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EXAMINING SUSTAINABLE DIETS FOR PLANETARY HEALTH: A MIXED METHODS STUDY OF SUSTAINABLE DIETS KNOWLEDGE CREATION, REPRODUCTION, AND RECOMMENDATIONS

A Dissertation Presented

by

Carolyn Hricko

to

The Faculty of the Graduate College

of

The University of Vermont

In Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy
Specializing in Food Systems

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ABSTRACT

Food systems are a vital component of planetary health, or the inextricably linked health of humans and the environment, with the capacity to both threaten and support all dimensions of sustainability. Sustainable diets are recognized as both a driver and outcome of a sustainable food system needed to support the well-being of people and the planet. Although attention to sustainable diets as both a lever for change and result of complex food system dynamics is growing both within academia and beyond, there have been limited efforts to comprehensively review and synthesize the evolution and current state of sustainable diets research. Similarly, few studies have systematically examined how and what kinds of sustainable diets research is created, reproduced, and recommended for future study and food systems change. This comprehensive understanding of sustainable diets knowledge is essential in determining whether and how this research acknowledges and accounts for the full suite of sustainability dimensions and broader food systems dynamics. It is critical in accurately and thoroughly assessing system trade-offs and designing just, effective strategies for a sustainable food system transformation. Without it, research and solutions run the risk of inhibiting and contradicting planetary health goals. This three article mixed methods dissertation aims to address these gaps in knowledge and analysis through a thematic scoping review, bibliometric and altmetric analysis, and content analysis.

Each chapter in this dissertation builds layers of detail and depth to our understanding of sustainable diets research and its implications for future study and food systems change. The first chapter presents a thematic scoping review of sustainable diets literature. This chapter uses topic modeling, a natural language processing method, to identify research gaps, trends, and themes over time and across disciplines, and examines how these themes align with components of sustainable diets described by the Food and Agriculture Organization of the United Nations. Chapter 2 studies how the literature considered in the thematic scoping review is created and reproduced. Drawing from the mutual aims of science of science and research impact evaluation, it examines the practice of science through a citation and altmetric analysis and evaluation of whether and how research characteristics and indicators of power are linked with impact metrics. Chapter 3 takes a closer look at the objectives and recommendations of the most highly cited sustainable diets literature through a content analysis. It also reviews how the literature aligns with upstream and downstream food system influences as described by the Food Systems Dashboard's Food Systems Framework to identify strengths and gaps in the research. The dissertation concludes with a summary of the findings and a critique of the ability of sustainable diets research to adequately address systems trade-offs necessary to designing solutions for a sustainable food system.

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DEDICATION

To Michael, thank you for your steadfast patience, optimism, and humor in this journey. It was only possible because of you. To my daughters, may this work contribute to a more livable future and my effort serve both as an inspiration for what determination can accomplish and a lesson in discerning when it is not sufficient. And to my mother and father, thank you for teaching me to love wild things, to care for others, to be curious in the world, and to question authority (whether or not that was intentional).

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INTRODUCTION

1.1 Overview of Sustainable Diets

The world is currently facing multiple and escalating threats to human health and the natural systems on which we depend. Advancements in human technology, improvements in health, and economic and development gains have come at the cost of future generations' ability to survive and flourish as we have been exploiting nature's resources at an unsustainable rate (Whitmee et al., 2015). Rapidly accelerating growth in the global population, pollution, and resource use since the 1950's has led us to the brink of numerous environmental tipping points that not only threaten human progress, but the ability of the planet to sustain life and our survival (Mago et al., 2024). Planetary health, a concept that has gained traction since it was proposed in 2015 by The Rockefeller Foundation-Lancet Commission, recognizes the inextricable link between the health of humans and the environment (Whitmee et al., 2015). The Planetary Health Alliance describes the concept as "a solutions-oriented, transdisciplinary field and social movement focused on analyzing and addressing the impacts of human disruptions to Earth's natural systems on human health and all life on Earth," (*Planetary Health Alliance*, 2024).

Food systems are recognized as an essential component of planetary health, with the power to both support and threaten all social, economic, and environmental dimensions of sustainability (Fan et al., 2021; Global Panel on Agriculture and Food Systems for Nutrition, 2020; IFPRI, 2020). The Food and Agriculture Organization of the United Nations (FAO) has identified a sustainable food system as one that "delivers food security and nutrition for all in such a way that the economic, social and environmental bases to

generate food security and nutrition for future generations are not compromised," (FAO, 2018). Research suggests that achieving sustainable food systems is necessary if sustainability, development, and planetary health goals are to be realized (Fan et al., 2021; Fanzo & Miachon, 2023; Willett et al., 2019).

The Food Systems Dashboard is one recent effort to describe and synthesize research on sustainable food systems and create actionable frameworks and guidelines to inform policies and interventions. First launched in 2020, this effort is led and supported by multisectoral collaborators, including universities, non-profits, research institutes, advocacy organizations, foundations, and international organizations (*About the Food Systems Dashboard*, 2024). Part of this effort to "bring together country-level data across all components of the food system and provide deeper analysis and guidance on how to use this data in meaningful ways" is the development of a Food Systems Framework (Figure 1, below) (*Food Systems Dashboard*, 2024). This Framework was adapted from the High-Level Panel of Experts on Food Security and Nutrition's conceptual framework in the 2017 Nutrition and Food Systems report (HLPE, 2017). It serves to visually define and describe the interrelated drivers, outcomes, and components of food systems.

