support athletic performance comparable to omnivorous diets (Craddock et al., 2016; H. Lynch et al., 2018; Nebl et al., 2019). Meanwhile, vegetarian diets consistently show 40-50% lower CO₂e emissions compared to omnivorous diets (Aleksandrowicz et al., 2016; Chai et al., 2019).

This evidence suggests that climate-adaptation does not require compromising performance outcomes. The existence of these high-performing, low-CO₂e emission outliers suggests that the challenge lies not in the physiological requirements of athletic performance, but rather in shifting established cultural and behavioral norms within sports communities.

The role of meal planning and barriers to change

Structured meal planning emerged as a factor in climate-conscious behavior across activity levels. CrossFit athletes' rigorous approach to nutrition planning resulted in minimal food waste, providing an inadvertent climate benefit in Paper III. Both highly-active and moderately-active recreational athletes employed similar organizational strategies, such as systematic meal planning and lunch box usage in Paper IV, though the data indicate that performance-focused individuals often selected higher-carbon options despite these planning practices.

The research identified several significant obstacles to adopting climate-friendly diets, while also revealing pathways for success. Performance prioritization and deeply held beliefs about animal protein necessity created resistance to dietary change, particularly among CrossFit and highly-active participants. Economic constraints emerged as another factor, especially among moderately-active participants, sometimes limiting access to what they considered sustainable options, and other times increased the amount of legumes in their diet due to their low cost.

Additionally, the data revealed limited awareness regarding the climate impact of specific protein sources, notably whey supplements, across all activity levels in both Papers III and IV. However, successful examples across activity levels indicate the feasibility of balancing performance with environmental responsibility. The research suggests that successful CO₂e reduction depends on addressing both knowledge gaps and ingrained beliefs about nutrition while leveraging existing dietary discipline and planning practices. These findings provide a foundation for developing targeted interventions that demonstrate possibilities to highly-active individuals and provide practical strategies for implementing sustainable practices while maintaining desired performance levels.

A social practice theory perspective

The research reveals multifaceted relationships between materials, competences, and meanings in athletic nutrition practices, offering insights into both opportunities and challenges for sustainable transitions.

Material elements

The material elements of athletic nutrition practices emerge prominently in the findings, encompassing not just food items like protein supplements and legumes, but also the tools and infrastructure that support dietary practices, such as meal

planning systems and lunch boxes. These material configurations, as Spurling et al. (2013) argue, fundamentally shape how practices develop and persist. The economic dimension adds another material layer, with financial resources notably influencing access to what participants perceive as sustainable options, sometimes constraining choices but occasionally promoting sustainable alternatives like legume consumption due to cost effectiveness.

Competences and knowledge gaps

In terms of competences, the research reveals a fascinating paradox. Athletes, particularly in the CrossFit community, demonstrate sophisticated knowledge and skills in nutrition planning and food waste reduction. However, there exists a notable gap in understanding the climate impact of various protein sources, including commonly used supplements. This aligns with the emphasis on how practical knowledge shapes practice performance and evolution (Shove & Pantzar, 2005). The presence of strong planning competences alongside environmental knowledge gaps suggests potential leverage points for intervention.

Meanings and cultural values

The meanings associated with athletic nutrition practices prove particularly crucial in understanding resistance to change. Deep-rooted beliefs about animal protein requirements and the prioritization of performance create significant barriers to adopting more sustainable practices. As Blue et al. (2016) observe in their analysis of health-related practices, such meanings can powerfully maintain existing practices even when they conflict with other goals like environmental sustainability.

Practice and pathways to change

The research demonstrates what Shove et al. (2012) term “practice bundles,” where multiple practices - athletic training, meal planning, environmental consciousness, and economic decision-making - intersect and influence each other. Understanding these interconnections proves crucial for identifying pathways to change. The existence of high-performing, low-CO₂e emission outliers suggests that transforming these practice bundles is possible without compromising athletic performance.

Drawing on Hargreaves’ (2011) work on climate-conscious behavior change, successful transitions likely require simultaneous interventions across all three

elements. This might involve reconfiguring material infrastructures to make sustainable options more accessible, developing competences around the climate impact of different protein sources, and transforming meanings to align athletic identity with environmental responsibility. Watson's (2012) research on sustainable transitions suggests that such multi-faceted approaches are most effective in shifting established practices.

The findings ultimately suggest that reducing CO₂e of athletic nutrition requires addressing both knowledge gaps and deeply held beliefs while building upon existing strengths in dietary discipline and planning. The presence of successful examples across activity levels demonstrates the feasibility of balancing performance with environmental responsibility, providing valuable models for future intervention (Shove and Walker, 2010).

These insights contribute to our understanding of how sustainable practices might be fostered within athletic communities, suggesting that change is possible when interventions account for the interplay of materials, competences, and meanings that constitute current practices. The challenge lies not in physiological requirements but in transforming the socially embedded practices that shape athletic nutrition choice

Method discussion

Carbon footprint

The selection of CO₂e as the primary environmental impact metric was supported by both theoretical and practical considerations. Harrison et al. (2022) showed that CO₂e emissions effectively served as a proxy for various environmental impacts, correlating strongly with factors such as eutrophication, acidification, and land use. This relationship allowed CO₂e to function as a comprehensive environmental indicator while maintaining methodological rigor.

CO₂e measurements provided a standardized methodology that captured environmental impact across the food supply chain, from farming and transportation to processing and packaging (IPCC, 2022; Tubiello et al., 2021). The widespread use of these measurements in the literature also enabled comparative analysis and integration with existing research.

However, CO₂e have limitations as a singular metric. While CO₂e served as an effective proxy for several environmental impacts, it could not capture all dimensions of environmental degradation. Particularly for biodiversity loss, ecosystem services, and local environmental stressors. Assessments such as Biodiversity Impact Assessments demonstrates that some ecological consequences requires dedicated evaluation methods (Eme et al., 2019). Despite these limitations, CO₂e remained the most practical choice for assessing environmental impact in food systems, especially when detailed multi-indicator assessment was not feasible.

CO₂e calculations were used consistently across all four papers, making them methodologically comparable. The climate database used had a limited number of calculated foods, requiring certain methodological choices. When an exact food item was not found in the database, a similar food was selected as a proxy. Detailed information about ingredients was gathered for each food item to select the most appropriate proxy. All choices followed the same protocol throughout the included papers. In one important case where a food item (whey protein) could not be found in the database, a LCA from Bacenetti et al. (2018) was incorporated into the calculations.

Iron absorption algorithm

The Hallberg & Hulthén (2000) algorithm is found to have the most comprehensive coverage (Hunt, 2010). The algorithm systematically incorporates comprehensive experimental data from isotopic tracer studies measuring iron bioavailability, thereby establishing itself as the most methodologically robust and validated model in the field (Hunt, 2010).

It is the only available algorithm that includes interactions between enhancers and inhibitors, specifically modeling how phytate's inhibitory effect is reduced in the presence of ascorbic acid or "meat factor" (Hallberg & Hulthén, 2000; Hunt, 2010). The algorithm, accounting for interaction factors, proved instrumental in estimations of iron bioavailability in school meal menus and facilitated the recipe optimization process, particularly by leveraging the "meat factor" to enhance iron absorption in hybrid recipes.

The algorithm has been internally validated through two complementary studies showing strong predictive accuracy. The first compared observed versus calculated non-heme iron absorption across 24 complete meals from three prior investigations. Results aligned remarkably with observed mean absorption, achieving a strong correlation coefficient ($R^2 = 0.987$) (Hallberg & Hulthén, 2000). This analysis required detailed meal composition data, including precise quantification of calcium, phytate, polyphenols, and ascorbic acid. The second study examined total iron absorption across 620 meals consumed by 31 male subjects over 5 days, confirming the algorithm's precision with a mean difference of only 0.06 mg (3.4%) between predicted and observed values ($P = 0.561$) (Hallberg & Hulthén, 2000). This validation approach used radiotracer methodology as the gold standard across diverse meal compositions, validating both single-meal predictions and the mathematical framework for estimating total dietary iron absorption.

Algorithmic calculation process

Validation of the Hallberg & Hulthén algorithm

External validation studies have corroborated the efficacy of this algorithm, with independent researchers documenting significant correlations between predicted and observed iron absorption values (M. B. Reddy, 2005). These findings suggest the algorithm surpasses the predictive accuracy of alternative approaches. In a comparative analysis, Hunt (2010) determined that the Hallberg & Hulthén

algorithm provided superior predictive capabilities across diverse dietary preferences, though with certain limitations.

The algorithm's high internal validation may be partially attributed to its methodological approach of adjusting predicted absorption based on subjects' iron status, rather than standardizing observed absorption values (Hunt, 2010).

Limitations and contextual considerations

The Hallberg & Hulthén algorithm shows some limitations in high-bioavailability dietary contexts. While it demonstrates robust performance in estimating iron absorption from low-bioavailability diets, it may overestimate non-heme iron absorption in high-bioavailability dietary patterns. This overestimation appears most pronounced in diets characterized by substantial quantities of both meat and ascorbic acid (Hunt, 2010). Given that climate-adapted meals typically contain limited amounts of meat, the algorithm's superior accuracy with low-bioavailability meals makes it particularly suitable for assessing absorbable iron content in public school meals.

Physiological Regulation of Iron Absorption

Iron absorption is physiologically regulated through interactions between dietary intake and body iron stores, with absorption rates inversely correlated to iron status (Rasmussen et al., 1974; Piskin et al., 2022). The Hallberg and Hulthén algorithm provides a quantitative framework for estimating iron absorption by incorporating serum ferritin levels as a biomarker of iron stores. This relationship exhibits considerable variability in absorption efficiency: individuals with depleted iron stores (serum ferritin ~ 15 $\mu\text{g/L}$) may absorb up to 60% of a reference dose, while those with adequate stores (serum ferritin ~ 100 $\mu\text{g/L}$) demonstrate substantially lower absorption rates of approximately 18% (Hallberg & Hulthén, 2000).

This physiological adaptation mechanism has important implications for iron intake recommendations. The conventional assumption of 15% absorption from a mixed diet may significantly underestimate actual absorption in iron-depleted individuals. Conversely, the body's homeostatic downregulation of absorption in iron-replete individuals provides natural protection against exceeding the Tolerable Upper Limit (UL). By incorporating iron status-dependent absorption, this methodology achieves a more precise assessment that reflects the target population's physiological state and better accounts for individual variations in iron requirements. In this thesis, ferritin levels were set at 15 $\mu\text{g/L}$, representing

the targeted study population of adolescent girls with depleted iron stores. Since iron absorption increases when stores are depleted, the risk of underestimating iron absorption was thus minimal.

Key dietary factors affecting iron absorption

Phytates, the assessment of phytate content in foods presented in Papers I and II relies on literature-derived values (Dahdouh et al., 2019; Ertaş, 2017; Hallberg & Hulthén, 2000; Mayer-Labba et al., 2022; Reddy & Sathe, 2001). These values represent averaged measurements across product categories rather than direct analytical measurements of specific products. While this approach introduces some inherent uncertainty, it may be advantageous for evaluating school meal production, where natural variation in phytate content occurs across different batches and sources of ingredients. It is worth noting that methodological differences in phytate analysis techniques may affect the direct comparability of reported values across different time periods. Nevertheless, the comprehensive inclusion of all available phytate content data provides the most complete picture possible given current methodological constraints and the inherent variability in food composition.

Ascorbic Acid, the ascorbic acid content estimation included adjustments for degradation during cooking and potential losses in fresh vegetables from the salad buffet. Research shows cooking losses range widely from 20-70% (Hailemariam & Wudineh, 2020; Mehmood & Zeb, 2020; Waheed-Uz-zaman et al., 2013), with significant variability in fresh vegetable degradation rates (Lee & Kader, 2000; Phillips et al., 2018). We applied a conservative median loss estimate of 50% across all preparations (cooked and fresh) to prevent overestimating the contribution of vitamin C. This standardized approach offers a reasonable analytical strategy given the challenges in measuring variable loss rates across different preparations and storage conditions. However, it may not fully account for ascorbic acid degradation during extended holding periods in school canteens, especially for students served later in the meal service.

Polyphenols, the inhibitory effect of polyphenols on iron absorption is well-documented in the literature (Kim et al., 2008; Ma et al., 2011; Ndiaye et al., 2020). However, the practical application of this knowledge in dietary assessment presents significant challenges due to two key limitations: the lack of standardized analytical methods for polyphenol quantification and incomplete food composition databases. While the impact of polyphenols from tea and coffee on iron absorption is well-established (Morck et al., 1983; Ndiaye et al., 2020), the

evidence base for other dietary sources remains limited, indicating a need for further research. Given that coffee and tea are not components of public-school meals, and considering the current methodological constraints, polyphenol content was not incorporated into our absorption calculations. This decision aligns with the current state of available evidence while acknowledging areas for future methodological advancement.

Calcium, research on calcium's effect on iron absorption has evolved considerably. Hallberg & Hulthén (2000) identified calcium as a significant inhibitor of both heme and nonheme iron absorption, with inhibition occurring from doses of 50 mg and maxing out at 600mg. However, subsequent studies have refined our understanding of this interaction.

Walczyk et al. (2014) suggests that calcium's inhibitory effect may be less severe than initially thought. Their research showed that ascorbic acid supplementation can counteract calcium's inhibitory effects, suggesting greater flexibility in the calcium-iron relationship. Additionally, according to the study by Benkhedda et al. (2010) calcium reduced iron absorption from a single meal from 4.8% to 10.2%. However, the authors noted that the calcium impact differed significantly across subjects who had similar iron stores, suggesting that physiological or genetic variables significantly impact iron absorption in people with similar body iron stores.

Studies consistently show no significant inhibition below approximately 50mg of calcium. However, at higher doses, the reported magnitude varies considerably. While Hallberg & Hulthén (2000) reported up to 80% inhibition at 300-600mg, Walczyk et al. (2014) found a more moderate 53% reduction with 500mg calcium. Benkhedda et al. (2010) observed the widest range, with inhibition varying from 0-84% at 500mg calcium.

The mechanistic understanding remains consistent across studies, with evidence from Piskin et al. (2022) supporting calcium's action at the cellular level rather than just within the intestinal lumen.

Meat factor, the incorporation of the meat factors' effect in the Hallberg & Hulthén algorithm represents a key methodological strength. This inclusion is supported by robust empirical evidence demonstrating that animal tissues significantly enhance nonheme iron absorption, with studies showing enhancement effects of up to 150% when meat products are added to plant-based meals (Bæch et al., 2003; Hurrell et al., 2006; Navas-Carretero et al., 2008).

The algorithm accounts for this "meat factor" a well-documented phenomenon where muscle tissue exhibits protein and peptide-related

enhancement of iron absorption (Hurrell et al., 2006). This enhancement operates in a dose-dependent manner, as demonstrated by controlled studies showing significant increases in iron bioavailability with the addition of as little as 50g of meat to meals high in absorption inhibitors (Bæch et al., 2003). By incorporating this effect, the algorithm provides a more accurate estimation of iron bioavailability in mixed diets compared to models that consider only inhibitory factors. This is particularly relevant for population-level dietary assessments where diverse protein sources are consumed, such as in school lunches.

Soy Protein, accounting for soy protein is important given its substantial inhibitory effect on iron absorption. Studies have shown that soy protein can reduce iron absorption by over 50% compared to other proteins, even when phytate is removed (Cook et al., 1981; Lynch et al., 1994; R. N. Reddy et al., 1996).

Incorporating the soy protein factor enables more precise estimation of iron bioavailability, especially in diets containing high amounts of soy products. This is particularly relevant when assessing vegetarian diets or populations with high intake of soy products. By accounting for the inhibitory effects of soy protein, the algorithm provides a more accurate prediction of dietary iron absorption, strengthening its utility in optimizing iron nutrition.

Food records

Food consumption data was collected using weighed food records, considered one of the most accurate methods for measuring individual food and nutrient intake (Gibson, 2024). Papers III and IV used two collection approaches: a split protocol of four plus three days and a continuous seven-day protocol, both capturing weekday and weekend eating habits.

The data collection process used a digital app that improved the traditional weighed food record method. The app allowed for immediate food recording with built-in quality checks, including the option to photograph nutrition labels and branded products. Research staff verified these photos, improving the accuracy of nutritional information. The app's messaging system allowed direct communication between participants and researchers to quickly resolve any questions (Zhang et al., 2021). This digital approach was especially suitable given its high acceptance among young adults, who are generally more comfortable with smartphone technology (Zhang et al., 2021).

While weighed food records are considered the best practice in dietary assessment (Gibson, 2024), several methodological issues should be noted. The

method's main advantage is its accuracy in measuring portion sizes, enhanced by the app's real-time support features. However, certain limitations remain, including the possibility that participants might change their normal eating habits due to the burden of recording or wanting to appear healthier. The long recording period may have caused participant fatigue, though the digital tools aimed to reduce these problems by making recording easier and offering immediate assistance (Gibson, 2024; L. Zhang et al., 2021).

The potential for selection bias significantly affects how we interpret findings from Papers III and IV. The voluntary recruitment approach likely attracted people who were already health-conscious and engaged in healthy behaviors, while excluding those less interested in health practices. The sample consisted mostly of highly educated young adults from urban areas, which limits how broadly our findings can apply to different populations, such as people from rural areas, different age groups, or varying education levels. This limitation highlights the need for future research to use more diverse recruitment methods to make findings more applicable across demographic groups.

It is important to note that the food records in this study served as part of a mixed-method approach, partially replacing techniques like shop-along and household food inventories commonly used in social practice theory (Evans, 2012; Fuentes & Svingstedt, 2017; Halkier & Jensen, 2011). As such, the data does not claim statistical power but rather provides a contextual picture of food consumption patterns within the mixed-methods framework of social practices and everyday food behaviors.

Statistics

Paper I

Statistical analyses employed Welch's ANOVA due to its robust performance with heterogeneous variances between groups, offering superior Type I error control and power compared to traditional ANOVA when variance homogeneity is violated (Delacre et al., 2017; Moder, 2010). Post-hoc comparisons utilized the Games-Howell test, selected for its complementary design with Welch's ANOVA and similar robustness to both unequal variances and sample sizes (Games & Howell, 1976). For continuous variable relationships, Pearson's correlation coefficient was employed given its standardized measurement of linear relationships and well-established statistical properties (Schober et al., 2018). This

methodological approach balances statistical rigor with practical applicability, providing robust results while maintaining interpretability when strict parametric assumptions may be unrealistic.

Paper II

Friedman's test was selected as a robust non-parametric alternative to repeated measures ANOVA, offering distinct advantages in handling data that violates parametric assumptions of normality and homogeneity of variance. This rank-based approach provides reliable analysis of repeated measures data while maintaining statistical power under various distributional conditions (Zimmerman & Zumbo, 1993). Post-hoc analyses employed Wilcoxon signed-rank tests with appropriate multiple comparison corrections, ensuring robust pairwise comparisons while controlling familywise error rates (Pereira et al., 2015). This methodological choice reflects a balanced approach between analytical rigor and practical applicability in research contexts where traditional parametric assumptions may not hold.

A modified penalty analysis was employed to evaluate the impact of sensory attribute deviations from ideal intensities on overall product liking (Pagès et al., 2014). This method extends traditional penalty analysis by incorporating Just-About-Right (JAR) scale data to quantify the relationship between attribute intensity deviations and consumer acceptance (Paries et al., 2022). The approach provides valuable insights into which sensory attributes significantly impact consumer liking when they deviate from optimal levels, while accounting for both positive and negative deviations in attribute intensities (Narayanan et al., 2014). The calculation of mean drops in liking scores between ideal and non-ideal intensity levels enables the identification of critical product attributes that warrant optimization, making this analytical approach particularly suitable for product development applications.

Paper III-IV

All statistics in Paper III-IV served a descriptive purpose to strengthen the findings in the mixed-methods approach. The statistical approach in these studies demonstrates several notable strengths while facing certain limitations. The integration of quantitative measurements with qualitative findings created a robust triangulation that enhanced the validity of conclusions.

The papers employed t-tests and ANOVA with Bonferroni corrections to identify significant differences between activity levels and genders, while correlation analyses effectively established relationships between energy intake and carbon footprint. The verification of food record reliability through EI/RMR calculations further strengthened data quality.

However, the relatively small sample size limited statistical power for detecting differences in some variables, particularly when comparing subgroups. The overrepresentation of university students (>50%) introduced potential sampling bias, potentially limiting generalizability.

Additionally, the carbon footprint calculations were restricted to CO₂e without addressing other sustainability metrics, providing a somewhat narrow environmental assessment. The homogeneity of the study population and possible self-selection bias among participants with pre-existing environmental awareness further constrain the broader applicability of the findings. Despite these limitations, the statistical methodology provided valuable insights that complemented and substantiated the qualitative components of the research.

Mixed-methods research

A convergent parallel mixed-methods design was employed to examine relationships between athletic performance, food choices, and climate consciousness. Following Denscombe's (2008) pragmatic “third paradigm” approach, this research combined quantitative seven-day food records with qualitative semi-structured interviews.

While acknowledging potential epistemological tensions, this integration leveraged complementary strengths of both methods (Bryman, 2022; Creswell, 2017). The quantitative data captured measurable dietary patterns and CO₂e emissions, while qualitative interviews explored the subjective experiences and sociocultural contexts shaping food choices. Concurrent data collection facilitated examination of sequential relationships while recognizing each methods distinct contribution to understanding the research questions (Creswell, 2017; Shove et al., 2012).

Initial analysis maintained methodological distinction to preserve the integrity of each approach (Creswell, 2017). The integration phase was designed to prevent subordination of either data type, instead identifying points of convergence and divergence that revealed different aspects of the phenomenon.

Social practice theory provided the theoretical framework for integrating quantitative and qualitative methods. Rather than seeking direct cross-validation, this framework examined how competencies, materials, and meanings interacted to shape sustainable food practices across participant groups.

Method integration offered complementary insights (Creswell, 2017), with each data type illuminating different aspects of the same practice. When participants expressed environmental awareness in interviews (meanings), we examined their documented food choices (materials) to understand how these elements combined in practice, exploring productive tensions between stated values and measured behaviors as facets of social practice rather than mere inconsistencies.

Social Practice Theory revealed how both highly-active and moderately-active groups achieved sustainable food consumption through different motivational pathways. Higher CO₂e among highly-active athletes, analyzed alongside performance-focused interview responses, demonstrated how different combinations of competencies, materials, and meanings aligned with individual circumstances while still supporting sustainable practices (Shove et al., 2012).

This theoretical framework proved valuable by suggesting that sustainable food practices may be more effective when tailored to different groups' primary

motivations, economic considerations for moderately-active individuals or performance optimization for highly-active individuals. Successful implementation of climate-conscious practices requires alignment of all three elements (competencies, materials, and meanings) while accommodating the different drivers important to each group.

Using social practice theory as an integrative framework allowed the research to maintain awareness of methodological complexities while pursuing practical research goals. While traditional social practice research often relies on home visits or participant observation during grocery shopping, this study captured participants' "doings" through detailed food records. These records provided insights into actual food consumption and preparation practices in daily life.

The methodology was further enriched by participants sharing photographs of lunch boxes and shopping carts, offering visual documentation of food practices in action. This approach, though different from conventional methods of examining refrigerator contents (Kendall et al., 2016) or conducting shopping observations (Fuentes & Fuentes, 2021; Marshall, 2016), enabled comprehensive understanding of how food practices integrated into participants' daily routines.

This methodology effectively documented not merely what participants consumed, but how they organized food practices within their day-to-day lifestyle. The combination of food records and photographic evidence provided rich data about participants' actual food practices rather than relying solely on accounts of intended behaviors. This adaptation of traditional social practice research methods demonstrates how food consumption practices can be effectively studied through alternative documentation forms while maintaining theoretical focus on actual "doings" rather than reported behaviors or attitudes.

General discussion

In the general discussion, I bring together key findings from all three themes explored in this thesis. This section provides an overarching view connecting insights across three areas: school meal programs, gender-based nutrition disparities, and the impact of physical activity. Here the findings are discussed in a broader perspective to put the results in a greater context. By examining these themes together rather than separately, offering a more complete understanding of the opportunities and challenges in creating sustainable food systems that work across different settings and populations.

Challenges in climate-adapted food systems

The transition toward climate-adapted food systems presents multiple challenges that extend beyond CO₂e calculations. Private consumers face barriers including limited access to sustainable options, higher costs of climate-friendly alternatives, and conflicting information about nutritional trade-offs. These challenges become even more pronounced in institutional settings. This thesis reveals fundamental tensions between environmental goals and nutritional adequacy, particularly in public meal settings where nutritional needs must be guaranteed across diverse populations. The innovative combination of climate impact metrics with bioavailability calculations provides novel insights for meal planning, revealing previously overlooked nutritional challenges in supposedly adequate menus, with implications for both institutional and private food choices.

Ethical considerations: agency and responsibility

A fundamental tension exists between adults' dietary autonomy and the limited agency of children and adolescents in public meal settings. While adults can make informed decisions about nutritional supplementation and dietary choices, pupils in educational institutions largely depend on predetermined meal options, with minimal influence over their food selections. Research demonstrates that adult vegetarians generally need supplementation to achieve adequate nutritional intake of crucial nutrients such as vitamin B₁₂ and iron (Schüpbach et al., 2017). Still,

female vegetarians remain at heightened risk for iron deficiency (Haider et al., 2018). In contrast, studies focusing on adolescents and young adults identify significant risks for deficiencies in several micronutrients, particularly vitamin D, iodine, and iron (Groufh-Jacobsen et al., 2024; Peddie et al., 2023). It is noteworthy, however, that vegetarians often exhibit higher serum folate levels (Haider et al., 2018) but simultaneously are associated with low levels of serum ferritin and hemoglobin (Hallström et al., 2025; Stubbendorff et al., 2025). The decision to increase the proportion of vegetarian meals must be grounded in nutritional science and ethical considerations of equality and fairness. A unilateral policy approach at the political level may not adequately address the diverse nutritional needs across populations. Therefore, any systemic changes to public meals should carefully consider nutritional requirements for all ages and genders they are obligated to serve.

This limited agency raises important ethical considerations regarding responsibility for climate action. While public meals, particularly in schools, present significant opportunities for reducing CO₂e emissions, we must question the fairness of placing substantial responsibility for climate-adaptation on children and adolescents. Especially when considering that school meals often represent a crucial source of daily nutrition for vulnerable populations (Eustachio Colombo et al., 2020).

Regional differences

In the studied populations in this thesis, urban-rural differences emerged in the adoption of climate-adapted practices. Large urban municipalities demonstrated the highest proportion of vegetarian meal servings, while smaller rural municipalities maintained higher levels of traditional meat-based meals. This aligns with regions known as the “meat belt”, where cultural resistance to plant-based alternatives was particularly strong (Pettersson et al., 2024). The situation was further complicated by limited political support in smaller municipalities in Sweden for implementing plant-based initiatives, creating a notable difference between urban and rural areas in their adoption of climate-adapted food practices.

The differences between municipalities in Paper I reflect broad societal divisions in climate-adapted food practices. This suggests the need for regionally tailored approaches to implementing climate-adapted meals, with particular attention to the cultural and practical constraints.

Implementation challenges and nutritional concerns

Implementation challenges include economic constraints, particularly in public settings, cultural resistance to dietary change, and supply chain capabilities. Current methodologies for evaluating school meal nutritional adequacy require revision, particularly in their treatment of iron content without adequate consideration of bioavailability. This oversight could systematically disadvantage female pupils, whose higher iron requirements necessitate more nuanced approaches to meal planning (Barre et al., 2018; Beal et al., 2023; Poinso et al., 2022).

Current menu planning systems lack systematic methods for incorporating nutrient bioavailability calculations, which is essential for climate-adaptive and sustainable school meal planning. Paper I revealed a more fundamental concern: the evaluated recipes failed to meet the recommended 4.5 mg of iron per meal. This recommendation assumes 15% bioavailability in an omnivorous diet (Domellöf & Sjöberg, 2024). Further, the recipes in Paper I achieved only 10.3% bioavailability, which likely represents a more accurate level given the current proportion of vegetarian meals.

This inadequacy in total iron content inherently excluded the possibility of achieving recommended levels of absorbable iron, regardless of potential bioavailability enhancement strategies. This finding underscores the need for a dual approach: first ensuring adequate total iron content in school lunch menus and subsequently addressing bioavailability optimization.

Framework for school meal development

This thesis provides a framework for school meal development that goes beyond traditional considerations of cost and nutrition, by incorporating iron bioavailability calculations alongside climate impact assessments and consumer acceptance metrics. This approach could serve as a model for raising the standards in school meal development. When implementing climate-adapted menus, ensuring access to nutritious meals should take precedence over environmental goals, particularly as school meals play a vital role in food security and wellbeing (Eustachio Colombo et al., 2020). Such an integrated framework could be particularly valuable in addressing both the nutritional needs of growing children and the increasing focus of climate considerations in public food service, ensuring that food system changes do not disproportionately affect vulnerable populations.

The relationship between CO₂e and iron bioavailability

This thesis revealed a significant relationship between CO₂e emissions and iron bioavailability, Paper I and II, emerging as a fundamental challenge in designing sustainable school meals. This conflict was particularly exemplified in municipal implementations, where the strongest climate adaptation through increased vegetarian meal servings coincided with the lowest levels of absorbable iron (Paper I). Further, Paper I reveals that soy-based meals present a nutritional paradox: despite having the highest total iron content (4.47 mg), they demonstrate the lowest bioavailability (3%) due to high phytate content and inhibitory effects of soy protein (Gleerup et al., 1993; Mayer-Labba et al., 2022; Reddy et al., 1996). This finding is important as soy-based products constitute 74.7% of PBMAs in the provided menus in Paper I, highlighting the importance of considering nutrient bioavailability in nutritional planning rather than total content alone.

There is a relationship between nutritional value and climate impact in different dietary choices. While meat-based meals in this thesis provided the highest iron content, both total and absorbable, they also carry the largest CO₂e (Caro et al., 2017). Vegetarian meals create lower CO₂e emissions than meat-based options (Aleksandrowicz et al., 2016; Chai et al., 2019; Poinsoot et al., 2022; Weidema et al., 2008) while still providing meaningful nutritional benefits, despite containing lower levels of absorbable iron (Chigwedere et al., 2023; Mayer-Labba et al., 2022).

On the other hand, research also highlights possible health risks with a high heme-iron intake, such as increased colorectal cancer risk (Aglago et al., 2023; Meng et al., 2019; Saarinen et al., 2025). However, current research reveals important sex differences in how heme iron intake affects colorectal cancer risk. Large epidemiological studies demonstrate that while men show increased colorectal cancer risk, no such association has been found in women. Therefore, while men may benefit both health-wise and environmentally from reducing their heme iron intake through decreased red meat consumption, women should focus on maintaining adequate iron stores without concerns of colorectal cancer risk.

Climate or nutritional trade-offs

Environmental and health impacts of meat

Meat production from livestock, especially ruminants like cattle, sheep, and goats, has multiple interactions with environmental and human health systems. From an

environmental perspective, ruminant production contributes significantly to CO₂e emissions through enteric fermentation (methane) and manure management (Stanley et al., 2018). The sector also drives land-use change, with pasture and feed crop production leading to deforestation in some regions. Additionally, intensive livestock operations can contribute to water pollution through nutrient runoff (Gerber et al., 2015; IPCC, 2022).

Nevertheless, ruminants may provide ecological benefits when managed appropriately. Well-managed grazing can enhance soil carbon sequestration, improve soil structure, and maintain grassland ecosystems that support biodiversity. While grazing animals can help maintain landscapes that evolved with large herbivores and can be integral to regenerative agriculture systems (Teague et al., 2008), this position has been challenged. Recent research suggests that even in cases where grazing might provide benefits, these could potentially be achieved more effectively through the reintroduction of native herbivores rather than domestic livestock (Torpmann & Rööös, 2024).

From a human health perspective, meat consumption presents both opportunities and challenges. As a nutrient dense food, meat provides essential nutrients including high-quality protein, vitamin B12, iron (particularly heme iron), zinc, and other micronutrients and the “meat factor” that support various physiological functions (Adesogan et al., 2020; Leser, 2013). These nutrients are particularly crucial for vulnerable populations, including pregnant women, growing children, and older adults. Since these groups are often the main recipients of public meals, it is essential to carefully consider how policy changes might affect their nutritional health. This concern is heightened by the fact that policy decisions are typically made by individuals who will not directly experience their consequences.

However, epidemiological studies have associated high consumption of red and processed meats with increased risks of certain health conditions, including cardiovascular disease, type 2 diabetes (Micha et al., 2010; Schwingshackl et al., 2017), and some forms of cancer, particularly colorectal cancer (Garcia-Larsen et al., 2019). The mechanisms may involve compounds formed during processing and cooking as well as high levels of saturated fats and sodium in processed meats (Garcia-Larsen et al., 2019).

Fish as a middle ground option

Fish-based meals appear to represent a middle ground, offering moderate levels of both iron content and climate impact but can be hard to implement due to other environmental factors such as overfishing and biodiversity loss. Overfishing poses a severe threat to marine ecosystems because it disrupts the delicate balance of ocean food webs, depletes fish populations faster than they can reproduce, and destroys critical marine habitats (Coleman & Williams, 2002). This not only endangers marine biodiversity and ecosystem stability but also threatens food security and livelihoods for millions of people who depend on healthy ocean resources (Coleman & Williams, 2002; Dulvy et al., 2021).

From a human health perspective, fish and seafood consumption offers substantial benefits while presenting certain risks. The primary beneficial components include high-quality protein, long-chain omega-3 polyunsaturated fatty acids (particularly EPA and DHA), vitamin D, selenium, and iodine. Regular fish consumption is associated with reduced risk of cardiovascular disease (FAO/WHO, 2011; Mozaffarian & Rimm, 2006). However, potential health risks exist, primarily from bioaccumulation of environmental contaminants. These include mercury, found mostly in large predatory fish, and long-lasting toxic chemicals like PCBs and dioxins that build up in fatty tissue. These contaminants may adversely affect neurodevelopment in fetuses and young children and potentially increase cancer risk in adults (FAO/WHO, 2011).

Given these competing factors, health authorities have reached a consensus that the benefits of moderate fish consumption (2–3 servings per week) generally outweigh the risks for most populations. However, they recommend that vulnerable groups, particularly pregnant women and young children, should exercise caution with species known to be high in mercury (Blomhoff & Nordic Council of Ministers, 2023; FAO/WHO, 2011; Gil & Gil, 2015).