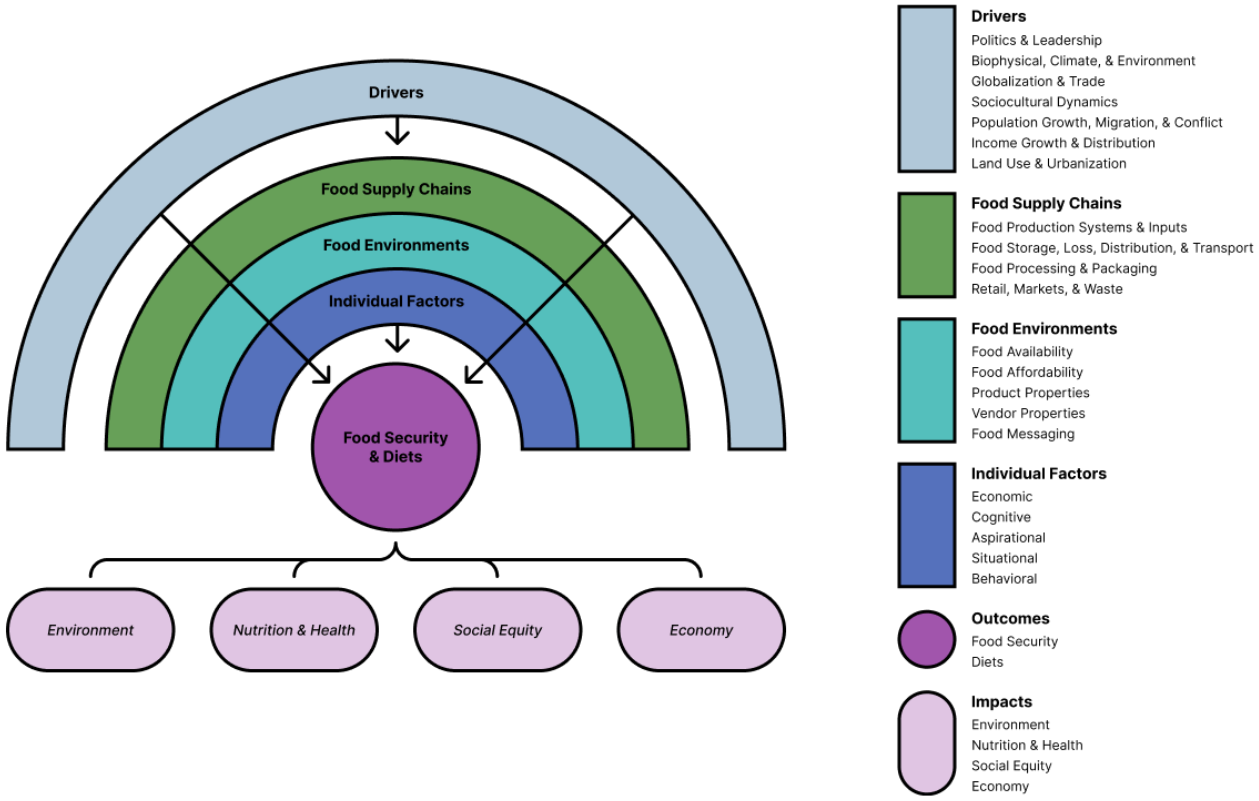

Figure 0-1. Food Systems Framework developed by the Food Systems Dashboard (used with permission, The Food Systems Dashboard, 2023).

Diets, or the totality of all foods eaten by individuals, create demand pressure on the food system and can therefore both influence food security and nutrition and be an outcome of the system (Meybeck & Gitz, 2017). Identifying what constitutes a sustainable diet has thus become a focus of the sustainable food system concept and research. The FAO defines sustainable diets as those "with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and

healthy; while optimizing natural and human resources," (Burlingame & Dernini, 2012). In 2010, the FAO and Bioversity International hosted the International Scientific Symposium "Biodiversity and Sustainable Diets: United Against Hunger" as part of World Food Day/Week. This event culminated in a book presenting what was then the current state of thought on sustainable diets and biodiversity. Included in this book is a schematic representation of the six key components of sustainable diets, depicted in Figure 2 below, which account for health, environment and biodiversity, equity, culture, and nutrition (Burlingame & Dernini, 2012).

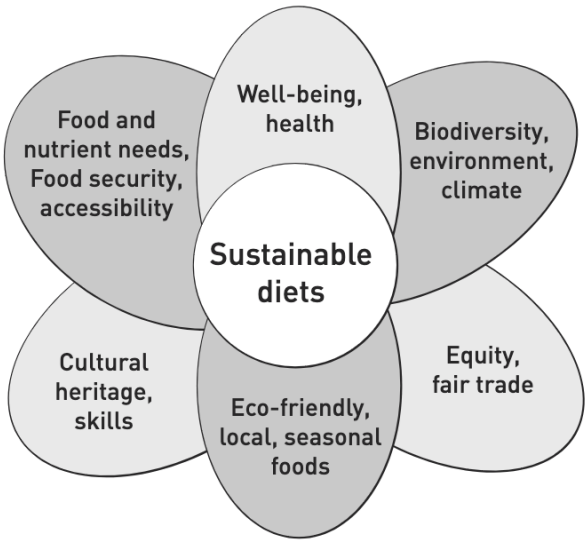

Figure 0-2. Schematic depiction of the components of a sustainable diet (Burlingame & Dernini, 2012). Source: Food and Agriculture Organization of the United Nations. Reproduced with permission.

Sustainable diets research has indeed addressed many of these components. For example, research over the last several decades has investigated environmental impacts of dietary patterns. Earlier studies focused largely climate impacts and greenhouse gas

emissions (e.g., Hedenus et al., 2014; Nelson et al., 2016; Popp et al., 2010; Stehfest et al., 2009), with more recent studies considering a broader set of environmental indicators, including land and energy use, water use and impacts, and biodiversity (e.g., Kozicka et al., 2023; Willett et al., 2019). More recent research has also expanded to include additional components of sustainable diets, such as food security and nutrition (e.g., Fanzo et al., 2022; Springmann, Wiebe, et al., 2018), economic considerations (e.g.., Baudry et al., 2023; Fan et al., 2021), and cultural factors (e.g., Monterrosa et al., 2020).

Numerous systematic reviews have been conducted to identify, appraise, and synthesize the growing number of sustainable diets studies using rigorous, comprehensive search and analysis protocols (Uman, 2011). The findings of these reviews support the conclusion that dietary patterns that limit or eliminate animal-based foods and emphasize plant-based foods can support improved health outcomes and alleviate environmental impacts of food production. Chai et al. (2019), for example, found that a vegan dietary pattern optimally minimized a range of environmental impacts, such as greenhouse gas emissions and water and land use footprints. Several additional recent systematic reviews highlight the important role plant-based foods play in human health. For example, consumption of diets high in plant-based foods is associated with reduced cardiovascular disease and mortality (Quek et al., 2021), reduced blood pressure (Tomé-Carneiro & Visioli, 2023), and greater emotional and physical well-being, including decreased depression, higher quality of life, and improved weight and diabetes management (Toumpanakis et al., 2018).

Plant-based dietary patterns are often considered an essential and necessary component of sustainable diets based on the improved health outcomes and lower environmental footprints associated with plant-based dietary shifts (FAO & WHO, 2019; Sabaté & Soret, 2014). However, despite the overlaps between the two, it is important to distinguish between plant-based diets and sustainable diets and recognize that they are not synonymous. For example, not all diets that emphasize plant-based foods and minimize or eliminate animal-based foods are sustainable. Prioritizing consumption of plant-based foods does not ensure that other critical sustainability criteria are considered or met. These include factors such as nutritional adequacy, food accessibility and affordability, and cultural acceptability as well as aspects of food production, such as food waste and fair labor practices (Fanzo et al., 2012; WHO, 2021).