Poultry: a popular alternative with many dimensions

While poultry stands out as the most popular meat alternative in Paper I with a substantially lower CO₂e than red meat, its environmental impact presents a multidimensional picture. On the positive side, poultry enjoys widespread cultural and religious acceptance across diverse societies, as evidenced by high consumption rates worldwide, with its broad adoption facilitated by practical advantages including affordability, availability, and perceived health benefits (House et al., 2024). According to consumption data and consumer research,

poultry's widespread adoption as the most consumed meat worldwide, coupled with its general acceptance, strongly suggests broad palatability across consumer groups (Connolly et al., 2022; House et al., 2024). However, intensive poultry farming raises significant environmental and health concerns, including CO₂e emissions, nutrient runoff into waterways, heavy metal contamination of soil, and the growing threat of antibiotic resistance. These environmental challenges highlight the importance of not considering CO₂e alone, but the broader ecological impact of our food choices (Gržinić et al., 2023).

Poultry consumption offers significant nutritional benefits as a lean protein source rich in essential nutrients. It provides high-quality complete protein, vitamin B complex (particularly B6 and B12), selenium, zinc, and low amount of iron in forms highly bioavailable to humans. White meat poultry is notably low in saturated fat compared to red meat, making it favorable for cardiovascular health when consumed as part of a balanced diet (Connolly et al., 2022; Marangoni et al., 2015). However, some processed poultry products, such as nuggets or breaded fried chicken may contain high levels of sodium and added compounds like nitrites, which have been associated with increased cardiovascular and cancer risks when consumed in excess (Micha et al., 2010). Still, the scientific consensus suggests that unprocessed poultry, when properly prepared, can be part of a healthy diet (Connolly et al., 2022).

Plant-based foods: environmental and health implications

Plant-based food production generally has a lower environmental footprint compared to animal products, particularly regarding CO₂e emissions and land use (Lacour et al., 2018). However, the environmental impact varies significantly depending on production methods, location, and crop type. While many plant crops can be produced efficiently, some intensive farming practices can lead to soil degradation, biodiversity loss, and water pollution through excessive fertilizer use (Carlsson-Kanyama & González, 2009; IPCC, 2022; Nelson et al., 2016).

Plant-based foods demonstrate significant health implications through their unique nutritional composition. Well-planned vegetarian meals are often characterized by high intake of fiber, antioxidants, and phytochemicals, while being lower in saturated fat and cholesterol compared to omnivorous diets (McEvoy et al., 2012; Oussalah et al., 2020). Legumes serve as primary protein sources in vegetarian diets, providing protein along with soluble and insoluble fiber. Their consumption is associated with improved glycemic control, reduced

LDL cholesterol, and enhanced gut microbiome diversity (FAO/WHO et al., 2007; Polak et al., 2015).

However, the bioavailability of minerals in plant foods may be limited by their phytate content (Sandberg, 2002). As stated throughout this thesis, a diet dominated by plant-based foods requires more knowledge and planning to avoid health risks. Adult vegetarians and vegans often rely on supplementation (Grouffh-Jacobsen et al., 2024), while adolescents following these diets have been found to have higher rates of nutrient deficiencies (Hallström et al., 2025; Stubbendorff et al., 2025).

Plant-based meat alternatives: opportunities and challenges

The high iron concentration in PBMA presents a promising opportunity for nutritional optimization in public food service. These products have gained acceptance among omnivorous consumers due to their familiar texture and palatability (Sogari et al., 2023; Szenderák et al., 2022), making them a preferred choice for public meal planners (Pettersson et al., 2024). While PBMA, primarily manufactured from texturized plant proteins, often contain a substantial total iron content but the bioavailability of this iron is often compromised by its binding to phytates.

Several strategies could enhance iron bioavailability in PBMA-based meals: incorporating absorption enhancers such as vitamin C, adding modest quantities of meat to create hybrid dishes, or, more fundamentally, modifying the processing techniques of texturized proteins to reduce phytate content prior to meal preparation. Studies have demonstrated that fermentation (Eklund-Jonsson et al., 2008; Knez et al., 2023) and hydrothermal processing (Lemmens et al., 2018) can increase the amount of bioavailable iron in legumes and whole grains. These interventions could improve the nutritional value of PBMA-based meals while maintaining their acceptability among diverse consumer groups.

Promising solutions and applications

Based on these findings, the thesis proposed several promising solutions. The successful development of hybrid recipes, such as the optimized chili con carne variants, demonstrates the feasibility of balancing CO₂e reduction with nutritional adequacy. While these technical solutions show promise, they must be accompanied by broader changes that recognize and address gender-specific nutritional needs for a sustainable food system transition.

The hybrid recipe development strategies that proved successful in school meals offer promising applications for athletic populations. This thesis demonstrated that strategic combinations of animal and plant-based protein sources in hybrid recipes can maintain high protein content and iron bioavailability while reducing CO_{2e} emissions by 16-84%. This approach could be particularly valuable for athletes, who showed strong preferences for animal-based protein sources due to performance concerns. The successful acceptance of hybrid formulations among school children suggests that similar strategies could help bridge the gap between sport nutrition and climate-adaptation in athletic populations, particularly given that the athletes in Paper III-IV demonstrated sophisticated meal planning practices that could accommodate such hybrid approaches.

The technical solutions developed for school meals, particularly the successful combination of iron bioavailability calculations with CO_{2e} metrics, provide a framework that could be adapted for other public food services. The methodology for optimizing hybrid recipes while maintaining acceptance could be valuable in sports facilities, workplace cafeterias, and other settings where nutritional adequacy must be balanced with climate goals.

Conclusion

Collectively, the findings of this thesis emphasize that promoting sustainable food consumption requires nuanced, context-specific approaches rather than one-size-fits-all solutions. Each of the three themes explored reveals important considerations for balancing climate goals with nutritional adequacy.

School meals as climate champions demonstrate both opportunities and challenges in sustainable food transitions. The research highlights how public-school meals can drive meaningful CO₂e reductions through strategic meal planning but raises important questions about letting children and adolescents, who have limited agency, carry the responsibility to reach ambitious climate goals. The successful development of hybrid recipes illustrates that technical solutions can effectively balance climate goals with nutritional adequacy while maintaining acceptability, providing a model for other institutional settings.

Gender disparities in low-carbon diets reveal a worrying pattern in which climate adaptation may affect women's nutritional status more than men's. The research challenges the current assumption that low CO₂ diets are inherently health-promoting, with findings pointing to nutritional deficiencies that particularly affect adolescent girls and women of reproductive age with respect to iron. Overlooking these gender disparities is both a methodological challenge and an equity concern in food system transitions. This theme highlights the need for gender-sensitive frameworks in sustainable food planning.

Balancing activity and CO₂e among young adult consumers demonstrates how physical activity levels interact with food choices to influence climate impact. While higher activity levels typically correlate with increased CO₂e emissions, the identification of successful low-emission, high-performance outliers suggests opportunities for viable pathways to unite athletic performance with climate goals. This finding challenges assumptions about inevitable trade-offs and points toward strategies that can support highly active individuals in adopting climate-conscious diets without compromising performance.

The thesis demonstrates how social practices, societal structures, and individual agency interact to shape sustainable food consumption across these themes. Looking ahead, this work indicates critical areas for development: creating gender-

sensitive frameworks for sustainable meal planning, further refining hybrid recipe formulations, and developing targeted strategies to support diverse populations in adopting climate-conscious diets. These advances will be essential for developing effective and fair approaches to promoting sustainable food consumption while ensuring that climate goals do not compromise individual health and well-being. The findings have broad implications for public health policy, climate sustainability efforts, and social equity in food system transitions, emphasizing the need for integrated approaches that balance climate goals with nutritional adequacy.

Future perspectives

The transition toward climate-adapted public meal systems presents both significant challenges and opportunities. Looking forward, several key areas for development emerge in this domain where environmental sustainability must be carefully balanced with nutritional needs.

Evidence base for climate-adapted diets

The EAT-Lancet Commission (Willett et al., 2019) and Nordic Nutrition Recommendations 2023 (Blomhoff & Nordic Council of Ministers, 2023) present compelling evidence that shifting towards plant-based food sources is essential for reducing CO₂e emissions from food production. The EAT-Lancet report specifically emphasizes that a global transition to predominantly plant-based diets could reduce food-related CO₂e emissions by up to 80% (Willett et al., 2019). This aligns with the Nordic Nutrition Recommendations 2023, which explicitly acknowledges the dual benefits of plant-based diets for both human health and environmental sustainability (Blomhoff & Nordic Council of Ministers, 2023). Adherence to the EAT-Lancet diet has simultaneously been linked to positive health outcomes (Stubbendorff et al., 2022), and modeling shows that following the Nordic Nutrition Recommendations, particularly increasing fruit and vegetable consumption and reducing salt intake, could prevent up to 19.7% of deaths from cardiovascular diseases and diet-related cancers in Nordic countries (Saha et al., 2019).

Nutritional considerations and challenges

While the evidence strongly supports both planetary and human health benefits of plant-based diets, potential nutritional challenges require careful consideration, particularly concerning mineral bioavailability. This issue is especially relevant for vulnerable populations, as reduced bioavailability of essential minerals in plant-based foods could lead to nutritional inadequacies if not properly managed. Young women, who often lead dietary transition trends toward plant-based consumption, may face increased nutritional risks if bioavailability concerns are not adequately addressed, particularly given their higher iron requirements and the lower absorption rates of non-heme iron from plant sources.

Research priorities

A key priority for future research lies in developing comprehensive gender-sensitive frameworks for sustainable meal planning that integrate differential nutritional requirements while maintaining climate objectives. Particular attention should be directed toward optimizing bioavailability metrics, especially for essential minerals like iron, where gender-specific needs intersect with climate goals. The development and validation of standardized assessment protocols that incorporate bioavailability measurements could significantly enhance the evaluation of public meal programs.

Practical strategies for implementation

To promote both health equity and climate-adaptation, public food services, particularly in schools, should implement evidence-based strategies to optimize mineral bioavailability such as strategic food combinations to enhance absorption. Food manufacturers should be encouraged to develop innovative products that simultaneously address climate concerns and nutritional adequacy through improved mineral bioavailability, with particular attention to iron content and absorption. Such developments might include the application of food processing techniques that reduce anti-nutritional factors, enhance mineral absorption, or incorporate novel plant varieties bred for higher mineral content and bioavailability.

The optimization of hybrid recipe formulations emerges as another promising research direction. These formulations, which strategically combine plant and animal ingredients, show potential in balancing environmental impact with nutritional adequacy. Future studies should focus on quantifying the synergistic effects of different ingredient combinations on nutrient bioavailability, particularly investigating the role of absorption enhancers in predominantly plant-based meals.

Implementation strategies require careful consideration in future research initiatives. The success of low-carbon recipes compared to mandatory vegetarian meals suggests that gradual, evidence-based transitions may be more effective than categorical dietary changes. Future research should examine the factors contributing to successful implementation, including:

- The development of tailored nutritional guidelines that simultaneously address gender-specific requirements and environmental impacts
- The design and evaluation of educational programs that address gender-specific barriers to sustainable dietary adoption
- The formulation of public policies that effectively balance nutritional adequacy with climate sustainability

Policy development and regulatory frameworks

Policy frameworks must evolve to better support institutional adoption of climate-adapted meals while protecting nutritional adequacy. Specific policy mechanisms require development and evaluation, including regulatory frameworks with mandatory reporting requirements for both nutritional bioavailability and CO₂e in public meals, standards for hybrid recipe development, and guidelines for gradual transition periods that allow cultural adaptation. Economic instruments should be developed to support this transition, including incentive systems for municipalities achieving both nutritional and climate targets and support mechanisms for rural communities.

Theoretical frameworks for sustainable transitions

Social practice theory offers valuable insights for implementing sustainable changes across different populations. Research has revealed how sustainable food practices emerge through the interaction of competencies (nutritional knowledge, cooking skills), materials (food availability, preparation tools), and meanings (performance goals, environmental values). Policy development should address all three elements simultaneously. For instance, school meal programs need to combine practical cooking skills and increased awareness of bioavailability (competencies) with appropriate kitchen equipment and ingredients (materials), while fostering positive associations with climate-adapted meals (meanings).

Several critical research gaps require focused investigation. Long-term impact studies are needed to evaluate the effectiveness of hybrid meal solutions on both nutritional status and climate goals, particularly in institutional settings. The

development of validated bioavailability prediction models that can be integrated into existing meal planning software represents another crucial area for investigation. Furthermore, research must address the regional variations in acceptance and implementation of climate-adapted meals, particularly the urban-rural divide. Studies examining how athletic performance is maintained with different proportions of plant-based protein sources would provide valuable insights for both institutional and individual dietary planning.

Path forward

The successful evolution of sustainable public meal systems will depend on integrating these various research streams into practical, evidence-based solutions. Future studies must maintain a balanced perspective that acknowledges both the urgency of environmental sustainability and the fundamental importance of meeting diverse nutritional needs across different population groups. A successful transition toward climate-adapted public-school meals requires a holistic societal approach, where school meals represent one component of a broader shift toward climate-adapted food consumption, carefully balancing climate goals with nutritional needs, individual agency, and social equity considerations while maintaining an evidence-based approach.

Acknowledgements

I'm sincerely grateful to all participants who dedicated their time to contribute to the included studies. Especially those in Paper III who made it possible during the challenging COVID-19 period, helping me launch my first study under difficult circumstances.

As I wrap up this exploration of climate-adapted food consumption, I'm thankful to everyone who guided me along the way.

To Agneta, my main supervisor, the true “Iron Lady” of this project – not only did you demonstrate expertise in bioavailability calculations, recipe optimization and the writing process, but your unwavering support proved more absorbable than any heme iron source! Your ability to balance rigorous scientific standards with practical applications inspired me throughout this process. Like a perfectly calibrated algorithm, you knew exactly when to enhance my confidence and when to inhibit my research twists.

To Anna, whose theoretical knowledge was not just crucial but truly transformative – you guided me through the labyrinth of social practice theory with the precision of a master chef working with hybrid recipes. Your insights connected the materials, competencies, and meanings of my research into something far greater than the sum of its parts.

The journey of pursuing a PhD is much like creating a climate-adapted school meal – it requires careful balance, persistence through resistance to change, and a willingness to try new approaches when traditional ones fall short. Thank you both for ensuring that this academic meal was both nutritionally complete and palatable!

To my fellow doctoral students who shared this journey – thank you for the camaraderie, the impromptu hallway discussions, and the shared understanding that only those in the PhD trenches can truly appreciate.

To Aleksandra – not only a brilliant colleague but truly the best of friends, never a dull moment with you by my side. The future lies ahead of us, and I can't wait to see where our paths will lead, knowing that our friendship will endure whatever comes next. We will always be a part of the everlasting IFSV, Docti Triumphabunt!

To my husband Niklas – your endless unconditional support and love have been my foundation through it all. Thank you for keeping me sane during the late nights and stressed days, for making me laugh when I needed it most, and for believing in me even when I doubted myself. You’ve been my constant through this roller coaster journey, and I couldn’t have done this without you.

To my son Max, the light of my life – thank you for your magical ability to pull me away from work and remind me what truly matters. Your smile, your curiosity, and your joy have been the best part of every day. You’ve taught me to be present in the moment and to see the world through fresh eyes. This work is for you and your future.

Göteborg, March 2025

Mari Wollmar

Cover Art Explanation

The amazing cover art was made by Alexandra Dahlqvist. The cover illustration visually represents the core themes explored throughout this thesis. At the center of the composition is the fundamental tension between nutritional adequacy and climate impact in food systems. The plate of food on the left depicts a hybrid meal combining plant-based ingredients with a modest amount of animal protein—reflecting the optimized recipe solutions developed in Papers I and II. The abundant green vegetables symbolize the shift toward more sustainable eating patterns.

The kettlebell marked “Fe” (iron) on the right side represents two interconnected aspects of the research: the importance of physical activity in personal wellbeing and the critical role of iron nutrition, particularly for women and highly active individuals as examined in Papers III and IV. The butterfly perched on the kettlebell serves as a metaphor for the delicate balance required when transitioning to climate-adapted diets without compromising nutritional needs.

The vibrant green background with varied textures evokes agricultural landscapes and sustainability, while the transition from red to green suggests the ongoing transformation of food systems toward more environmentally responsible practices. This visual narrative encapsulates the thesis's ultimate message: achieving harmony between nutrition, physical performance, and environmental responsibility requires thoughtful integration of science, practice, and policy.