Furthermore, an important nuance in the relationship between the consumption of plant-based diets and health outcomes is the composition of the diet. A 2023 cohort study of over 100,000 participants, for example, found that while adherence to healthful plant-based diets (those with lower amounts of sugary drinks, snacks, desserts, refined grains, potatoes, and fruit juices) was associated with lower rates of mortality, cancer, and CVD and lower risks of myocardial infarction and ischemic stroke, unhealthful plant-based diets (those with higher amounts of the aforementioned food types) were associated with higher risks of mortality, CVD, and cancer (Thompson et al., 2023). A 2021 review describes the emergence, growth, and increasing consumption of highly processed plant-based food products that are high in fat, energy, sugar, and salt and have higher environmental footprints than minimally processed counterparts. While these highly processed options

address the desire and need for convenient, affordable plant-based food options, the author cautions that over dependence on these options may contradict the health and environmental benefits of reducing animal-based food consumption (Macdiarmid, 2021).

In addition, focusing on plant-based dietary shifts alone may overlook the contributions and benefits of animal agriculture for both health and the environment. The need for this recognition, alongside the need for moderation and targeted reductions, is reflected in a 2023 review that highlights the importance of animal-based foods in achieving nutrition security, particularly for populations in Sub-Saharan Africa and South Asia. This review also acknowledges the important role animal-based foods can have in circular and diverse agroecosystems that can, when produced at the appropriate scale and in harmony with local ecosystems, support biodiversity, land restoration, and greenhouse gas mitigation (Beal et al., 2023). Additional research highlights how well-managed animal agriculture and animal-based food consumption can be environmentally sustainable, play an important role in achieving food security, and have cultural, societal, and economic significance (Leroy et al., 2022). This research also acknowledges the need for moderation given associations between high consumption of red meat with various chronic diseases and the need to mitigate impacts of animal agriculture, including overgrazing, deforestation, intensive cropping, and water pollution. Research also recognizes that a multipronged approach will be necessary to support healthy, sustainable food systems and remain within environmental limits. In addition to the adoption of plant-based diets, research suggests strategies such as reducing food loss and waste and increasing

agricultural efficiency through management and technological improvements (Springmann, Clark, et al., 2018; Willett et al., 2019).

There have been efforts to comprehensively summarize sustainable diets research, such as through the systematic reviews of plant-based diets highlighted above. Although they are thorough, they are narrowly focused by design and examine a small subset of outcomes and impacts of dietary patterns. There is little work to holistically examine the full body of sustainable diets literature across disciplines, time, and against systems-oriented frameworks for food systems and sustainable diets, such as in Figures 1 and 2. The need for this comprehensive understanding and analysis is highlighted by earlier work, such as that by Garnett (2013), who argues for integrated, systems-oriented approaches to research and policy to account for many perspectives and successfully avoid favoring one at the expense of others. In a more recent editorial, Schwarz and colleagues make the case for the necessity of transdisciplinary approaches to research and a sustainable food system transformation to develop effect solutions that address inequality and the marginalization of people and places (Schwarz et al., 2021).

The need for a holistic examination of sustainable diets research is also timely, as the field continues to grow and is increasingly capturing attention beyond academia. This is evident in the advisory reports focused on sustainable diets (e.g., IPES-Food, 2023; Meridian Institute, 2015) and in attention from organizations ranging from financial institutions to foundations (e.g., Rockefeller Foundation, 2020; World Bank, 2023). Sustainable diets have also been incorporated into national policies, such as dietary guidelines in Brazil and Sweden (FAO, 2024) and food procurement reforms (Swensson

& Tartanac, 2020). Sustainable diets are increasingly visible in media and consumer facing initiatives as well, such as with articles in popular health and wellness outlets (Mayer, 2023; Johnson & Holland, 2019), at-home meal kit advertising (*Hungryroot*, 2024), and behavior change campaigns such as Meatless Monday (*About Meatless Monday*, n.d.).

This translation of research to arenas beyond academia highlights a central premise of this doctoral work, which is that sustainable diets research matters because it contributes to a knowledge base that can influence policy and behavior with consequences for human and environmental health. This research can be used to develop and advance solutions for pressing planetary health challenges, yet research is not always informed by relevant policy questions, nor are policies with planetary health consequences necessarily based on scientific evidence (Posner & Cvitanovic, 2019). There is increasing interest, particularly in environmental fields, for research to have impact and for improved knowledge exchange between scientists and policy communities (Louder et al., 2021; Posner & Cvitanovic, 2019).

One conceptualization of such efforts to improve collaboration and communication between scientific and policy spheres is known as boundary spanning, or "work to enable exchange between the production and use of knowledge to support evidence-informed decision-making in a specific context" (Bednarek et al., 2018). Two of the potential and anticipated impacts of boundary spanning work are improved knowledge exchange and increased trust between scientists and policy makers (Bednarek et al., 2018). I argue that in order to improve knowledge exchange and build trust, it's imperative to have a robust and comprehensive understanding of the current state of knowledge. As underscored above

by Garnett (2013) and Schwarz et al. (2021), understanding research gaps, limitations, and strengths is essential as research is communicated across sectors and translated into policy and interventions. It is central to the design of effective, just solutions necessary to support sustainable food systems and planetary health.

This dissertation aims to address these knowledge gaps through a multi-step mixed methods approach. This work utilizes quantitative data collection and analysis in the first and second chapters, and a combination of qualitative data collection with both qualitative and quantitative data analysis in the third chapter.. Through a thematic scoping review (Chapter 1), bibliometric analysis (Chapter 2), and content analysis (Chapter 3), this work seeks to shed light on the evolution and state of sustainable diets research, on how this knowledge is produced and reproduced, and understand the aims and recommendations of this work and how it can contribute to a sustainable food system transformation.

Chapter one uses topic modeling, a type of natural language processing, to perform a thematic scoping review of sustainable diets literature. This method identifies trends and themes in a way that is rapid, reproducible, transparent, and reliable. The review includes 855 articles published between 2000-2022 and aims to identify research trends, gaps, and emerging themes over time and across disciplines. This chapter also examines whether and to what extent the themes that emerge from the literature align with the components of a sustainable diet as described by the FAO and depicted in Figure 2.

Chapter 2 builds on the first chapter by examining how the literature considered in the thematic scoping review is produced and reproduced. This chapter merges the aims science of science and research impact evaluation and applies them to the field of

sustainable diets. It seeks to shed light on the practice of science itself by using big data to examine citation dynamics, investigate altmetrics, and analyze how indicators of power and research characteristics are linked with measures of impact. Citation analysis is used to examine highly cited articles and journals. Correlation between citation counts and altmetric scores, an alternative measure of research impact and reach, is also examined. This chapter also examines the association between research impact, as measured by citation counts and altmetric scores, and measures of academic power, including global institutional ranking, geographic region of these institutions, and the economic status of the institution's home country. Study methodology, dominant research themes, open access status are also examined as potential factors associated with citation counts and altmetric scores.