References

- Adesogan, A. T., Havelaar, A. H., McKune, S. L., Eilittä, M., & Dahl, G. E. (2020). Animal source foods: Sustainability problem or malnutrition and sustainability solution? Perspective matters. *Global Food Security*, 25, 100325. <https://doi.org/10.1016/j.gfs.2019.100325>
- Aiking, H., & de Boer, J. (2020). The next protein transition. *Trends in Food Science & Technology*, 105, 515–522. <https://doi.org/10.1016/j.tifs.2018.07.008>
- Aldaya, M. M., Ibanez, F. C., Dominguez-Lacueva, P., Murillo-Arbizu, M. T., Rubio-Varas, M., Soret, B., & Beriain, M. J. (2021). Indicators and Recommendations for Assessing Sustainable Healthy Diets. *Foods*, 10(5), 999. <https://doi.org/10.3390/foods10050999>
- Aleksandrowicz, L., Green, R., Joy, E. J. M., Smith, P., & Haines, A. (2016). The impacts of dietary change on greenhouse gas emissions, land use, water use, and health: A systematic review. *PloS One*, 11(11), e0165797. <https://doi.org/10.1371/journal.pone.0165797>
- Amcoff, E., Konde, Å. B., Jansson, A., & Färnstrand, J. S. (2015). Byta till Nyckelhålet - så påverkar det näringsintaget (Switch to the Keyhole - how it affects nutritional intake).
- André, E., Eustachio Colombo, P., Schäfer Elinder, L., Larsson, J., & Hunsberger, M. (2024). Acceptance of Low-Carbon School Meals with and without Information—A Controlled Intervention Study. *Journal of Consumer Policy*, 47(1), 109–125. <https://doi.org/10.1007/s10603-023-09557-4>
- Archundia-Herrera, M. C., Nunes, F., Barrios, I. D., Park, C. Y., Bell, R. C., & O'Brien, K. O. (2024). Development of a Database for the Estimation of Heme Iron and Nonheme Iron Content of Animal-Based Foods. *Current Developments in Nutrition*, 8(4), 102130–102130. <https://doi.org/10.1016/j.cdnut.2024.102130>
- Arvanitoyannis, I. S., Kotsanopoulos, K. V., & Veikou, A. (2014). Life Cycle Assessment (ISO 14040) Implementation in Foods of Animal and Plant Origin: Review. *Critical Reviews in Food Science and Nutrition*, 54(10), 1253–1282. <https://doi.org/10.1080/10408398.2011.631170>
- Bacchetti, J., Bava, L., Schievano, A., & Zucali, M. (2018). Whey protein concentrate (WPC) production: Environmental impact assessment. *Journal of Food Engineering*, 224, 139–147.
- Backstrand, J. R. (2002). The History and Future of Food Fortification in the United States: A Public Health Perspective. *Nutrition Reviews*, 60(1), 15–26. <https://doi.org/10.1301/002966402760240390>
- Bæch, S. B., Hansen, M., Bukhave, K., Jensen, M., Sørensen, S. S., Kristensen, L., Purslow, P. P., Skibsted, L. H., & Sandström, B. (2003). Nonheme-iron absorption from a phytate-rich meal is increased by the addition of small amounts of pork meat¹²³⁴. *The American Journal of Clinical Nutrition*, 77(1), 173–179. <https://doi.org/10.1093/ajcn/77.1.173>
- Bailey, R. L., West, K. P., & Black, R. E. (2015). The Epidemiology of Global Micronutrient Deficiencies. *Annals of Nutrition and Metabolism*, 66(Suppl 2), 22–33. <https://doi.org/10.1159/000371618>
- Bakkman, L., Mattsson, S., Melin, A., & Pettersson, S. (2016). Sveriges Olympiska Kommité: Kostrekommendationer för olympiska idrottare.

- Baroni, L., Cenci, L., Tettamanti, M., & Berati, M. (2007). Evaluating the environmental impact of various dietary patterns combined with different food production systems. *European Journal of Clinical Nutrition*, 61(2), 279–286. <https://doi.org/10.1038/sj.ejcn.1602522>
- Barre, T., Perignon, M., Gazan, R., Vieux, F., Micard, V., Amiot, M.-J., Darmon, N., & de Souza, R. J. (2018). Integrating nutrient bioavailability and co-production links when identifying sustainable diets: How low should we reduce meat consumption? *PloS One*, 13(2), e0191767–e0191767. <https://doi.org/10.1371/journal.pone.0191767>
- Basheer, S., Wang, X., Farooque, A. A., Nawaz, R. A., Pang, T., & Neokye, E. O. (2024). A Review of Greenhouse Gas Emissions from Agricultural Soil. *Sustainability*, 16(11). <https://doi.org/10.3390/su16114789>
- Baune, M.-C., Broucke, K., Ebert, S., Gibis, M., Weiss, J., Enneking, U., Profeta, A., Terjung, N., & Heinz, V. (2023). Meat hybrids—An assessment of sensorial aspects, consumer acceptance, and nutritional properties. *Frontiers in Nutrition*, 10. <https://doi.org/10.3389/fnut.2023.1101479>
- Beal, T., Ortenzi, F., & Fanzo, J. (2023). Estimated micronutrient shortfalls of the EAT–Lancet planetary health diet. *The Lancet Planetary Health*, 7(3), e233–e237. [https://doi.org/10.1016/S2542-5196\(23\)00006-2](https://doi.org/10.1016/S2542-5196(23)00006-2)
- Becker, W., Lindroos, A. K., Nalsen, C., Warensjo Lemming, E., & Ohrvik, V. (2016). Dietary habits, nutrient intake and biomarkers for folate, vitamin D, iodine and iron status among women of childbearing age in Sweden. *Ups J Med Sci*, 121(4), 271–275. <https://doi.org/10.1080/03009734.2016.1201176>
- Bendavid, I., Lobo, D. N., Barazzoni, R., Cederholm, T., Coëffier, M., de van der Schueren, M., Fontaine, E., Hiesmayr, M., Laviano, A., Pichard, C., & Singer, P. (2021). The centenary of the Harris–Benedict equations: How to assess energy requirements best? Recommendations from the ESPEN expert group. *Clinical Nutrition (Edinburgh, Scotland)*, 40(3), 690–701. <https://doi.org/10.1016/j.clnu.2020.11.012>
- Benkhedda, K., L’Abbé, M. R., & Cockell, K. A. (2010). Effect of calcium on iron absorption in women with marginal iron status. *British Journal of Nutrition*, 103(5), 742–748. Cambridge Core. <https://doi.org/10.1017/S0007114509992418>
- Berthy, F., Brunin, J., Allès, B., Reuzé, A., Touvier, M., Hercberg, S., Lairon, D., Pointereau, P., Mariotti, F., Baudry, J., & Kesse-Guyot, E. (2023). Higher adherence to the EAT–Lancet reference diet is associated with higher nutrient adequacy in the NutriNet–Santé cohort: A cross-sectional study. *The American Journal of Clinical Nutrition*, 117(6), 1174–1185. <https://doi.org/10.1016/j.ajcnut.2023.03.029>
- Biermann G, Rau H. (2020) The meaning of meat: (Un)sustainable eating practices at home and out of home. *Appetite*. 2020;153:104730–104730.
- Bingham, S. A., Gill, C., Welch, A., Day, K., Cassidy, A., Khaw, K. T., Sneyd, M. J., Key, T. J. A., Roe, L., & Day, N. E. (1994). Comparison of dietary assessment methods in nutritional epidemiology: Weighed records v. 24 h recalls, food-frequency questionnaires and estimated-diet records. *British Journal of Nutrition*, 72(4), 619–643. <https://doi.org/10.1079/BJN19940064>
- Birkenhead, K. L., & Slater, G. (2015). A Review of Factors Influencing Athletes’ Food Choices. *Sports Medicine (Auckland, N.Z.)*, 45(11), 1511–1522. <https://doi.org/10.1007/s40279-015-0372-1>
- Bjorn Rasmussen, E., Hallberg, L., Isaksson, B., & Arvidsson, B. (1974). Food iron absorption in man. Applications of the two pool extrinsic tag method to measure heme and nonheme

- iron absorption from the whole diet. *The Journal of Clinical Investigation*, 53(1), 247–255. <https://doi.org/10.1172/JCI107545>
- Blomhoff, R., Andersen, R., Arnesen, E. K., Christensen, J. J., Eneroth, H., Erkkola, M., Gudavaničienė, I., Halldórsson, T. I., Høyer-Lund, A., Lemming, E. W., Meltzer, H. M., Pitsi, T., Schwab, U., Siksna, I., Thorsdóttir, I., & Trolle, E. (2023). *Nordic Nutrition Recommendations 2023*. Nordic Council of Ministers.
- Blomhoff, R. & Nordic Council of Ministers. (2023). *Nordic nutrition recommendations 2023: Integrating environmental aspects* ([New edition]). Copenhagen : Nordic Council of Ministers.
- Bourdieu, P., & Nice, R. (1977). *Outline of a theory of practice*. Cambridge University Press.
- Brooker, P. G., Hendrie, G. A., Anastasiou, K., & Colgrave, M. L. (2022). The range and nutrient profile of alternative protein products sold in Australian supermarkets between 2014 and 2021. *International Journal of Food Sciences and Nutrition*, 1–13. <https://doi.org/10.1080/09637486.2022.2137786>
- Bryman, A. (2022). *Social research methods*. New York, NY : Oxford University Press.
- Bryngelsson, S., Moshtaghian, H., Bianchi, M., & Hallström, E. (2022). Nutritional assessment of plant-based meat analogues on the Swedish market. *International Journal of Food Sciences and Nutrition*, 73(7), 889–901. <https://doi.org/10.1080/09637486.2022.2078286>
- Bull, F. C., Al-Ansari, S. S., Biddle, S., Borodulin, K., Buman, M. P., Cardon, G., Carty, C., Chaput, J.-P., Chastin, S., Chou, R., Dempsey, P. C., DiPietro, L., Ekelund, U., Firth, J., Friedenreich, C. M., Garcia, L., Gichu, M., Jago, R., Katzmarzyk, P. T., ... Willumsen, J. F. (2020). World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *British Journal of Sports Medicine*, 54(24), 1451–1462. <https://doi.org/10.1136/bjsports-2020-102955>
- Burke, L. M., Jones, A. M., Jeukendrup, A. E., & Mooses, M. (2019). Contemporary nutrition strategies to optimize performance in distance runners and race walkers. *International Journal of Sport Nutrition and Exercise Metabolism*, 29(2), 117–129. <https://doi.org/10.1123/ijsnem.2019-0004>
- Bytomski, J. R. (2018). Fueling for Performance. *Sports Health*, 10(1), 47–53. <https://doi.org/10.1177/1941738117743913>
- Cambeses-Franco, C., González-García, S., Feijoo, G., & Moreira, M. T. (2021). Is the Paleo diet safe for health and the environment? *The Science of the Total Environment*, 781, 146717–146717. <https://doi.org/10.1016/j.scitotenv.2021.146717>
- Carlsson-Kanyama, A., & González, A. D. (2009). Potential contributions of food consumption patterns to climate change²³. *The American Journal of Clinical Nutrition*, 89(5), 1704S–1709S. <https://doi.org/10.3945/ajcn.2009.26736AA>
- Caro, D., Davis, S. J., Bastianoni, S., & Caldeira, K. (2017). Greenhouse Gas Emissions Due to Meat Production in the Last Fifty Years. In M. Ahmed & C. O. Stockle (Eds.), *Quantification of Climate Variability, Adaptation and Mitigation for Agricultural Sustainability* (pp. 27–37). Springer International Publishing. https://doi.org/10.1007/978-3-319-32059-5_2
- Chai, B. C., van der Voort, J. R., Grofelnik, K., Eliasdóttir, H. G., Klöss, I., & Perez-Cueto, F. J. A. (2019). Which Diet Has the Least Environmental Impact on Our Planet? A Systematic Review of Vegan, Vegetarian and Omnivorous Diets. *Sustainability*, 11(15). <https://doi.org/10.3390/su11154110>

- Chigwedere, C. M., Stone, A., Konieczny, D., Lindsay, D., Huang, S., Glahn, R., House, J. D., Warkentin, T. D., & Nickerson, M. (2023). Examination of the functional properties, protein quality, and iron bioavailability of low-phytate pea protein ingredients. *European Food Research and Technology*, 249(6), 1517–1529. <https://doi.org/10.1007/s00217-023-04232-x>
- Claudino, J. G., Gabbett, T. J., Bourgeois, F., Souza, H. de S., Miranda, R. C., Mezêncio, B., Soncin, R., Cardoso Filho, C. A., Bottaro, M., Hernandez, A. J., Amadio, A. C., & Serrão, J. C. (2018). CrossFit Overview: Systematic Review and Meta-analysis. *Sports Medicine - Open*, 4(1), 11. <https://doi.org/10.1186/s40798-018-0124-5>
- Cohen, J. F. W., Verguet, S., Giyose, B. B., & Bundy, D. (2023). Universal free school meals: The future of school meal programmes? *The Lancet*, 402(10405), 831–833. [https://doi.org/10.1016/S0140-6736\(23\)01516-7](https://doi.org/10.1016/S0140-6736(23)01516-7)
- Coleman, F. C., & Williams, S. L. (2002). Overexploiting marine ecosystem engineers: Potential consequences for biodiversity. *Trends in Ecology & Evolution*, 17(1), 40–44. [https://doi.org/10.1016/S0169-5347\(01\)02330-8](https://doi.org/10.1016/S0169-5347(01)02330-8)
- Colomb, V., Ait Amar, S., Mens, C. B., Gac, A., Gaillard, G., Koch, P., Mousset, J., Salou, T., Tailleux, A., & van der Werf, H. M. G. (2015). AGRIBALYSE®, the French LCI Database for agricultural products: High quality data for producers and environmental labelling. *Oléagineux Corps Gras Lipides*, 22(1), D104. <https://doi.org/10.1051/ocl/20140047>
- Colombo, P. E., Patterson, E., Elinder, L. S., Lindroos, A. K., Sonesson, U., Darmon, N., & Parlesak, A. (2019). Optimizing school food supply: Integrating environmental, health, economic, and cultural dimensions of diet sustainability with linear programming. *International Journal of Environmental Research and Public Health*, 16(17), 3019. <https://doi.org/10.3390/ijerph16173019>
- Colombo, P. E., Patterson, E., Lindroos, A. K., Parlesak, A., & Elinder, L. S. (2020). Sustainable and acceptable school meals through optimization analysis: An intervention study. *Nutrition Journal*, 19(1), 61–15. <https://doi.org/10.1186/s12937-020-00579-z>
- Connolly, G., Clark, C. M., Campbell, R. E., Byers, A. W., Reed, J. B., & Campbell, W. W. (2022). Poultry Consumption and Human Health: How Much Is Really Known? A Systematically Searched Scoping Review and Research Perspective. *Advances in Nutrition* (Bethesda, Md.), 13(6), 2115–2124. <https://doi.org/10.1093/advances/nmac074>
- Cook, J. D., Morck, T. A., & Lynch, S. R. (1981). The inhibitory effect of soy products on nonheme iron absorption in man. *The American Journal of Clinical Nutrition*, 34(12), 2622–2629. <https://doi.org/10.1093/ajcn/34.12.2622>
- Creswell, J. W. (2017). *Designing and conducting mixed methods research* (Third Edition). Los Angeles : SAGE.
- Crippa, M., Solazzo, E., Guizzardi, D., Monforti-Ferrario, F., Tubiello, F. N., & Leip, A. (2021). Food systems are responsible for a third of global anthropogenic GHG emissions. *Nature Food*, 2(3), 198–209. <https://doi.org/10.1038/s43016-021-00225-9>
- CrossFit. (2021, December). Retrieved March 17, 2021, from https://journal.crossfit.com/?tags=Lifestyle&_ga=2.116181892.38269768.1639388587-1138781602.1610011598
- Cucurachi, S., Scherer, L., Guinée, J., & Tukker, A. (2019). Life Cycle Assessment of Food Systems. *One Earth*, 1(3), Article 3. <https://doi.org/10.1016/j.oneear.2019.10.014>

- Dahdouh, S., Grande, F., Espinosa, S. N., Vincent, A., Gibson, R., Bailey, K., King, J., Rittenschober, D., & Charrondi re, U. R. (2019). Development of the FAO/INFOODS/IZINCG Global Food Composition Database for Phytate. *Journal of Food Composition and Analysis*, 78, 42–48. <https://doi.org/10.1016/j.jfca.2019.01.023>
- Evans, D. (2012). Beyond the Throwaway Society: Ordinary Domestic Practice and a Sociological Approach to Household Food Waste. *Sociology (Oxford)*, 2012;46(1):41–56.
- Dawkins, E., Andr e, K., Leander, E., Axelsson, K., & Gerger Swartling,  . (2023). Policy for sustainable consumption – an assessment of Swedish municipalities. *Frontiers in Sustainability (Lausanne)*, 4. <https://doi.org/10.3389/frsus.2023.1265733>
- Dawson, M. C. (2017). CrossFit: Fitness cult or reinventive institution? *International Review for the Sociology of Sport*, 52(3), Article 3. <https://doi.org/10.1177/1012690215591793>
- Deac, A. (2018). Regulation (EU) 2016/679 of the European Parliament and of the Council on the protection of individuals with regard to the processing of personal data and the free movement of these data. *Perspectives of Law and Public Administration*, 7(2), 151–156.
- Denscombe, M. (2008). Communities of Practice: A Research Paradigm for the Mixed Methods Approach. *Journal of Mixed Methods Research*, 2(3), 270–283. <https://doi.org/10.1177/1558689808316807>
- Di Lodovico, L., Dubertret, C., & Ameller, A. (2018). Vulnerability to exercise addiction, socio-demographic, behavioral and psychological characteristics of runners at risk for eating disorders. *Comprehensive Psychiatry*, 81, 48–52. <https://doi.org/10.1016/j.comppsy.2017.11.006>
- Dobrowolski, H., Karczema, A., & Wlodarek, D. (2020). Nutrition for Female Soccer Players-Recommendations. *Medicina (Kaunas, Lithuania)*, 56(1), 28. <https://doi.org/10.3390/medicina56010028>
- Domell f, M., & Sj berg, A. (2024). Iron – a background article for the Nordic Nutrition Recommendations 2023. *Food & Nutrition Research*, 68, 1–21. <https://doi.org/10.29219/fnr.v68.10451>
- Dubuisson-Quellier, S., & Gojard, S. (2016). Why are Food Practices not (More) Environmentally Friendly in France? The role of collective standards and symbolic boundaries in food practices. *Environmental Policy and Governance*, 26(2), 89–100.
- European Parliament and Council. (2004). Regulation (EC) No 852/2004 of the European Parliament and of the Council of 29 April 2004 on the hygiene of foodstuffs. Retrieved from <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32004R0852>
- Eklund-Jonsson, C., Sandberg, A.-S., Hulth n, L., & Alminger, M. (2008). Tempe Fermentation of Whole Grain Barley Increased Human Iron Absorption and In vitro Iron Availability. *The Open Nutrition Journal*, 2008, Vol. 2, Pp. 42-47.
- Eme, P. E., Douwes, J., Kim, N., Foliaki, S., & Burlingame, B. (2019). Review of Methodologies for Assessing Sustainable Diets and Potential for Development of Harmonised Indicators. *International Journal of Environmental Research and Public Health*, 16(7), 1184. <https://doi.org/10.3390/ijerph16071184>
- Engle-Stone, R., Aaron, G. J., Huang, J., Wirth, J. P., Namaste, S. M., Williams, A. M., Peerson, J. M., Rohner, F., Varadhan, R., Addo, O. Y., Temple, V., Rayco-Solon, P., Macdonald, B., & Suchdev, P. S. (2017). Predictors of anemia in preschool children: Biomarkers Reflecting Inflammation and Nutritional Determinants of Anemia (BRINDA) project. *The American Journal of Clinical Nutrition*, 106, 402S-415S. <https://doi.org/10.3945/ajcn.116.142323>