Chapter 3 follows these sequential quantitative studies with a qualitative content analysis of the most highly cited sustainable diets literature highlighted in Chapter 2. This chapter explores this literature in greater depth to identify the objectives of this research, the mechanisms proposed for change, and where these recommendations are located within an upstream-downstream interpretation of the food systems components and influences described by the Food Systems Dashboard's Food Systems Framework (Figure 1). The chapter concludes with a reflection on where more research attention is needed and a critique of the capacity of sustainable diets research to assess systems trade-offs and contribute to transdisciplinary, systems-based, effective solutions for a sustainable food systems transformation.

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CHAPTER 1: SCOPING REVIEW OF SUSTAINABLE DIETS RESEARCH REVEALS A THEMATIC AND DISCIPLINARY EMPHASIS ON NUTRITION AND ENVIRONMENT

1.1 Abstract

Sustainable diets have been identified as an important component of a food systems transformation that is urgently needed to meet global sustainability and development goals. This study addresses the lack of a comprehensive synthesis and overview of the sustainable diets literature, including its evolution over time and across disciplines, and sheds light on whether and how this body of work addresses dimensions of sustainability as defined by the Food and Agriculture Organization of the United Nation's (FAO) sustainable diets framework. Topic modeling, a type of natural language processing, was used to perform a thematic scoping review of 855 articles published between 2000-2022 to identify trends and themes in a way that was rapid, transparent, reliable, and reproducible. This research finds demonstrated growth in the field of sustainable diets research, with the majority (66%) of sustainable diets articles considered in this study published in the last three years of the study period. Sixty-three percent of the sustainable diets research articles can be characterized by two topics, "sustainability impacts of dietary patterns" and "sustainable diets and food system policy." FAO components of sustainable diets related to local and seasonal foods, culture, and equity receive relatively little research attention, whereas components of health, environment, and food security each align with approximately a third of the research literature. This is also reflected in the subject classification analysis,

in which nearly half of the research (44%) was classified as Nutrition and Dietetics and/or Environmental Studies. This research highlights the need for more transdisciplinary research that addresses areas of equity, culture, social processes, and context as well as the intersections of sustainability dimensions to better understand the need for, implications, and directions of sustainable diets to support a sustainable food systems transformation.

Keywords:

Sustainable diets, food systems, planetary health, natural language processing, scoping review

1.2 Introduction

A growing body of research indicates that food systems are integral to environmental, social, and economic dimensions of sustainability, with the power to threaten and support them all (Canavan et al., 2017; Springmann, Clark, et al., 2018; Willett et al., 2019; Zurek et al., 2022; IFPRI, 2020). Producing enough food for a growing population while supporting sustainability has been identified as a critical and immediate global challenge (Fanzo et al., 2022; FAO, 2016; *The 17 Goals: History*, n.d.; van Berkum et al., 2018; WWF, 2020). There is a growing consensus that a sustainable food system, or one that "delivers food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition for future generations are not compromised" is urgently needed and necessary in order to meet broader global sustainability and development goals (Fanzo & Miachon, 2023; FAO, 2018; Willett et al.,

2019). Sustainable food systems are the focus of numerous advisory and landscape reports (e.g., IPES-Food, 2023; Meridian Institute, 2015; Searchinger et al., 2019) and have garnered attention across a range of institutions (European Commission, 2020; *Food System Transformation*, 2022; The Rockefeller Foundation, 2023; World Bank, 2023). Sustainable food systems have also been adopted in national priorities and international policies, including in the United States, Europe, and beyond (European Commission, n.d.; USDA, 2021).

As described by Meybeck and Gitz (2017), a diet is the collection of foods eaten by an individual that are selected from what is made available by the food system. The totality of all diets generates demand pressure on the food system. Meybeck and Gitz (2017) thus identify diets as both a driver of food systems, with the power to influence food security and nutrition, and an outcome of these systems. Identifying and understanding what constitutes a sustainable diet is therefore important for supporting a transition to a sustainable food system, and, relatedly, measuring how sustainable that system is. Sustainable diets, defined by the Food and Agriculture Organization of the United Nations (FAO) in 2010, are those "with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources," (Burlingame & Dernini, 2012) (Figure 1-1). Early sustainable diets research largely focused on greenhouse gas and land use impacts of current and projected global food production and dietary patterns (Clune et al., 2017;

Hedenus et al., 2014; Nelson et al., 2016; Popp et al., 2010; Stehfest et al., 2009). More recent studies have widened the scope of analysis by considering a broader range of environmental impacts and a finer geographic scale. For example, more recent studies incorporate environmental impacts in addition to greenhouse gas emissions, such as land and energy use, blue and green water footprints, acidification and eutrophication potential, and biodiversity (Kozicka et al., 2023; Springmann, Wiebe, et al., 2018; Willett et al., 2019). The geographic scale of analysis has shifted from global to include regional and country-level studies (Beal, Gardner, et al., 2023; Kim et al., 2020; Springmann, Wiebe, et al., 2018). More recent studies have also shifted to incorporate additional dimensions of sustainability. These include, for example, food security and public health nutrition (Kim et al., 2020; Shepon et al., 2018; Springmann, Wiebe, et al., 2018; Willett et al., 2019), as well as economic and cultural factors (Baudry et al., 2023; Shepon et al., 2018; Springmann et al., 2021).

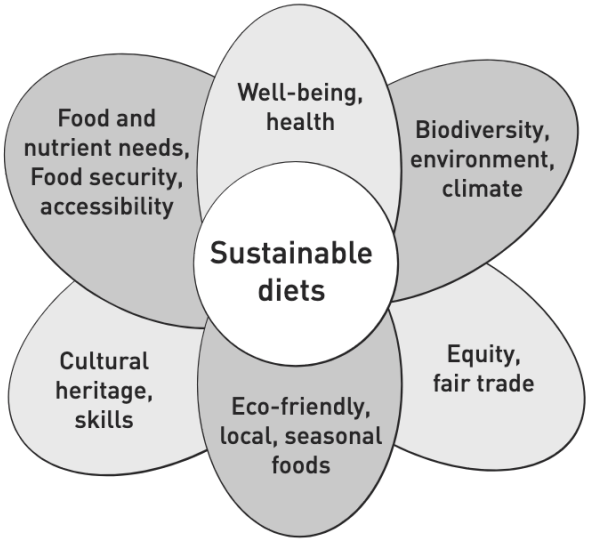

Figure 1-1. Schematic depiction of the components of a sustainable diet (Burlingame & Dernini, 2012). Source: Food and Agriculture Organization of the United Nations. Reproduced with permission.

As sustainable diets research has grown in breadth and depth, a number of systematic reviews have been conducted to identify, appraise, synthesize and summarize existing research using detailed and comprehensive search and analysis plans established prior to conducting the review to limit bias (Uman, 2011). These reviews support a growing consensus that dietary patterns that emphasize plant-based foods while limiting or excluding animal-based foods are associated with lower environmental impacts and improved health outcomes (Nelson et al., 2016; Reinhardt et al., 2020). For example, a 2019 systematic review evaluating which dietary pattern has the least environmental impacts, including greenhouse gas emissions, water footprint, and land use, found that a vegan diet was optimal for the environment (Chai et al., 2019). In regards to health outcomes, a recent systematic review and meta-analysis examining plant-based foods and cardiovascular disease highlights the "favorable role of healthful plant-based foods in reducing cardiovascular mortality and CVD [cardiovascular disease]," (Quek et al., 2021) while a 2023 systematic review found that diets based on plant foods are linked to reduced blood pressure (Tomé-Carneiro & Visioli, 2023). A 2018 systematic review concluded that consumption of diets high in plant-based foods were associated with improvements in emotional and physical well-being, depression, quality of life, general health, weight, and management of diabetes (Toumpanakis et al., 2018).

One interpretation of these findings is that the pathway toward a sustainable future is paved by a dietary transition away from animal-based foods and toward those that are plant-based. Plant-based diets are dietary patterns that are characterized by an emphasis on plant-based foods alongside a reduction or exclusion of animal-based foods. Diets

considered plant-based range from vegan, or those that omit all animal products, to variations of vegetarian diets such as lacto-ovo vegetarian (exclude all animal-based foods except for dairy and eggs) and pescatarian (no meat, but includes fish, dairy, and eggs) to flexitarian diets, which are mostly vegetarian but may include animal-based products in small amounts and/or on limited occasions (WHO, 2021). An important distinction must be made, however, between a plant-based diet and a sustainable diet. According to the FAO, sustainable diets are "those diets with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources," (Burlingame & Dernini, 2012). Since a plant-based dietary shift is associated with improved health outcomes and decreased environmental impacts, it is often included as a core component of sustainable diets (FAO & WHO, 2019; Sabaté & Soret, 2014).

However, not all plant-based diets are considered sustainable diets, and sustainable diets are not inherently only plant-based. It is possible to eat solely or primarily plant-based foods without meeting important components of sustainable diets, such as nutritional adequacy, cultural acceptability, accessibility, and food production practices, including working conditions and food waste (Fanzo et al., 2012; WHO, 2021). Furthermore, not all animal-based foods have the same footprint; ruminant meat and dairy, for example, have relatively high environmental impacts compared to other animal-based foods such as pork and poultry (Springmann, Wiebe, et al., 2018). Similarly, some plant-based foods, such as

nuts, can have substantial environmental footprints depending on production conditions (Springmann, Wiebe, et al., 2018). In addition, emphasis on a plant-based dietary transition alone may not recognize the environmental and health contributions and benefits of animal agriculture. When produced at appropriate scales in harmony with local ecosystems, well-managed animal agriculture can have an important role in circular and diverse agroecosystems (Beal, Gardner, et al., 2023). They can support biodiversity, restore degraded lands, and reduce greenhouse gas emissions while contributing to food security and supporting their cultural, societal, and economic significance (Beal, Gardner, et al., 2023; Leroy et al., 2022).

While there have been some efforts to systematically review specific outcomes and impacts of plant-based dietary patterns, described above, there has been little work to comprehensively synthesize the broader sustainable diets research, and its evolution, across disciplines and over time. The ability for future research to account for research trends and address knowledge gaps is limited without this research review and synthesis. Furthermore, these research limitations may also impede the development of evidence-informed policies and programs designed to build a more sustainable food system.

Despite the absence of a comprehensive understanding of the strengths and shortcomings of this body of evidence, the existing evidence for sustainable diets is already being mobilized by many institutions, governments, and advocacy organizations. This is evidenced in the efforts around achieving a dietary transition away from animal-based foods and toward those that are plant-based, for example, from the consumer level (e.g., Meatless Monday), to the institutional level (e.g., food procurement reform in finance,

business, education, retail and healthcare), to the policy level (e.g., incorporating plant-based diets in national dietary guidelines and legislation for plant-based school food) (*About Meatless Monday*, n.d.; *Climate-Friendly School Food*, n.d.; *Plant-Forward Future*, n.d.; Dietary Guidelines Advisory Committee, 2015; Reinhardt et al., 2020).

Understanding the state of the sustainable diets research is a necessary step in working toward a sustainable food system. The need for this synthesis is underscored by the recognition that sustainable food systems are essential to human and planetary health. Furthermore, the extent to which this body of research comprehensively addresses and incorporates sustainability topics and issues is unknown. Understanding whether and how the sustainable diets body of literature reflects various dimensions of sustainability will help determine if there are areas of sustainability that are under-researched or absent and inform a holistic approach to sustainable food systems research that acknowledges and accounts for the complex and interconnected elements of sustainability. This research will investigate how the sustainable diets body of work aligns with a holistic view of sustainability using the FAO's 2010 concept of sustainable diets as a multi-dimensional system that considers "nutrition, culture, pleasure, equity, well-being and health, environment and biodiversity protection for all" (Figure 1-1) (Burlingame & Dernini, 2012). This framework represents a mainstream, consensus-based framework that is linked with the Sustainable Development Goals and associated national policy commitments. This framework provides an opportunity to investigate how the compilation of extant research addressing sustainable diets does, and does not, align with a dominant discourse on

sustainability that is linked to the design and implementation of national policies and international goals.

1.2.1 Research Aims and Questions

The aim of this research is to conduct a comprehensive thematic scoping of the sustainable diets literature. This analysis aims to identify research trends, gaps, and emerging themes in the sustainable diets literature over time. This research will also assess the extent to which the sustainable diets literature aligns with the components of a sustainable diet (Figure 1-1) as outlined by the FAO (Burlingame & Dernini, 2012). The following research questions seek to address the aims of this study:

- How does the rate of publication of peer reviewed, academic research articles on sustainable diets catalogued in Scopus vary in the time period considered (2000-2022)?
- What journals and disciplines are represented in the data set over the study time period?
- What are the key topics of focus in the sustainable diets literature, and how do they vary over the study time period?
- How does the sustainable diets literature align with the components of sustainable diets as described by the FAO? What gaps exist?