- Ertaş, N. (2017). A comparison of industrial and homemade bulgur in Turkey in terms of physical, chemical and nutritional properties. *Chemical Industry and Chemical Engineering Quarterly*, 23(3), 341–348. <https://doi.org/10.2298/CICEQ160112047E>
- European Commission & Directorate-General for Communication. (2021). *European green deal – Delivering on our targets*. Publications Office of the European Union. <https://doi.org/10.2775/373022>
- Eustachio Colombo, P. E., Schäfer Elinder, L., & Carlsson Kanyama, A. (2020). Vegobarometern: En undersökning av svenskarnas benägenhet att välja vegetarisk mat under åren 2016-2019 (No. 1:5). *Mistra Sustainable Consumption*.
- Eustachio Colombo, P., Patterson, E., Elinder, L. S., & Lindroos, A. K. (2020). The importance of school lunches to the overall dietary intake of children in Sweden: A nationally representative study. *Public Health Nutrition*, 23(10), 1705–1715. <https://doi.org/10.1017/S1368980020000099>
- Food and Agriculture Organization. (2020). *Emissions due to agriculture: Global, regional and country trends 2000–2018*. FAOSTAT Analytical Brief Series No 18. <https://doi.org/10.2775/373022>.
- Food and Agriculture Organization of the United Nations. (2013). *Food waste gap footprint: Impacts on natural resources*. FAO. Retrieved from <https://openknowledge.fao.org/server/api/core/bitstreams/1694038d-98f7-40f6-be4b-98782544b9f9/content>
- Food and Agriculture Organization of the United Nations & World Health Organization. (2011). *Report of the Joint Expert Consultation on the Risks and Benefits of Fish Consumption*, Rome, Italy, 25-29 January 2010. Retrieved from <https://apps.who.int/iris/handle/10665/446661>(<https://apps.who.int/iris/handle/10665/44666>)
- Food and Agriculture Organization of the United Nations & World Health Organization. (2007). *Cereals, pulses, legumes and vegetable proteins (1st ed.)*. World Health Organization: Food and Agriculture Organization of the United Nations.
- Feilzer, Y. (2010). Doing Mixed Methods Research Pragmatically: Implications for the Rediscovery of Pragmatism as a Research Paradigm. *Journal of Mixed Methods Research*, 4(1), 6–16. <https://doi.org/10.1177/1558689809349691>
- Filer, L. J., & Ziegler, E. E. (1996). *Present knowledge in nutrition (7. ed.)*. Washington, DC. ILSI Press.
- Florén, B., Amani, P., & Davis, J. (2017). Climate database facilitating climate smart meal planning for the public sector in Sweden. *International Journal on Food System Dynamics*, 8(1), Article 1.
- Foss, C., & Ellefsen, B. (2002). The value of combining qualitative and quantitative approaches in nursing research by means of method triangulation. *Journal of Advanced Nursing*, 40(2), 242–248. <https://doi.org/10.1046/j.1365-2648.2002.02366.x>
- Fraczek, B., Pieta, A., Burda, A., Mazur-Kurach, P., & Tyrala, F. (2021). Paleolithic Diet-Effect on the Health Status and Performance of Athletes? *Nutrients*, 13(3), 1019–1019. <https://doi.org/10.3390/nu13031019>
- Franca, P. A. P., Gonçalves Lima, C. K. A. Z., Oliveira, T. M. de, Ferreira, T. J., da Silva, R. R. M., Loureiro, L. L., & Pierucci, A. P. T. R. (2022). Effectiveness of current protein

- recommendations in adolescent athletes on a low-carbon diet. *Frontiers in Nutrition*, 9. <https://doi.org/10.3389/fnut.2022.1016409>
- Friedman, M. (1937). The use of ranks to avoid the assumption of normality implicit in the analysis of variance. *Journal of the American Statistical Association*, 32(200), 675–701.
- Fuentes, M., & Fuentes, C. (2021). Reconfiguring food materialities: Plant-based food consumption practices in antagonistic landscapes. *Food, Culture & Society*, 1–20. <https://doi.org/10.1080/15528014.2021.1903716>
- Fuentes C, Svingstedt A. (2017) Mobile phones and the practice of shopping: A study of how young adults use smartphones to shop. *Journal of retailing and consumer services*. 2017;38(3):137–46.
- Fuhrman, J., & Ferreri, D. M. (2010). Fueling the vegetarian (vegan) athlete. *Current Sports Medicine Reports*, 9(4), Article 4. <https://doi.org/10.1249/JSR.0b013e3181e93a6f>
- Garcia-Larsen, V., Morton, V., Norat, T., Moreira, A., Potts, J. F., Reeves, T., & Bakolis, I. (2019). Dietary patterns derived from principal component analysis (PCA) and risk of colorectal cancer: A systematic review and meta-analysis. *European Journal of Clinical Nutrition*, 73(3), 366–386. <https://doi.org/10.1038/s41430-018-0234-7>
- Gardner, C. D., Hartle, J. C., Garrett, R. D., Offringa, L. C., & Wasserman, A. S. (2019). Maximizing the intersection of human health and the health of the environment with regard to the amount and type of protein produced and consumed in the United States. *Nutrition Reviews*, 77(4), 197–215. <https://doi.org/10.1093/nutrit/nuy073>
- Garnett, T. (2016). Plating up solutions. *Science*, 353(6305), 1202–1204. <https://doi.org/10.1126/science.aah4765>
- Gerber, P. J., Mottet, A., Opio, C. I., Falcucci, A., & Teillard, F. (2015). Environmental impacts of beef production: Review of challenges and perspectives for durability. 61st International Congress of Meat Science and Technology (61st ICoMST), 23–28 August 2015, Clermont Ferrand, France, 109, 2–12. <https://doi.org/10.1016/j.meatsci.2015.05.013>
- Gernand, A. D., Schulze, K. J., Stewart, C. P., West, K. P. J., & Christian, P. (2016). Micronutrient deficiencies in pregnancy worldwide: Health effects and prevention. *Nature Reviews. Endocrinology*, 12(5), 274–289. <https://doi.org/10.1038/nrendo.2016.37>
- Gibson, R. S. (2024). Food consumption of individuals. In *Principles of Nutritional Assessment* (2nd ed., Vol. 2024). Oxford University Press. <http://files/45/books.html>
- Giddens, A. (1984). *The constitution of society outline of the theory of structuration*. Cambridge : Polity Press.
- Gil, A., & Gil, F. (2015). Fish, a Mediterranean source of n-3 PUFA: benefits do not justify limiting consumption. *British Journal of Nutrition*, 113(S2), S58–S67. <https://doi.org/10.1017/S0007114514003742>
- Glassman, G. (2002). What is fitness? *The CrossFit Journal*.
- Gleerup, A., Rossander-Hultén, L., & Hallberg, L. (1993). Duration of the inhibitory effect of calcium on non-haem iron absorption in man. *European Journal of Clinical Nutrition*, 47(12), 875–879.
- Glossary:Greenhouse gas (GHG)—Statistics Explained. (2020). [https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Greenhouse_gas_\(GHG\)](https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Greenhouse_gas_(GHG))

- Goris, A. H. C., & Westerterp, K. R. (1999). Underreporting of habitual food intake is explained by undereating in highly motivated lean women. *The Journal of Nutrition*, 129(4), Article 4. <https://doi.org/10.1093/jn/129.4.878>
- Göteborgs Universitet. (2015). Regler för forskningsinfrastrukturer vid Göteborgs Universitet. Retrieved from (https://www.gu.se/sites/default/files/2022-01/1696171_180809-regler-fo--r-forskningsinfrastrukturer-vid-go--teborgs-universitet.pdf)
- Groufh-Jacobsen, S., Larsson, C., Margerison, C., Mulkerrins, I., Aune, D., & Medin, A. C. (2024). Micronutrient intake and status in young vegans, lacto-ovo-vegetarians, pescatarians, flexitarians, and omnivores. *European Journal of Nutrition*, 2024.
- Gullberg, E. (2004). *Det välnärda barnet: Föreställningar och politik i skolmåltidens historia*. Diss. Linköping: Univ., 2004.
- Gullberg, E. (2006). Food for Future Citizens: School Meal Culture in Sweden. *Food, Culture, & Society*, 9(3), 337–343. <https://doi.org/10.2752/155280106778813279>
- Haider, L. M., Schwingshackl, L., Hoffmann, G., & Ekmekcioglu, C. (2018). The effect of vegetarian diets on iron status in adults: A systematic review and meta-analysis. *Critical Reviews in Food Science and Nutrition*, 58(8), 1359–1374. <https://doi.org/10.1080/10408398.2016.1259210>
- Hailemariam, G. A., Wudinch, T. A. (2020). Effect of Cooking Methods on Ascorbic Acid Destruction of Green Leafy Vegetables. *Journal of Food Quality*, 2020, 1–5.
- Halkier B., Jensen I. (2011) Doing “healthier” food in everyday life? A qualitative study of how Pakistani Danes handle nutritional communication. *Critical public health*. 2011;21(4):471–83.
- Hallberg, L., & Hulthén, L. (2000). Prediction of dietary iron absorption: An algorithm for calculating absorption and bioavailability of dietary iron. *The American Journal of Clinical Nutrition*, 71(5), Article 5. <https://doi.org/10.1093/ajcn/71.5.1147>
- Hallstrom, E., Carlsson-Kanyama, A., & Borjesson, P. (2015). Environmental impact of dietary change: A systematic review. *Journal of Cleaner Production*, 91, 1–1. <https://doi.org/10.1016/j.jclepro.2014.12.008>
- Hallström, E., Löfvenborg, J. E., Moreaus, L., Sjöberg, A., Winkvist, A., & Lindroos, A. K. (2025). Iron intake and iron status of Swedish adolescents with diets of varying climate impact. *European Journal of Nutrition*, 64(2), 93. <https://doi.org/10.1007/s00394-024-03572-y>
- Hansen, A. R., Laakso, S., Jack, T., & Neuman, N. (2024). Welfare within planetary boundaries in the Nordics: Can sufficiency pave the path forward for sustainable policy and practice? *Consumption and Society*, 3(3), 224–234. <https://doi.org/10.1332/27528499Y2024D000000031>
- Hansson, H., Säll, S., Abouhatab, A., Ahlgren, S., Berggren, Å., Hallström, E., Lundqvist, P., Persson, U. M., Rydhmer, L., Röös, E., Tidåker, P., Winkvist, A., & Zhu, L. (2024). An indicator framework to guide food system sustainability transition – The case of Sweden. *Environmental and Sustainability Indicators*, 22, 100403. <https://doi.org/10.1016/j.indic.2024.100403>
- Hargreaves, T. (2011). Practice-ing behaviour change: Applying social practice theory to pro-environmental behaviour change. *Journal of Consumer Culture*, 11(1), 79–99. <https://doi.org/10.1177/1469540510390500>

- Harrison, M. R., Palma, G., Buendia, T., Bueno-Tarodo, M., Quell, D., & Hachem, F. (2022). A Scoping Review of Indicators for Sustainable Healthy Diets. *Frontiers in Sustainable Food Systems*, 5. <https://doi.org/10.3389/fsufs.2021.822263>
- Hay, G., Sandstad, B., Whitelaw, A., & Borch-Johnsen, B. (2004). Iron status in a group of Norwegian children aged 6-24 months. *Acta Paediatrica*, 93(5), 592–598. <https://doi.org/10.1111/j.1651-2227.2004.tb02983.x>
- Hein, K. A., Jaeger, S. R., Tom Carr, B., & Delahunty, C. M. (2008). Comparison of five common acceptance and preference methods. *Food Quality and Preference*, 19(7), 651–661. <https://doi.org/10.1016/j.foodqual.2008.06.001>
- Henchion, M., Hayes, M., Mullen, A. M., Fenelon, M., & Tiwari, B. (2017). Future Protein Supply and Demand: Strategies and Factors Influencing a Sustainable Equilibrium. *Foods*, 6(7). <https://doi.org/10.3390/foods6070053>
- Herz, J. C. 1. (2014). *Learning to breathe fire: the rise of CrossFit and the primal future of fitness*. First edition. Crown Archetype.
- Hoek, A. C., Malekpour, S., Raven, R., Court, E., & Byrne, E. (2021). Towards environmentally sustainable food systems: Decision-making factors in sustainable food production and consumption. *Sustainable Production and Consumption*, 26, 610–626. <https://doi.org/10.1016/j.spc.2020.12.009>
- Hoppe, M., Sjöberg, A., Hallberg, L., & Hulthén, L. (2008). Iron status in Swedish teenage girls: Impact of low dietary iron bioavailability. *Nutrition*, 24(7), 638–645. <https://doi.org/10.1016/j.nut.2008.03.007>
- Houston, B. L., Hurrie, D., Graham, J., Perija, B., Rimmer, E., Rabbani, R., Bernstein, C. N., Turgeon, A. F., Fergusson, D. A., Houston, D. S., Abou-Setta, A. M., & Zarychanski, R. (2018). Efficacy of iron supplementation on fatigue and physical capacity in non-anaemic iron-deficient adults: A systematic review of randomised controlled trials. *BMJ Open*, 8(4), e019240–e019240. <https://doi.org/10.1136/bmjopen-2017-019240>
- How Many People Do CrossFit? (2020, October 28). <https://www.crossfitfortify.com/how-many-people-do-crossfit>
- Hunt, J. R. (2010). Algorithms for iron and zinc bioavailability: are they accurate? *International Journal for Vitamin and Nutrition Research*, 80(4–5), 257–262. <https://doi.org/10.1024/0300-9831/a000032>
- Hurrell, R. F., Reddy, M. B., Juillerat, M., & Cook, J. D. (2006). Meat Protein Fractions Enhance Nonheme Iron Absorption in Humans1. *The Journal of Nutrition*, 136(11), 2808–2812. <https://doi.org/10.1093/jn/136.11.2808>
- IPCC. (2022). *Climate Change and Land: IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems*. Cambridge University Press. <https://doi.org/10.1017/9781009157988>
- Ishangulyev, S., Kim, S., & Lee, S. H. (2019). Understanding food loss and waste-why are we losing and wasting food? *Foods*, 8(8), 297. <https://doi.org/10.3390/foods8080297>
- Joint WHO/FAO/UNU Expert Consultation. (2007). *Protein and amino acid requirements in human nutrition*. World Health Organization Technical Report Series, 935, 1–265. Retrieved from [https://iris.who.int/handle/10665/43411\[1\]\(https://iris.who.int/handle/10665/43411\)](https://iris.who.int/handle/10665/43411[1](https://iris.who.int/handle/10665/43411))

- Karavasiloglou, N., Thompson, A. S., Pestoni, G., Knuppel, A., Papier, K., Cassidy, A., Kühn, T., & Rohrmann, S. (2023). Adherence to the EAT-Lancet reference diet is associated with a reduced risk of incident cancer and all-cause mortality in UK adults. *One Earth*, 6(12), 1726–1734. <https://doi.org/10.1016/j.oneear.2023.11.002>
- Kassebaum, N. J., Jasrasaria, R., Naghavi, M., Wulf, S. K., Johns, N., Lozano, R., Regan, M., Weatherall, D., Chou, D. P., Eisele, T. P., Flaxman, S. R., Pullan, R. L., Brooker, S. J., & Murray, C. J. L. (2014). A systematic analysis of global anemia burden from 1990 to 2010. *Blood*, 123(5), 615–624. <https://doi.org/10.1182/blood-2013-06-508325>
- Kaufman, M., Nguyen, C., Shetty, M., Opezzo, M., Barrack, M., & Fredericson, M. (2023). Popular Dietary Trends' Impact on Athletic Performance: A Critical Analysis Review. *Nutrients*, 15(16), 3511. <https://doi.org/10.3390/nu15163511>
- Keller, M., Halkier, B., & Wilska, T. (2016). Policy and Governance for Sustainable Consumption at the Crossroads of Theories and Concepts. *Environmental Policy and Governance*, 26(2), Article 2. <https://doi.org/10.1002/eet.1702>
- Kendall, H., Brennan, M., Seal, C., Ladha, C., & Kuznesof, S. (2016). Behind the kitchen door: A novel mixed method approach for exploring the food provisioning practices of the older consumer. *Food Quality and Preference*, 53, 105–116. <https://doi.org/10.1016/j.foodqual.2016.06.005>
- Kershaw, P. (2017). *Social Learning Theory's Impact on Perceptions of Professional Athletes as Role Models*. ProQuest Dissertations Publishing.
- Kim, E.-Y., Ham, S.-K., Shigenaga, M. K., & Han, O. (2008). Bioactive Dietary Polyphenolic Compounds Reduce Nonheme Iron Transport across Human Intestinal Cell Monolayers. *The Journal of Nutrition*, 138(9), 1647–1651. <https://doi.org/10.1093/jn/138.9.1647>
- Kirkpatrick, S. (2024). Measurement Error in Dietary Assessment. In *Principles of Nutritional Assessment* (2nd ed., Vol. 2024). Oxford University Press. <http://files/45/books.html>
- Knez, E., Kadac-Czapska, K., & Grembecka, M. (2023). Effect of Fermentation on the Nutritional Quality of the Selected Vegetables and Legumes and Their Health Effects. *Life* (Basel, Switzerland), 13(3). <https://doi.org/10.3390/life13030655>
- Knuppel, A., Papier, K., Key, T. J., & Travis, R. C. (2019). EAT-Lancet score and major health outcomes: The EPIC-Oxford study. *The Lancet (British Edition)*, 394(10194), 213–214. [https://doi.org/10.1016/S0140-6736\(19\)31236-X](https://doi.org/10.1016/S0140-6736(19)31236-X)
- Koury, M. J., & Ponka, P. (2004). New insights into erythropoiesis: The roles of folate, vitamin B12, and iron. *Annual Review of Nutrition*, 24, 105–131. <https://doi.org/10.1146/annurev.nutr.24.012003.132306>
- Kuch, A. (2021). *Recreational Female CrossFit Athletes and Low Energy Availability*.
- Lacour, C., Seconda, L., Allès, B., Hercberg, S., Langevin, B., Pointereau, P., Lairon, D., Baudry, J., & Kesse-Guyot, E. (2018). Environmental Impacts of Plant-Based Diets: How Does Organic Food Consumption Contribute to Environmental Sustainability? *Frontiers in Nutrition* (Lausanne), 5, 8–8. <https://doi.org/10.3389/fnut.2018.00008>
- Lang, M. (2020). Consumer acceptance of blending plant-based ingredients into traditional meat-based foods: Evidence from the meat-mushroom blend. *Food Quality and Preference*, 79, 103758. <https://doi.org/10.1016/j.foodqual.2019.103758>
- Langmann, F., Ibsen, D. B., Tjønneland, A., Olsen, A., Overvad, K., & Dahm, C. C. (2023). Adherence to the EAT-Lancet diet is associated with a lower risk of type 2 diabetes: The

- Danish Diet, Cancer and Health cohort. *European Journal of Nutrition*, 62(3), 1493–1502. <https://doi.org/10.1007/s00394-023-03090-3>
- Lawless, H. T., & Heymann, H. (1999). Acceptance and Preference Testing. In H. T. Lawless & H. Heymann (Eds.), *Sensory Evaluation of Food: Principles and Practices* (pp. 430–479). Springer US. https://doi.org/10.1007/978-1-4615-7843-7_13
- Lee, S. K., & Kader, A. A. (2000). Preharvest and postharvest factors influencing vitamin C content of horticultural crops. *Postharvest Biology and Technology*, 20(3), 207–220. [https://doi.org/10.1016/S0925-5214\(00\)00133-2](https://doi.org/10.1016/S0925-5214(00)00133-2)
- Lemmens, E., De Brier, N., Spiers, K. M., Ryan, C., Garrevoet, J., Falkenberg, G., Goos, P., Smolders, E., & Delcour, J. A. (2018). The impact of steeping, germination and hydrothermal processing of wheat (*Triticum aestivum* L.) grains on phytate hydrolysis and the distribution, speciation and bio-accessibility of iron and zinc elements. *Food Chemistry*, 264, 367–376. <https://doi.org/10.1016/j.foodchem.2018.04.125>
- Leonard, U. M., Leydon, C. L., Arranz, E., & Kiely, M. E. (2024). Impact of consuming an environmentally protective diet on micronutrients: A systematic literature review. *The American Journal of Clinical Nutrition*. <https://doi.org/10.1016/j.ajcnut.2024.01.014>
- Leser, S. (2013). The 2013 FAO report on dietary protein quality evaluation in human nutrition: Recommendations and implications. *Nutrition Bulletin*, 38(4), 421–428. <https://doi.org/10.1111/nbu.12063>
- Lim, J. (2011). Hedonic scaling: A review of methods and theory. *Food Quality and Preference*, 22(8), 733–747. <https://doi.org/10.1016/j.foodqual.2011.05.008>
- Lim, S. H., Chin, N. L., Sulaiman, A., Tay, C. H., & Wong, T. H. (2022). Sensory Analysis for Cow Milk Product Development Using High Pressure Processing (HPP) in the Dairy Industry. *Food*, 11(9), 1233. <https://doi.org/10.3390/foods11091233>
- Livsmedelsverket. (2012). Riksmaten 2010–11: Livsmedels- och näringsintag bland vuxna i Sverige. Retrieved from https://www.livsmedelsverket.se/globalassets/matvanor-halsamiljo/kostradmatvanor/matvaneundersokningar/riksmaten_2010_20111.pdf
- Livsmedelsverket. (2013). Skolmältiden – en viktig del av en bra skola. Retrieved from <https://www.livsmedelsverket.se/om-oss/publikationer/broschyr/skolmaltiden-en-viktig-del-av-en-bra-skola> Livsmedelsverket.
- Livsmedelsverket. (2018). Bra måltider i skolan. Retrieved from <https://www.livsmedelsverket.se/globalassets/publikationsdatabas/broschyrer-foldrar/riktlinjer-for-maltider-i-skolan.pdf> Livsmedelsverket. (2018a).
- Livsmedelsverket. (2018). Riksmaten ungdom 2016-17: Näringsintag och näringsstatus bland ungdomar i Sverige (No. 23). Retrieved from <https://www.livsmedelsverket.se/globalassets/publikationsdatabas/rapporter/2018/2018-nr-23-riksmaten-ungdom-del-2-naringsintag-och-naringsstatus.pdf> (2018b)
- Livsmedelsverket. (2019). Nationella riktlinjer för måltider i skolan: Råd för förskoleklass, grundskola, gymnasieskola och fritidshem. Livsmedelsverket. <https://www.livsmedelsverket.se/globalassets/publikationsdatabas/broschyrer-foldrar/riktlinjer-for-maltider-i-skolan.pdf>
- Livsmedelsverket. (2022, May 24). Livsmedelsverkets livsmedelsdatabas version 2022-05-24. Sök Näringsinnehåll. <https://www7.slv.se/SokNaringsinnehall>
- Livsmedelsverket. (2024a, August 23). Kostråd - Livsmedelsverket; Livsmedelsverket. <https://www.livsmedelsverket.se/matvanor-halsa-miljo/kostrad>

- Livsmedelsverket. (2024b, December 5). Livsmedelsverkets livsmedelsdatabas version 2024-12-05. Sök Näringsinnehåll. <https://www7.slv.se/SokNaringsinnehall>
- Lozoff, B., Beard, J., Connor, J., Felt, B., Georgieff, M., & Schallert, T. (2006). Long-lasting neural and behavioral effects of iron deficiency in infancy. *Nutrition Reviews*, 64(5), S34–S43. <https://doi.org/10.1301/nr.2006.may.S34-S43>
- Lundmark, B. (2002). Kvalitet som utsaga och praktik: Kvalitetsaspekter med fokus på skolmåltiden i Sverige. Licentiatavhandling Uppsala : Uppsala universitet, 2002.
- Lynch, S., Dassenko, S., Cook, J., Juillerat, M., & Hurrell, R. (1994). Inhibitory effect of a soybean-protein-related moiety on iron absorption in humans. *The American Journal of Clinical Nutrition*, 60(4), 567–572. <https://doi.org/10.1093/ajcn/60.4.567>
- Ma, Q., Kim, E.-Y., Lindsay, E. A., & Han, O. (2011). Bioactive Dietary Polyphenols Inhibit Heme Iron Absorption in a Dose-Dependent Manner in Human Intestinal Caco-2 Cells. *Journal of Food Science*, 76(5), H143–H150. <https://doi.org/10.1111/j.1750-3841.2011.02184.x>
- Marangoni, F., Corsello, G., Cricelli, C., Ferrara, N., Ghiselli, A., Lucchin, L., & Poli, A. (2015). Role of poultry meat in a balanced diet aimed at maintaining health and wellbeing: An Italian consensus document. *Food & Nutrition Research*, 59.
- Marshall, M., & Umeå universitet. Institutionen för kultur och medier. (2016). Hållbarhet till middag : en etnologisk studie om hur miljövänligt ätande praktiseras i vardagslivet. Brutus Östlings bokförlag Symposion.
- Martorell, R. (2017). Improved nutrition in the first 1000 days and adult human capital and health. *American Journal of Human Biology*, 29(2), np-n/a. <https://doi.org/10.1002/ajhb.22952>
- Masset, G., Soler, L.-G., Vieux, F., & Darmon, N. (2014). Identifying sustainable foods: The relationship between environmental impact, nutritional quality, and prices of foods representative of the French diet. *Journal of the Academy of Nutrition and Dietetics*, 114(6), 862-870. <https://doi.org/10.1016/j.jand.2014.02.002>
- Mathisen, T. F., Heia, J., Raustøl, M., Sandeggen, M., Fjellestad, I., & Sundgot-Borgen, J. (2020). Physical health and symptoms of relative energy deficiency in female fitness athletes. *Scandinavian Journal of Medicine & Science in Sports*, 30(1), 135–147. <https://doi.org/10.1111/sms.13568>
- Mayer Labba, I.-C., Hoppe, M., Gramatkovski, E., Hjellström, M., Abdollahi, M., Undeland, I., Hulthén, L., & Sandberg, A.-S. (2022). Lower Non-Heme Iron Absorption in Healthy Females from Single Meals with Texturized Fava Bean Protein Compared to Beef and Cod Protein Meals: Two Single-Blinded Randomized Trials. *Nutrients*, 14(15). <https://doi.org/10.3390/nu14153162>
- Mayer-Labba, I.-C., Steinhausen, H., Almius, L., Bach Knudsen, K. E., & Sandberg, A.-S. (2022). Nutritional Composition and Estimated Iron and Zinc Bioavailability of Meat Substitutes Available on the Swedish Market. *Nutrients*, 14(19), 3903. <https://doi.org/10.3390/nu14193903>
- McCann, J. C., & Ames, B. N. (2007). An overview of evidence for a causal relation between iron deficiency during development and deficits in cognitive or behavioral function2. *The American Journal of Clinical Nutrition*, 85(4), 931–945. <https://doi.org/10.1093/ajcn/85.4.931>

- McCrickerd, K., & Forde, C. G. (2016). Sensory influences on food intake control: Moving beyond palatability. *Obesity Reviews*, 17(1), 18–29. <https://doi.org/10.1111/obr.12340>
- McEvoy, C. T., Temple, N., & Woodside, J. V. (2012). Vegetarian diets, low-meat diets and health: A review. *Public Health Nutrition*, 15(12), 2287–2294. <https://doi.org/10.1017/S1368980012000936>
- Mehmood, A., & Zeb, A. (2020). Effects of different cooking techniques on bioactive contents of leafy vegetables. *International Journal of Gastronomy and Food Science*. <https://api.semanticscholar.org/CorpusID:224869211>
- Melin, A., Tornberg, Å. B., Skouby, S., Møller, S., Faber, J., Sundgot-Borgen, J., & Sjödin, A. (2016). Low-energy density and high fiber intake are dietary concerns in female endurance athletes. *Scandinavian Journal of Medicine & Science in Sports*, 26(9), 1060–1071. <https://doi.org/10.1111/sms.12516>
- Mesías, M., Seiquer, I., & Navarro, M. P. (2013). Iron Nutrition in Adolescence. *Critical Reviews in Food Science and Nutrition*, 53(11), 1226–1237. <https://doi.org/10.1080/10408398.2011.564333>
- Meullenet, J.-F., Xiong, R., & Findlay, C. J. (2008). Multivariate and probabilistic analyses of sensory science problems. John Wiley & Sons.
- Meyer, N. L., Reguant-Closa, A., & Nemecek, T. (2020). Sustainable Diets for Athletes. *Current Nutrition Reports*, 9(3), 147–162. <https://doi.org/10.1007/s13668-020-00318-0>
- Micha, R., Wallace, S. K., & Mozaffarian, D. (2010). Red and processed meat consumption and risk of incident coronary heart disease, stroke, and diabetes mellitus: A systematic review and meta-analysis. *Circulation (New York, N.Y.)*, 121(21), 2271–2283. <https://doi.org/10.1161/CIRCULATIONAHA.109.924977>
- Upphandlingsmyndigheten. (n.d.). Miljömässigt hållbar upphandling. Retrieved November 20, 2022, from <https://www.upphandlingsmyndigheten.se/om-hallbar-upphandling/miljomassigt-hallbar-upphandling/>
- Miller, L., Krebs, N. F., & Hambidge, K. M. (2011). Mathematical model of iron absorption based on biochemistry of absorption. *The FASEB Journal*, 25, 607.18-607.18. https://doi.org/10.1096/fasebj.25.1_supplement.607.18
- Milman, N., Pedersen, A. N., Ovesen, L., & Schroll, M. (2004). Iron status in 358 apparently healthy 80-year-old Danish men and women: Relation to food composition and dietary and supplemental iron intake. *Annals of Hematology*, 83(7), 423–429. <https://doi.org/10.1007/s00277-003-0830-y>
- Milner, J., Green, R., Dangour, A. D., Haines, A., Chalabi, Z., Spadaro, J., Markandya, A., & Wilkinson, P. (2015). Health effects of adopting low greenhouse gas emission diets in the UK. *BMJ Open*, 5(4), e007364–e007364. <https://doi.org/10.1136/bmjopen-2014-007364>
- Morales, F., Montserrat-de la Paz, S., Leon, M. J., & Rivero-Pino, F. (2023). Effects of Malnutrition on the Immune System and Infection and the Role of Nutritional Strategies Regarding Improvements in Children's Health Status: A Literature Review. *Nutrients*, 16(1). <https://doi.org/10.3390/nu16010001>
- Morck, T., Lynch, S., & Cook, J. (1983). Inhibition of food iron absorption by coffee. *The American Journal of Clinical Nutrition*, 37(3), 416–420. <https://doi.org/10.1093/ajcn/37.3.416>

- Moretti, D. (2017). 39—Plant-Based Diets and Iron Status. In F. Mariotti (Ed.), *Vegetarian and Plant-Based Diets in Health and Disease Prevention* (pp. 715–727). Academic Press. <https://doi.org/10.1016/B978-0-12-803968-7.00039-3>
- Mozaffarian, D., & Rimm, E. B. (2006). Fish Intake, Contaminants, and Human Health: Evaluating the Risks and the Benefits. *JAMA : The Journal of the American Medical Association*, 296(15), 1885–1899. <https://doi.org/10.1001/jama.296.15.1885>
- Naturvårdsverket. (2022, February). Konsumtionsbaserade växthusgasutsläpp per person och år. <https://www.naturvardsverket.se/data-och-statistik/konsumtion/vaxthusgaser-konsumtionsbaserade-utslapp-per-person>
- Navas-Carretero, S., Pérez-Granados, A. M., Sarriá, B., Carbajal, A., Pedrosa, M. M., Roe, M. A., Fairweather-Tait, S. J., & Vaquero, M. P. (2008). Oily Fish Increases Iron Bioavailability of a Phytate Rich Meal in Young Iron Deficient Women. *Journal of the American College of Nutrition*, 27(1), 96–101. <https://doi.org/10.1080/07315724.2008.10719680>
- Ndiaye, N. F., Idohou-Dossou, N., Bürkli, S., Diouf, A., Loucoubar, C., Guiro, A. T., Zimmermann, M. B., Wade, S., & Moretti, D. (2020). Polyphenol-rich tea decreases iron absorption from fortified wheat bread in Senegalese mother–child pairs and bioavailability of ferrous fumarate is sharply lower in children. *European Journal of Clinical Nutrition*, 74(8), 1221–1228. <https://doi.org/10.1038/s41430-020-0601-z>
- Nelson, M., Zak, K., Davine, T., & Pau, S. (2016). Climate Change and Food Systems Research: Current Trends and Future Directions: Climate Change and Food Systems Research Review. *Geography Compass*, 10(10), 414–428. <https://doi.org/10.1111/gcc3.12281>
- Nemecek, T., Bengoa, X., Lansche, J., Roesch, A., Faist-Emmenegger, M., Rossi, V., Humbert, S., Mouron, P., & Riedener, E. (2019). World food LCA database. Methodological Guidelines for the Life Cycle Inventory of Agricultural Products, 3.
- Noll, M., De Mendonça, C. R., De Souza Rosa, L. P., & Silveira, E. A. (2017). Determinants of eating patterns and nutrient intake among adolescent athletes: A systematic review. *Nutrition Journal*, 16(1), 46–46. <https://doi.org/10.1186/s12937-017-0267-0>
- Nordic Council of Ministers. (2014). Nordic Nutrition Recommendations 2012: Integrating nutrition and physical activity. *Nord*, 627–627. https://doi.org/10.26530/OAPEN_483279
- Nyckelhälet. (n.d.). Retrieved 20 November 2022, from <https://www.livsmedelverket.se/livsmedel-och-innehall/text-pa-forpackning-markning/nyckelhalet>
- O'Malley, K., Willits-Smith, A., Aranda, R., Heller, M., & Rose, D. (2019). Vegan vs Paleo: Carbon Footprints and Diet Quality of 5 Popular Eating Patterns as Reported by US Consumers (P03-007-19). *Current Developments in Nutrition*, 3, Article Suppl 1. <https://doi.org/10.1093/cdn/nzz047.P03-007-19>
- O'Mara, F. P. (2011). The significance of livestock as a contributor to global greenhouse gas emissions today and in the near future. *Animal Feed Science and Technology*, 166–167, 7–15. <https://doi.org/10.1016/j.anifeedsci.2011.04.074>
- Onwuegbuzie, A. J., Johnson, R. B., & Collins, K. M. (2009). Call for mixed analysis: A philosophical framework for combining qualitative and quantitative approaches. *International Journal of Multiple Research Approaches*, 3(2), 114–139. <https://doi.org/10.5172/mra.3.2.114>