1.3 Methods

These questions were answered by reviewing and analyzing sustainable diets literature using descriptive statistics and topic modeling. Topic modeling is an unsupervised Natural Language Processing (NLP) technique that uses computational approaches to identify topics and their interrelationships within text without the use of manual coding. Topic modeling is an emerging method for conducting high-level reviews of research literature. This method uses computational algorithms to understand and produce language content (Hirschberg & Manning, 2015), process and structure large volumes of textual data, convert text to other visualization features, and identify relationships (Ghosh & Gunning, 2019). Similar to some qualitative methods such as grounded theory and content analysis, NLP methods such as topic modeling allow categories and themes to emerge from data. This method can achieve a high degree of consistency and accuracy because of the uniform application of an algorithm. A 2018 medical research study comparing NLP with qualitative approaches found that NLP was able to identify major themes that were summarized through a traditional, manual text analysis (Guetterman et al., 2018). In a study of the compatibility between text mining – a type of NLP – and manual qualitative text analysis, researchers found that this element of reliability is compatible with the criteria of rigorous qualitative research methods (Yu et al., 2011). In addition, a 2019 healthcare study assessing research on enhanced and assisted living environments found that this method is able to speed the process of surveying research literature and conducting trend analysis, and was able to analyze the abstracts of more than 70,000 articles automatically and visualize trends of interest (Zdravevski et al.,

2019). Although this method has been applied within food systems research (e.g. Cooper et al., 2020), and in other disciplines, such as biomedical sciences and urban planning Cai, 2021), the application to investigate the sustainable diets literature is new.

The topic modeling analysis was performed on the text from abstracts, as this text captures a concise summary of the entire study, often including a brief description of the study background, problem statement, research aims, methods, results, conclusions, and implications. Topic areas that emerged from the analysis were then manually assigned labels, validated, and mapped onto the components of sustainable diets as described by the FAO (Burlingame & Dernini, 2012). Descriptive statistics and time series analyses were also used to summarize the data and identify trends over time.

1.3.1 Literature Search

The literature search was conducted using Scopus, a "comprehensive, multidisciplinary, trusted abstract and citation database" of research literature (*Elsevier*, 2023). Since the topic modeling analysis is conducted using abstract text, it was prudent to search a database of abstracts. Focusing the search on Scopus is based on the precedent set by Cooper et al.'s (2020) topic modeling analysis of food security literature. In addition, a 2021 analysis by Singh et al. found that nearly all journals indexed by Web of Science are also indexed by Scopus (99.11%), so there was marginal benefit in extending the search to this additional database.

The Scopus database was queried on February 8, 2023 using the search terms "sustainable diet", "sustainable diets" and "sustainable dietary pattern*" and applying the

search to article titles, abstracts and keywords. As demonstrated and discussed by Cooper et al.'s (2020) thematic scoping analysis of food security literature, querying a database using a topic or key phrase is a common approach in research that uses NLP to examine a body of research. Also based on Cooper et al.'s (2020) study, only peer-reviewed, academic literature was included. Original research and review articles were included, while opinion pieces, book chapters, editorials, and conference papers were excluded. Studies published between 2000 and 2022 were included in the analysis to capture the period from when the United Nations Millennium Declaration was signed in 2000, committing world leaders to the Millennium Development Goals (the precursors to the Sustainable Development Goals, established in 2016) and raising the profile of global challenges, including food systems issues of hunger and environmental sustainability (United Nations, n.d.). December 2022 was used as the endpoint for the time period to allow for complete calendar years to bookend the search period. Duplicate records were removed so that each abstract included in the data set is unique. Duplicates were identified using a Pandas duplicated function in python (Van Rossum & Drake Jr, 2009). Records were also organized in alphabetical order by title and reviewed manually for duplicates that were not identified in the automated search.

1.3.2 Screening

All articles identified in the search were manually screened for inclusion in the analysis. This screening process aired on the side of inclusion, as the aim of the study is to conduct a comprehensive, holistic review of the body of literature on sustainable diets. All

studies that were justified by, framed by, or contributed to knowledge on sustainable diets were included. This included studies that related results or conclusions to sustainable diets and/or the "core system" of a sustainable food system as described by the FAO, which includes the "activities through which food products flow (production, aggregation, processing, distribution and consumption, including waste disposal)," (FAO, 2018).

1.3.3 Publication Rate, Journal, and Disciplinary Analysis

Descriptive statistics and time series analyses were used to summarize trends in the sustainable diets body of work over the time period considered in this study, from 2000 through 2022. This included examining the rate of publication over time, normalized by the overall number of publications in the Scopus database (using the same search parameters described above but without specifying search terms). All unique journal titles in the dataset were identified and descriptive statistics were used to summarize the distribution of articles across these journals.

Ulrich's Periodicals Directory subject classifications was used to characterize the disciplinary focus of each journal, and each article published within that journal, in the dataset. Ulrich's Periodicals Directory is an "authoritative source of bibliographic and publisher information on more than 300,000 periodicals of all types," that is updated daily by a team of multilingual editors (*Ulrich's Serials Analysis System*, 2023). Included in each periodical listing is a subject classification, or subject heading. These proprietary headings are generally based on the Library of Congress subjects and are assigned by the Ulrich's editorial team to classify the periodicals in the database. Although Scopus also provides

disciplinary categories for the records within its database, there are only 27 subject categories compared to Ulrich's Periodicals Directory's approximately 100 top-level subject headings. These additional subject areas in Ulrich's directory present a greater degree of detail and specificity that are relevant to the sustainable diets body of work. For example, while Scopus includes broad categories such as "Agricultural and Biological Sciences," "Medicine," and "Health Professions,", Ulrich's include those such as "Agriculture," "Food and Food Industries," "Public Health and Safety," and "Nutrition and Dietetics." While some journals were assigned just one subject classification, others were assigned multiple. This analysis includes each top-level subject classification assigned by Ulrich's and weights them evenly as they are listed alphabetically in the periodical listing and without an indication of the degree to which the journals represent the different subject classifications they are assigned. The distribution of publications across the journals was assessed by calculating publications per journal in the dataset. A time series analysis was conducted to examine the disciplinary focus of the body of work from 2000-2022.

1.3.4 Topic Modeling and Time Series Analysis

The topic modeling analysis was conducted on all the abstracts collected in the above process to generate topics from the literature. The analysis was conducted using Latent Dirichlet Allocation (LDA) (Blei, Ng, & Jordan, 2001), an unsupervised probabilistic modelling method, from Gensim, a natural language processing package in Python 3.10.7 for macOS (Řehůřek & Sojka, 2011). A 2019 paper presenting a methodological framework for topic modeling in exploratory literature reviews identifies

LDA as a commonly used, effective model (Asmussen & Møller, 2019). This model uses words as the basic unit of analysis within a document, with each abstract representing a document. LDA identifies groups of words that occur together with similar frequency across documents, and these word groups are analyzed as topics (Blei, 2012). For more detail on the LDA model and the method for selecting the number of topics to include in the model, see Supplementary Materials.