- Oussalah, A., Levy, J., Berthezène, C., Alpers, D. H., & Guéant, J.-L. (2020). Health outcomes associated with vegetarian diets: An umbrella review of systematic reviews and meta-analyses. *Clinical Nutrition (Edinburgh, Scotland)*, 39(11), 3283–3307. <https://doi.org/10.1016/j.clnu.2020.02.037>
- Pagès, J., Berthelo, S., Brossier, M., & Gourret, D. (2014). Statistical penalty analysis. "Sensometrics 2012: 'New Skin for the Old Ceremony'", 32, 16–23. <https://doi.org/10.1016/j.foodqual.2013.07.008>
- Pagliarini, E., Proserpio, C., Spinelli, S., Lavelli, V., Laureati, M., Arena, E., Di Monaco, R., Menghi, L., Gallina Toschi, T., Braghieri, A., Torri, L., Monteleone, E., & Dinnella, C. (2021). The role of sour and bitter perception in liking, familiarity and choice for phenol-rich plant-based foods. *Food Quality and Preference*, 93, 104250. <https://doi.org/10.1016/j.foodqual.2021.104250>
- Paolo, D., Bianchi, G., Morelli, C. F., Speranza, G., Campanelli, G., Kidmose, U., & Lo Scalzo, R. (2019). Impact of drying techniques, seasonal variation and organic growing on flavor compounds profiles in two Italian tomato varieties. *Food Chemistry*, 298, 125062. <https://doi.org/10.1016/j.foodchem.2019.125062>
- Patricha, S.-R., Tye-Din, J., Muckenthaler, M. U., & Swinkels, D. W. (2021). Iron deficiency. *The Lancet (British Edition)*, 397(10270), 233–248. [https://doi.org/10.1016/S0140-6736\(20\)32594-0](https://doi.org/10.1016/S0140-6736(20)32594-0)
- Passarelli S, Free CM, Shepon A, Beal T, Batis C, Golden CD. Global estimation of dietary micronutrient inadequacies: a modelling analysis. *The Lancet global health*. 2024;12(10):e1590–9.
- Passarelli, S., Free, C. M., Allen, L. H., Batis, C., Beal, T., Biloft-Jensen, A. P., Bromage, S., Cao, L., Castellanos-Gutiérrez, A., Christensen, T., Crispim, S. P., Dekkers, A., De Ridder, K., Kronsteiner-Gicevic, S., Lee, C., Li, Y., Moursi, M., Moyersoen, I., Schmidhuber, J., ... Golden, C. D. (2022). Estimating national and subnational nutrient intake distributions of global diets. *The American Journal of Clinical Nutrition*, 116(2), 551–560. <https://doi.org/10.1093/ajcn/nqac108>
- Patterson, E., Eustachio Colombo, P., Milner, J., Green, R., & Elinder, L. S. (2021). Potential health impact of increasing adoption of sustainable dietary practices in Sweden. *BMC Public Health*, 21(1), 1–1332. <https://doi.org/10.1186/s12889-021-11256-z>
- Pearson, T. R. H., Brown, S., Murray, L., & Sidman, G. (2017). Greenhouse gas emissions from tropical forest degradation: An underestimated source. *Carbon Balance and Management*, 12(1), 3. <https://doi.org/10.1186/s13021-017-0072-2>
- Peddie, M. C., Gale, J. T., Haszard, J. J., Scott, T., Ranasinghe, C., Heath, A. L. M., Gibson, R. S., & Houghton, L. A. (2023). Micronutrient status of New Zealand adolescent women consuming vegetarian and non-vegetarian diets. *Asia Pacific Journal of Clinical Nutrition*, 32(4), 434–443. [https://doi.org/10.6133/apjcn.202312_32\(4\).0008](https://doi.org/10.6133/apjcn.202312_32(4).0008)
- Perignon, M., Vieux, F., Soler, L.-G., Masset, G., & Darmon, N. (2017). Improving diet sustainability through evolution of food choices: Review of epidemiological studies on the environmental impact of diets. *Nutrition Reviews*, 75(1), 2–17. <https://doi.org/10.1093/nutrit/nuw043>
- Persson Osowski, C., & Fjellström, C. (2019). Understanding the ideology of the Swedish tax-paid school meal. *Health Education Journal*, 78(4), 388–398. <https://doi.org/10.1177/0017896918798421>

- Petry, N., Olofin, I., Hurrell, R. F., Boy, E., Wirth, J. P., Moursi, M., & et al. (2016). The proportion of anemia associated with iron deficiency in low, medium, and high human development index countries: A systematic analysis of national surveys. *Nutrients*, 8(11), 693. <https://doi.org/10.3390/nu8110693>
- Pettersson, J., Post, A., Elf, M., Wollmar, M., & Sjöberg, A. (2024). Meat substitutes in Swedish school meals: Nutritional quality, ingredients, and insights from meal planners. *International Journal of Food Sciences and Nutrition*, 75(7), 637–649. <https://doi.org/10.1080/09637486.2024.2395810>
- Phillips, K. M., Tarrago-Trani, M. T., McGinty, R. C., Rasor, A. S., Haytowitz, D. B., & Pehrsson, P. R. (2018). Seasonal variability of the vitamin C content of fresh fruits and vegetables in a local retail market. *Journal of the Science of Food and Agriculture*, 98(11), 4191–4204. <https://doi.org/10.1002/jsfa.8941>
- Piercy, K. L., Troiano, R. P., Ballard, R. M., Carlson, S. A., Fulton, J. E., Galuska, D. A., George, S. M., & Olson, R. D. (2018). The Physical Activity Guidelines for Americans. *JAMA: The Journal of the American Medical Association*, 320(19), 2020–2028. <https://doi.org/10.1001/jama.2018.14854>
- Piskin, E., Cianciosi, D., Gulec, S., Tomas, M., & Capanoglu, E. (2022). Iron Absorption: Factors, Limitations, and Improvement Methods. *ACS Omega*, 7(24), 20441–20456. <https://doi.org/10.1021/acsomega.2c01833>
- Poinsot, R., Vieux, F., Maillot, M., & Darmon, N. (2022). Number of meal components, nutritional guidelines, vegetarian meals, avoiding ruminant meat: What is the best trade-off for improving school meal sustainability? *European Journal of Nutrition*, 61(6), 3003–3018. <https://doi.org/10.1007/s00394-022-02868-1>
- Polak, R., Phillips, E. M., & Campbell, A. (2015). Legumes: Health benefits and culinary approaches to increase intake. *Clinical Diabetes*, 33(4), 198–205. <https://doi.org/10.2337/diaclin.33.4.198>
- Pontzer, H., Durazo-Arvizu, R., Dugas, L. R., Plange-Rhule, J., Bovet, P., Forrester, T. E., Lambert, E. V., Cooper, R. S., Schoeller, D. A., & Luke, A. (2016). Constrained Total Energy Expenditure and Metabolic Adaptation to Physical Activity in Adult Humans. *Current Biology*, 26(3), 410–417. <https://doi.org/10.1016/j.cub.2015.12.046>
- Potgieter, S. (2013). Sport nutrition: A review of the latest guidelines for exercise and sport nutrition from the American College of Sport Nutrition, the International Olympic Committee and the International Society for Sports Nutrition. *The South African Journal of Clinical Nutrition*, 26(1), Article 1. <https://doi.org/10.1080/16070658.2013.11734434>
- Profeta, A., Baune, M. C., Smetana, S., Broucke, K., Van Royen, G., Weiss, J., Heinz, V., & Terjung, N. (2020). Discrete choice analysis of consumer preferences for meathybrids—Findings from Germany and Belgium. *Foods*, 10(1), 71. <https://doi.org/10.3390/foods10010071>
- Qian, H., Zhu, X., Huang, S., Linquist, B., Kuzyakov, Y., Wassmann, R., Minamikawa, K., Martinez-Eixarch, M., Yan, X., Zhou, F., Sander, B. O., Zhang, W., Shang, Z., Zou, J., Zheng, X., Li, G., Liu, Z., Wang, S., Ding, Y., ... Jiang, Y. (2023). Greenhouse gas emissions and mitigation in rice agriculture. *Nature Reviews Earth & Environment*, 4(10), 716–732. <https://doi.org/10.1038/s43017-023-00482-1>
- Ran, Y., Cederberg, C., Jonell, M., Bergman, K., De Boer, I. J. M., Einarsson, R., Karlsson, J., Potter, H. K., Martín, M., Metson, G. S., Nemecek, T., Nicholas, K. A., Strand, Å., Tidåker, P., Van der Werf, H., Vanham, D., Van Zanten, H. H. E., Veronesi, F., & Rööfs, E. (2024).

- Environmental assessment of diets: Overview and guidance on indicator choice. *The Lancet. Planetary Health*, 8(3), e172–e187. [https://doi.org/10.1016/S2542-5196\(24\)00006-8](https://doi.org/10.1016/S2542-5196(24)00006-8)
- Reckwitz, A. (2002). Toward a Theory of Social Practices: A Development in Culturalist Theorizing. *European Journal of Social Theory*, 5(2), 243–263. <https://doi.org/10.1177/13684310222225432>
- Reddy, M. B. (2005). Algorithms to assess non-heme iron bioavailability. *International Journal for Vitamin and Nutrition Research*, 75(6), 405–412. <https://doi.org/10.1024/0300-9831.75.6.405>
- Reddy, N. R., & Sathe, S. K. (2001). *Food Phytates: Vol. 1 st Edition*. CRC Press.
- Reddy, R. N., Hurrell, R., Juillerat, M., & Cook, J. (1996). The influence of different protein sources on phytate inhibition of nonheme-iron absorption in humans. *The American Journal of Clinical Nutrition*, 63(2), 203–207. <https://doi.org/10.1093/ajcn/63.2.203>
- Richardson, K., Steffen, W., Lucht, W., Bendtsen, J., Cornell, S. E., Donges, J. F., Drüke, M., Fetzer, I., Bala, G., von Bloh, W., Feulner, G., Fiedler, S., Gerten, D., Gleeson, T., Hofmann, M., Huiskamp, W., Kummu, M., Mohan, C., Nogués-Bravo, D., ... Rockström, J. (2023). Earth beyond six of nine planetary boundaries. *Science Advances*, 9(37), eadh2458–eadh2458. <https://doi.org/10.1126/sciadv.adh2458>
- Richert, A. (2019). *Vego i världsklass: Hållbar mat för en aktiv livsstil*. Stockholm: Norstedts.
- Ridoutt, B. G., Hendrie, G. A., & Noakes, M. (2017). Dietary Strategies to Reduce Environmental Impact: A Critical Review of the Evidence Base. *Advances in Nutrition* (Bethesda, Md.), 8(6), 933–946. <https://doi.org/10.3945/an.117.016691>
- RISE food climate database | RISE. (n.d.). Retrieved 15 December 2024, from <https://www.ri.se/en/what-we-do/expertises/rise-food-climate-database>
- Rogerson, D. (2017). Vegan diets: Practical advice for athletes and exercisers. (Report). *Journal of the International Society of Sports Nutrition*, 14(1). <https://doi.org/10.1186/s12970-017-0192-9>
- Rööös, E., Sundberg, C., Tidåker, P., Strid, I., & Hansson, P.-A. (2013). Can carbon footprint serve as an indicator of the environmental impact of meat production? *Ecological Indicators*, 24, 573–581. <https://doi.org/10.1016/j.ecolind.2012.08.004>
- Rosenzweig, C., Mbow, C., Barioni, L. G., Benton, T. G., Herrero, M., Krishnapillai, M., Liwenga, E. T., Pradhan, P., Rivera-Ferre, M. G., Sapkota, T., Tubiello, F. N., Xu, Y., Mencos Contreras, E., & Portugal-Pereira, J. (2020). Climate change responses benefit from a global food system approach. *Nature Food*, 1(2), 94–97. <https://doi.org/10.1038/s43016-020-0031-z>
- Rothman, L. (2007). 17 – The use of just-about-right (JAR) scales in food product development and reformulation. <https://api.semanticscholar.org/CorpusID:166556533>
- Rothman, L., & Parker, M. (2009). *Just-about-right (JAR) scales*. West Conshohocken, PA: ASTM International.
- Så fungerar arbetet med Sveriges miljömål—Sveriges miljömål. (n.d.). Retrieved 20 November 2022, from <https://www.sverigesmiljomal.se/sa-fungerar-arbetet-med-sveriges-miljomal/>
- Saha, S., Nordström, J., Mattisson, I., Nilsson, P. M., & Gerdtham, U.-G. (2019). Modelling the Effect of Compliance with Nordic Nutrition Recommendations on Cardiovascular Disease

- and Cancer Mortality in the Nordic Countries. *Nutrients*, 11(6).
<https://doi.org/10.3390/nu11061434>
- Salomé, M., de Gavelle, E., Dufour, A., Dubuisson, C., Volatier, J.-L., Fouillet, H., Huneau, J.-F., & Mariotti, F. (2020). Plant-Protein Diversity Is Critical to Ensuring the Nutritional Adequacy of Diets When Replacing Animal With Plant Protein: Observed and Modeled Diets of French Adults (INCA3). *The Journal of Nutrition*, 150(3), 536–545.
<https://doi.org/10.1093/jn/nxz252>
- Sandberg, A.-S. (2002). Bioavailability of minerals in legumes. *British Journal of Nutrition*, 88(S3), 281–285. <https://doi.org/10.1079/BJN/2002718>
- Schanes, K., Giljum, S., & Hertwich, E. (2016). Low carbon lifestyles: A framework to structure consumption strategies and options to reduce carbon footprints. *Journal of Cleaner Production*, 139, 1033–1043. <https://doi.org/10.1016/j.jclepro.2016.08.154>
- Schatzki, T. R., Knorr-Cetina, K., & Savigny, E. von. (2001). *The practice turn in contemporary theory*. London: Routledge.
- Scheuermann, M., Wood, A., Gordon, L. J., Röös, E., & Schultz, L. (2024). Leverage points for increased grain legume consumption: A Swedish case study. *Renewable Agriculture and Food Systems*, 39, e27. Cambridge Core. <https://doi.org/10.1017/S1742170524000267>
- Schulze, M., Janssen, M., & Aschemann-Witzel, J. (2024). How to move the transition to sustainable food consumption towards a societal tipping point. *Technological Forecasting and Social Change*, 203, 123329. <https://doi.org/10.1016/j.techfore.2024.123329>
- Schüpbach, R., Wegmüller, R., Berguerand, C., Bui, M., & Herter-Aeberli, I. (2017). Micronutrient status and intake in omnivores, vegetarians and vegans in Switzerland. *European Journal of Nutrition*, 56(1), 283–293. <https://doi.org/10.1007/s00394-015-1079-7>
- Schwingshackl, L., Schwedhelm, C., Hoffmann, G., Lampousi, A. M., Knüppel, S., Iqbal, K., Bechthold, A., Schlesinger, S., & Boeing, H. (2017). Food groups and risk of all-cause mortality: A systematic review and meta-analysis of prospective studies. *The American Journal of Clinical Nutrition*, 105(6), 1462–1473. <https://doi.org/10.3945/ajcn.117.153148>
- Sejian, V., Lal, R., Lakritz, J., & Ezeji, T. (2011). Measurement and prediction of enteric methane emission. *International Journal of Biometeorology*, 55(1), 1–16.
<https://doi.org/10.1007/s00484-010-0356-7>
- Shabir, I., Dash, K. K., Dar, A. H., Pandey, V. K., Fayaz, U., Srivastava, S., & R, N. (2023). Carbon footprints evaluation for sustainable food processing system development: A comprehensive review. *Future Foods*, 7, 100215.
<https://doi.org/10.1016/j.fufo.2023.100215>
- Shameem, N., Yaseen Mir, M., & Parray, J. A. (2019). *Soil Health and Food Security* (pp. 271–299). Singapore: Springer. https://doi.org/10.1007/978-981-13-8840-8_6
- Sharp, P., & Srai, S. K. (2007). Molecular mechanisms involved in intestinal iron absorption. *World Journal of Gastroenterology: WJG*, 13(35), 4716–4724.
<https://doi.org/10.3748/wjg.v13.i35.4716>
- Shils, M. E. (2006). *Modern nutrition in health and disease* (10. ed.). Philadelphia, Pa. London : Lippincott Williams & Wilkins.
- Shove, E., Pantzar, M., & Watson, M. (2012). *The Dynamics of Social Practice: Everyday Life and How It Changes*. SAGE Publications Ltd.

- Sjöberg A, Hulthen L. Comparison of food habits, iron intake and iron status in adolescents before and after the withdrawal of the general iron fortification in Sweden. *European journal of clinical nutrition*. 2015;69(4):494–500.
- Skolmat. (n.d.). Retrieved 22 September 2024, from <https://skr.se/skr/skolakulturfrid/forskolagrundochgymnasieskolakomvux/elevhalsaskolmat/skolmat.2062.html>
- Smart, L. R., & Bisogni, C. A. (2001). Personal food systems of male college hockey players. *Appetite*, 37(1), Article 1. <https://doi.org/10.1006/appe.2001.0408>
- Sogari, G., Caputo, V., Joshua Petterson, A., Mora, C., & Boukid, F. (2023). A sensory study on consumer valuation for plant-based meat alternatives: What is liked and disliked the most? *Food Research International*, 169, 112813. <https://doi.org/10.1016/j.foodres.2023.112813>
- Song, J., Xia, Y., & Zhong, F. (2021). Consumers with high frequency of ‘just about right’ in JAR scales may use lower cognitive effort: Evidence from the concurrent 9-point hedonic scale and CATA question. *Food Research International*, 143, 110285–110285. <https://doi.org/10.1016/j.foodres.2021.110285>
- Sørensen, L. B., Møller, P., Flint, A., Martens, M., & Raben, A. (2003). Effect of sensory perception of foods on appetite and food intake: A review of studies on humans. *International Journal of Obesity*, 27(10), 1152–1166. <https://doi.org/10.1038/sj.ijo.0802391>
- Souza, M., Sena, M., & Junior, V. C. (2020). Resting Energy Expenditure In Crossfit® Practitioners: Indirect Calorimetry Versus Predictive Equations: 3950 Board #267 May 30 9:00 AM - 10:30 AM. *Medicine and Science in Sports and Exercise*, 52(7 Suppl), 1089–1090. <https://doi.org/10.1249/01.mss.0000687512.79185.8c>
- Stanley, P. L., Rowntree, J. E., Beede, D. K., DeLonge, M. S., & Hamm, M. W. (2018). Impacts of soil carbon sequestration on life cycle greenhouse gas emissions in Midwestern USA beef finishing systems. *Agricultural Systems*, 162, 249–258. <https://doi.org/10.1016/j.agsy.2018.02.003>
- Stevens, G. A., Beal, T., Mbuya, M. N. N., Luo, H., Neufeld, L. M., Addo, O. Y., Adu-Afarwuah, S., Alayón, S., Bhutta, Z., Brown, K. H., Jefferds, M. E., Engle-Stone, R., Fawzi, W., Hess, S. Y., Johnston, R., Katz, J., Krasevec, J., McDonald, C. M., Mei, Z., ... Young, M. F. (2022). Micronutrient deficiencies among preschool-aged children and women of reproductive age worldwide: A pooled analysis of individual-level data from population-representative surveys. *The Lancet Global Health*, 10(11), e1590–e1599. [https://doi.org/10.1016/S2214-109X\(22\)00367-9](https://doi.org/10.1016/S2214-109X(22)00367-9)
- Stubbendorff, A., Sonestedt, E., Ramne, S., Drake, I., Hallström, E., & Ericson, U. (2022). Development of an EAT-Lancet index and its relation to mortality in a Swedish population. *The American Journal of Clinical Nutrition*, 115(3), 705–716. <https://doi.org/10.1093/ajcn/nqab369>
- Stubbendorff, A., Borgström Bolmsjö, B., Bejersten, T., Warensjö Lemming, E., Calling, S., & Wolff, M. (2025). Iron insight: Exploring dietary patterns and iron deficiency among teenage girls in Sweden. *European Journal of Nutrition*, 64(3), 107. <https://doi.org/10.1007/s00394-025-03630-z>
- Styhre, A. (2024). *The value of theorizing: How new theory matters in research work and university governance practice*. Northampton: Edward Elgar Publishing.

- Sundgot-Borgen, J., & Torstveit, M. K. (2010). Aspects of disordered eating continuum in elite high-intensity sports. *Scandinavian Journal of Medicine & Science in Sports*, 20(s2), 112–121. <https://doi.org/10.1111/j.1600-0838.2010.01190.x>
- Sundin, N., Malefors, C., Danielsson, M., Hardiyanti, M., Persson Osowski, C., & Eriksson, M. (2023). Investigating goal conflicts in menu planning in Swedish school catering on the pathway to sustainable development. *Resources, Conservation and Recycling*, 190, 106822. <https://doi.org/10.1016/j.resconrec.2022.106822>
- Swedish Food Agency. (2022). Fakta om offentliga måltider 2021: Kartläggning av måltider i kommunalt drivna förskolor, skolor och omsorgsverksamheter. Swedish Food Agency. <https://www.livsmedelsverket.se/globalassets/publikationsdatabas/rapporter/2022/1-2022-nr-01-fakta-om-offentliga-maltider-2021.pdf>
- Swedish Food Agency. (2024, October 24). The Swedish Food Composition Database. <https://www.livsmedelsverket.se/en/food-and-content/naringsamnen/livsmedelsdatabasen>
- Swedish Parliament. (2010). Skollag (2010:800) Svensk författningssamling 2010:2010:800 TO.M. SFS 2022:275. Riksdagen. https://www.riksdagen.se/sv/dokument-lagar/dokument/svensk-forfattningssamling/skollag-2010800_sfs-2010-800
- Swedish Research Council. (2017). Good Research Practice. <https://www.vr.se/english/analysis/reports/our-reports/2017-08-31-good-research-practice.html>
- Szenderák, J., Fróna, D., & Rákos, M. (2022). Consumer Acceptance of Plant-Based Meat Substitutes: A Narrative Review. *Foods (Basel, Switzerland)*, 11(9). <https://doi.org/10.3390/foods11091274>
- Tanner, C., & Wölfling Kast, S. (2003). Promoting sustainable consumption: Determinants of green purchases by Swiss consumers. *Psychology & Marketing*, 20(10), 883–902. <https://doi.org/10.1002/mar.10101>
- Tchonkouang, R. D., Onyeka, H., & Nkoutchou, H. (2024). Assessing the vulnerability of food supply chains to climate change-induced disruptions. *Science of The Total Environment*, 920, 171047. <https://doi.org/10.1016/j.scitotenv.2024.171047>
- Teague, R., Provenza, F., Norton, B., Steffens, T., Barnes, M., Kothmann, M., & Roath, R. (2008). Benefits of multi-paddock grazing management on rangelands: Limitations of experimental grazing research and knowledge gaps. *Grasslands: Ecology, Management and Restoration*. Hauppauge, NY, USA: Nova Science Publishers, 41–80.
- ten Haaf, T. P. G., & Weijs, P. J. M. (2014). Resting Energy Expenditure Prediction in Recreational Athletes of 18-35 Years: Confirmation of Cunningham Equation and an Improved Weight-Based Alternative. *PloS One*, 9(10), e108460–e108460. <https://doi.org/10.1371/journal.pone.0108460>
- Thomas, D. T., Erdman, K. A., & Burke, L. M. (2016). Position of the Academy of Nutrition and Dietetics, Dietitians of Canada, and the American College of Sports Medicine: Nutrition and Athletic Performance. *Journal of the Academy of Nutrition and Dietetics*, 116(3), 501–528. <https://doi.org/10.1016/j.jand.2015.12.006>
- Thurecht, R., & Pelly, F. (2020). Key Factors Influencing the Food Choices of Athletes at two Distinct Major International Competitions. *Nutrients*, 12(4). <https://doi.org/10.3390/nu12040924>

- Torpman, O., & Rööös, E. (2024). Are Animals Needed for Food Supply, Efficient Resource Use, and Sustainable Cropping Systems? An Argumentation Analysis Regarding Livestock Farming. *Food Ethics*, 9(2). <https://doi.org/10.1007/s41055-024-00147-9>
- Tribst, A. A. L., Falcade, L. T. P., Carvalho, N. S., Leite Júnior, B. R. de C., & Oliveira, M. M. de. (2020). Are stirring and homogenisation processes capable of improving physicochemical and sensory characteristics of stirred yoghurt produced with fresh, refrigerated and frozen/thawed sheep milk? *International Dairy Journal*, 109, 104778. <https://doi.org/10.1016/j.idairyj.2020.104778>
- Trotti, L. M., Becker, L. A., & Trotti, L. M. (2019). Iron for the treatment of restless legs syndrome. *Cochrane Database of Systematic Reviews*, 2019(1), CD007834. <https://doi.org/10.1002/14651858.CD007834.pub3>
- Tubiello, F. N., Rosenzweig, C., Conchedda, G., Karl, K., Gütschow, J., Xueyao, P., Oblit-Laryea, G., Wanner, N., Qiu, S. Y., Barros, J. D., Flammini, A., Mencos-Contreras, E., Souza, L., Quadrelli, R., Heiðarsdóttir, H. H., Benoit, P., Hayek, M., & Sandalow, D. (2021). Greenhouse gas emissions from food systems: Building the evidence base. *Environmental Research Letters*, 16(6), 65007. <https://doi.org/10.1088/1748-9326/ac018e>
- UN General Assembly. (2015). United Nations, 2015. Transforming our world: The 2030 agenda for sustainable development. In: *Proceedings of the General Assembly 70 Session 15–23 December 2015*. (No. A/RES/70/1; Issue A/RES/70/1). UN General Assembly.
- van Dooren, C., Aiking, H., & Vellinga, P. (2018). In search of indicators to assess the environmental impact of diets. *The International Journal of Life Cycle Assessment*, 23(6), 1297–1314. <https://doi.org/10.1007/s11367-017-1371-2>
- Vandevijvere, S., Michels, N., Verstraete, S., Ferrari, M., Leclercq, C., Cuenca-García, M., Grammatikaki, E., Manios, Y., Gottrand, F., Valtuena, J., Kersting, M., Gonzalez-Gross, M., Moreno, L., Mouratidou, T., Stevens, K., Meirhaeghe, A., Dallongeville, J., Sjoestrom, M., Hallstrom, L., ... Huybrechts, I. (2013). Intake and dietary sources of haem and non-haem iron among European adolescents and their association with iron status and different lifestyle and socio-economic factors (vol 67, pg 765, 2013). *European Journal of Clinical Nutrition*, 67(11), 1227–1227. <https://doi.org/10.1038/ejcn.2013.189>
- Vieux, F., PhD, Dubois, C., PhD, Allegre, L., RD, Mandon, L., MSc, Ciantar, L., MSc, & Darmon, N., PhD. (2013). Dietary Standards for School Catering in France: Serving Moderate Quantities to Improve Dietary Quality Without Increasing the Food-related Cost of Meals. *Journal of Nutrition Education and Behavior*, 45(6), 533–539. <https://doi.org/10.1016/j.jneb.2013.02.004>
- Vigiliouk, E., Blanco Mejia, S., Kendall, C. W. C., & Sievenpiper, J. L. (2017). Can pulses play a role in improving cardiometabolic health? Evidence from systematic reviews and meta-analyses. *Annals of the New York Academy of Sciences*, 1392(1), 43–57. <https://doi.org/10.1111/nyas.13312>
- Villanueva, N. D. M., & Da Silva, M. A. A. P. (2009). Comparative performance of the nine-point hedonic, hybrid and self-adjusting scales in the generation of internal preference maps. *Food Quality and Preference*, 20(1), 1–12. <https://doi.org/10.1016/j.foodqual.2008.06.003>
- Wahced-Uz-zaman, Akram, M., & Rehman, R. (2013). Effect of temperature variations during cooking and storage on ascorbic acid contents of vegetables: A comparative study. *Journal of the Chemical Society of Pakistan*, 35(1), 1–4.

- Walczyk, T., Muthayya, S., Wegmüller, R., Thankachan, P., Sierksma, A., Frenken, L. G. J., Thomas, T., Kurpad, A., & Hurrell, R. F. (2014). Inhibition of Iron Absorption by Calcium Is Modest in an Iron-Fortified, Casein- and Whey-Based Drink in Indian Children and Is Easily Compensated for by Addition of Ascorbic Acid^{1,2}. *The Journal of Nutrition*, 144(11), 1703.
- Warde, A. (2005). Consumption and Theories of Practice. *Journal of Consumer Culture*, 5(2), Article 2. <https://doi.org/10.1177/1469540505053090>
- Warde, A. (2014). After taste: Culture, consumption and theories of practice. *Journal of Consumer Culture*, 14(3), Article 3. <https://doi.org/10.1177/1469540514547828>
- Warde, A. (2016). *The practice of eating*. Cambridge: Polity Press.
- Warde, A. (2017). *Consumption: A sociological analysis*. Basingstok: Palgrave Macmillan.
- Weidema, B. P., Wesnæs, M., Hermansen, J., Kristensen, T., Halberg, N., Eder, P., & Delgado, L. (2008). Environmental improvement potentials of meat and dairy products. European Commission–Joint Research Centre–Institute for Prospective Technological Studies, Luxembourg: Office for Official Publications of the European Communities.
- Westling, M., Wennström, S., & Öström, Å. (2021). A recipe development process model designed to support a crop's sensory qualities. *International Journal of Food Design*, 6(1), 3–26. https://doi.org/10.1386/ijfd_00022_1
- Westling, M., Wennström, S., & Öström, Å. (2022). Public meals as a platform for culinary action? Tweens' and teens' acceptance of a new plant-based food. *International Journal of Gastronomy and Food Science*, 27, 100485. <https://doi.org/10.1016/j.ijgfs.2022.100485>
- Wickramasinghe, K., Breda, J., Berdzuli, N., Rippin, H., Farrand, C., & Halloran, A. (2021). The shift to plant-based diets: Are we missing the point? *Global Food Security*, 29, 100530. <https://doi.org/10.1016/j.gfs.2021.100530>
- Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., Jonell, M., Clark, M., Gordon, L. J., Fanzo, J., Hawkes, C., Zurayk, R., Rivera, J. A., De Vries, W., Majele Sibanda, L., ... Murray, C. J. L. (2019). Food in the Anthropocene: The EAT–Lancet Commission on healthy diets from sustainable food systems. *The Lancet*, 393(10170), 447–492. [https://doi.org/10.1016/S0140-6736\(18\)31788-4](https://doi.org/10.1016/S0140-6736(18)31788-4)
- Wollmar, M., Post, A., & Sjöberg, A. (2024). Food choice, activity level, and carbon footprint: Exploring potential for sustainable food consumption practices in young adults. *Frontiers in Nutrition (Lausanne)*, 11, 1449054. <https://doi.org/10.3389/fnut.2024.1449054>
- Wollmar, M., Sjöberg, A., & Post, A. (2022). Swedish recreational athletes as subjects for sustainable food consumption: Focus on performance and sustainability. *International Journal of Food Sciences and Nutrition*, 1–13. <https://doi.org/10.1080/09637486.2022.2141208>
- World Health Organization. (2017). Nutritional anaemias: Tools for effective prevention and control. WHO. <https://apps.who.int/iris/handle/10665/25942>
- World Medical Association. (1964). Declaration of Helsinki. <https://www.wma.net/policies-post/wma-declaration-of-helsinki-ethical-principles-for-medical-research-involving-human-subjects/>
- Zhang, L., Misir, A., Boshuizen, H., & Ocké, M. (2021). A Systematic Review and Meta-Analysis of Validation Studies Performed on Dietary Record Apps. *Advances in Nutrition (Bethesda, Md.)*, 12(6), 2321–2332. <https://doi.org/10.1093/advances/nmab058>

Zhang, S., Dukuzimana, J., Stubbendorff, A., Ericson, U., Borné, Y., & Sonestedt, E. (2023). Adherence to the EAT-Lancet diet and risk of coronary events in the Malmö Diet and Cancer cohort study. *The American Journal of Clinical Nutrition*, 117(5), 903–909. <https://doi.org/10.1016/j.ajcnut.2023.02.018>

Zhi, R., Zhao, L., & Shi, J. (2016). Improving the sensory quality of flavored liquid milk by engaging sensory analysis and consumer preference. *Journal of Dairy Science*, 99(7), 5305–5317. <https://doi.org/10.3168/jds.2015-10612>

This thesis examines climate-adapted food consumption through four studies balancing carbon footprint reduction with nutrition. This thesis reveals three key themes: school meals as climate champions, gender's role in sustainable food practices, and relationships between physical activity and carbon footprint.

The journey toward climate-adapted eating reveals a paradox: as our meals become kinder to the planet, they may deprive our bodies of essential nutrients. This research uncovers how school meals—potential climate champions in our food system—struggled to deliver sufficient iron when focused solely on reducing carbon footprint, particularly affecting adolescent girls. Women stand at the frontlines of this shift—initiating sustainable practices in their households while simultaneously facing the greatest nutritional risks. Even among athletes, where protein-rich diets typically drive-up carbon footprints, some pioneers demonstrate that performance and climate-consciousness can coexist through thoughtful food choices. This thesis challenges us to move beyond simplistic “eat less meat” narratives toward a more nuanced approach that honors both environmental goals and human wellbeing, recognizing that the path to truly sustainable eating must nourish both people and planet.



Mari Wollmar is a dietitian and a food and nutrition scientist with expertise in iron bioavailability and carbon footprint calculations.