Once the topics were generated, they were manually assigned a label, similar to the process outlined by Asmussen & Møller (2019) and used by Cooper et al. (2020). Asmussen & Møller (2019) recognize that topic labeling, and any subsequent grouping of these labels into themes, is subjective. To lower the risk of assigning inaccurate topic labels, they suggest reviewing the most frequent words for each topic along with a title review of the papers assigned to those topics. Cooper et al. (2020) provide an example of this dual approach in which they assign labels to topics, and then group these labels into themes, by combining a review the top three words generated for each topic with a review of the title of a representative article. This study follows a similar protocol whereby the top 15 words for each topic area were reviewed along with a title review of the studies representative of that topic. Following the Asmussen & Møller (2019) framework, these labels were validated using semantic validation, in which the results are examined and evaluated using expert reasoning and content knowledge. Cooper et al. (2020) also use this type of semantic validation, stating that the process of identifying and assigning labels is based upon the expertise of the author team.

The time series analysis was modeled after that of Cooper et al. (2020) in which the proportion of literature related to each topic area was examined over time. Topics are groupings of words that co-occur across documents. Topic weights were calculated for each article in the dataset and trends were identified by examining how these weights varied across the five time categories (described below). The topic weights are generated by the model and presented as set percentages that represent how much the abstract text aligns with each topic based on the words occurring in that abstract. Calculating topic weights involves comparing the distribution of words within an abstract to the distribution of words within each of the topic areas and determining how closely the abstract matches each topic. A probability, expressed as a percentage, is generated that demonstrates how closely the text matches a particular topic area. Seven probabilities are generated for each abstract, one for each topic area, and sum to one. Trends in topic areas were examined by averaging topic weights across abstracts for each time period (below) to understand the relative dominance of the topics over time. Trends in the dominant topic were examined by assigning each abstract to the topic area with the highest weight and then examining the proportion of papers assigned to each topic area over the five time categories.

The 2000-2022 timeframe was broken into five categories that roughly reflect the distribution of publications over time, with approximately 15-25% of the publications contained within each time category: 2000-2016, 2017-2019, 2020, 2021, and 2022. The 2000-2016 time category reflects a broader development and sustainability context for the research, with 2000 marking the establishment of the Millennium Development Goals and

2016 heralding the implementation of the Sustainable Development Goals (*United Nations Sustainable Development Goals*, n.d.).

1.3.5 Distribution of Research Across Topics

To examine the distribution of research across the topics overall, each article was allocated to a single topic area. Papers were allocated to the topic area with the highest topic weight, as described above. This allocation of papers to topics is based on the process used by Asmussen & Møller (2019) in their framework for using topic modeling in exploratory literature reviews. Papers for which several topics have high or similar topic weights may indicate that the paper is at the intersection between two or more topics. In these cases, the topic with the highest probability was still assigned. It is possible, though rare, for a paper to have two or more equal topic weights. It was deemed that these situations would be evaluated on a case-by-case basis should they have arisen. No such situation arose in this analysis, however.

1.3.6 Mapping Results onto Food System Sustainability

The topic labels from the topic modeling data analysis were mapped onto the components of sustainable diets as identified by the FAO (Figure 1-1). Alignment with the components, or "petals", of the FAO sustainable diets framework was determined by reviewing the top 15 most relevant terms for each topic area as well as a title review of the most representative papers for each topic area. The extent to which the body of literature reflects these dimensions and components of sustainability and systems thinking was

examined and described. The topics that do not fit within the FAO framework for sustainable diets were also identified and described along with trends that emerged in how the topic labels do and do not map onto the FAO schematic for sustainable diets. The distribution of the research by topic was also examined in relation to the topic alignment with the FAO framework.

1.4 Results

1.4.1 Literature Search and Screening

A total of 1,016 records were identified in the initial Scopus search. Of these, 855 records were included in the analysis after applying search criteria, removing duplicates and records without abstracts, and screening for relevance to sustainable diets (Figure 1-2). One duplicate article was identified using the Pandas duplicated function in python. An additional duplicate was identified using the manual review of titles. It was missed by the automated search due to the inclusion of both the Spanish language title and the English translation of that title in the title field. Fourteen articles were identified for exclusion through the screening process. These articles were excluded as they were deemed outside the scope of sustainable diets. For example, some were biomedical studies that used the term “sustainable” to describe adherence to a particular medical treatment, one article was related to the sustainability of pet foods, and some studies were adjacent to the sustainability of human diets but limited in scope to a particular element of human health or medicine, such as metabolic biomarkers, weight loss for kidney transplants, gut

microbiota, or clinical treatment of diet-related disease. One study was excluded as it was published outside the time period considered for this analysis (2023).

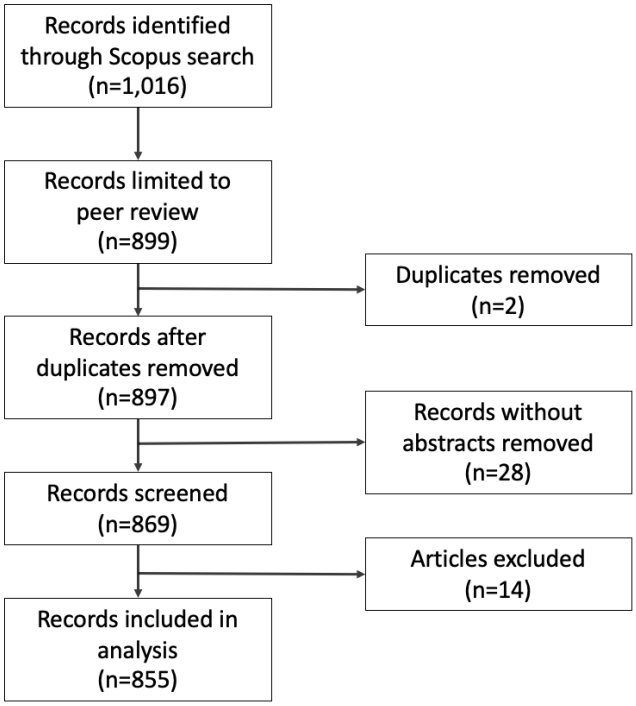

Figure 1-2. Study flow diagram

Rate of Publication

The publication rate of sustainable diets literature has trended upward in the time period considered (2000-2022) (Figure 1-3). This trend is also observed after adjusting the publication rate by examining the sustainable diets publications as a proportion of the total number of Scopus publications per year.

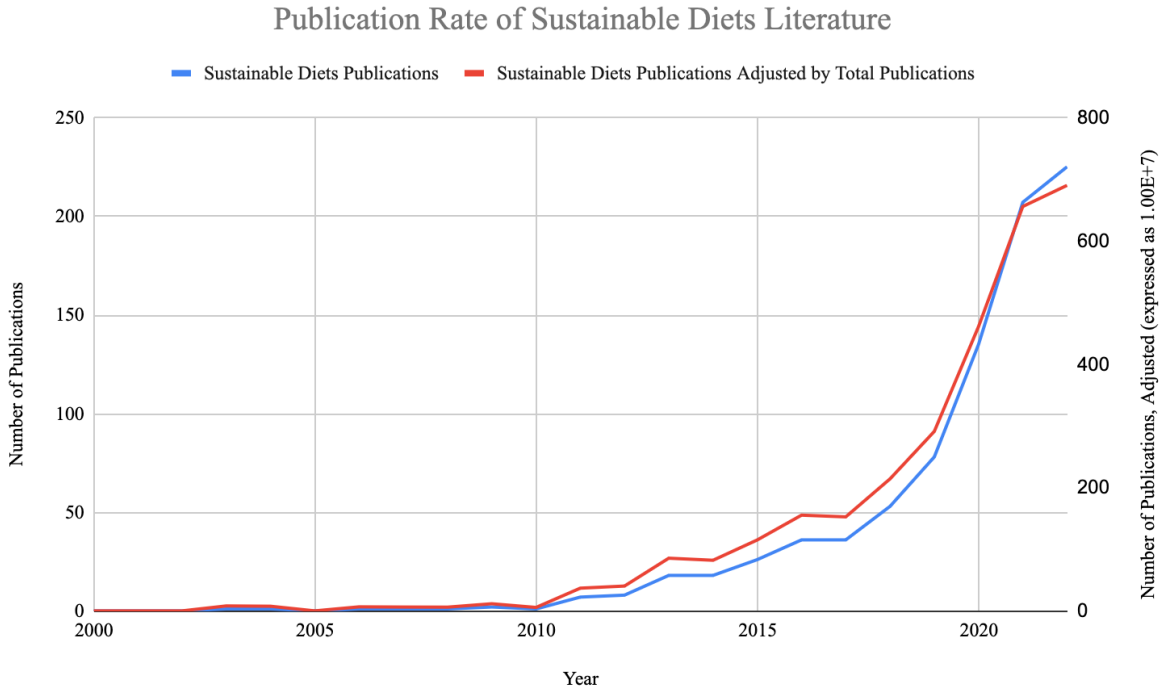

Figure 1- 3. Publication rate of sustainable diets literature

While there were fewer than 10 articles published a year prior to 2012, more than a quarter of all publications in the dataset were published in the most recent year considered, 2022, and half were published in the final two years of the 22-year period considered in this study, in years 2021 and 2022 (Table 1-1). Table 1-1 also shows the distribution of the research publications across the five time categories used to analyze trends in topics over time. As described in the methods, these categories were used as they reflect the broader context for the research, with 2000 and 2016 marking the establishment of the Millennium Development Goals and the implementation of the Sustainable Development Goals, respectively. These time categories also represent approximately 15-25% of the publications in the dataset.

Table 1-1. Distribution of publications across five time categories

Time Period	Number of Publications	Proportion of Total Publications
2000-2016	121	14%
2017-2019	167	20%
2020	135	16%
2021	207	24%
2022	225	26%

1.4.2 Journal and Subject Classification Analysis

Journals

The dataset contained 255 unique journals. Three of the journals were not listed in Ulrich's Periodicals Directory and excluded from this analysis (ABAC Journal, Development (Basingstoke), and Iranian Journal of Nutrition Sciences and Food Technology). The 252 journals included in the analysis had an average of 3.4 publications (range=1-71, median=1). While 75% of the journals had just one or two publications (interquartile range=1-2), the top 10% of the journals (n=28) by number of publications represented over half (59%) of all the publications in the dataset. The top 5% of journals by number of publications and their subject classifications are presented below (Table 1-2). Of these 5% of journals, 43% (6) were classified as Nutrition and Dietetics, 36% (5) as Environmental Studies, 29% (4) as Food and Food Industries, 21% (3) as Public Health and Safety. Engineering, Agriculture, and Sciences: Comprehensive Works each represented 7% (1) of the top of 5% of journals.

Table 1-2. Top 5% of journals by number of publications and their subject classifications according to Ulrich's Periodicals Directory.

Journal Title	Number of Publications	Subject Classification
Nutrients	71	Nutrition and Dietetics
Sustainability (Switzerland)	63	Environmental Studies
Frontiers in Nutrition	34	Nutrition and Dietetics
Public Health Nutrition	34	Nutrition and Dietetics; Public Health and Safety
Journal of Cleaner Production	32	Engineering; Environmental Studies
Appetite	25	Nutrition and Dietetics
Frontiers in Sustainable Food Systems	25	Agriculture; Food and Food Industries
Foods	19	Food and Food Industries
Global Food Security	15	Environmental Studies; Food and Food Industries
Science of the Total Environment	15	Environmental Studies
Advances in Nutrition	14	Nutrition and Dietetics
BMC Public Health	12	Public Health and Safety
International Journal of Environmental Research and Public Health	12	Environmental Studies; Sciences: Comprehensive Works; Public Health and Safety
Nutrition Bulletin	12	Nutrition and Dietetics; Food and Food Industries

Subject Classification

Ulrich's Periodicals Directory was used to identify the subject classification of each journal included in the dataset. These subject classifications are proprietary headings based on subjects in the Library of Congress. They are used here to represent the disciplinary focus of the journals and their publications. There were 44 subject classifications for the 252 journals included in the analysis. Some journals, and therefore the articles in the dataset associated with those journals, had multiple subject classifications while others had a single classification. In calculating the frequency of subject classifications by article, each subject

classification was counted once, even if there were multiple classifications for an article. Thus, the total number of articles in the subject classification analysis is greater than the total number of articles in the dataset (1,169 versus 855, respectively). The subject classifications had an average of 27 articles, though the range extended from 1-296 articles per subject with a median of 4 articles (Figure 1-4). Six subject areas accounted for 76% of all the articles in this analysis. Nutrition and Dietetics and Environmental Studies account for nearly half of all the article counts (25% and 19%, respectively), while Food and Food Industries (12%), Public Health and Safety (8%), Agriculture (7%), and Medical Sciences (5%) account for approximately a third of the article counts.

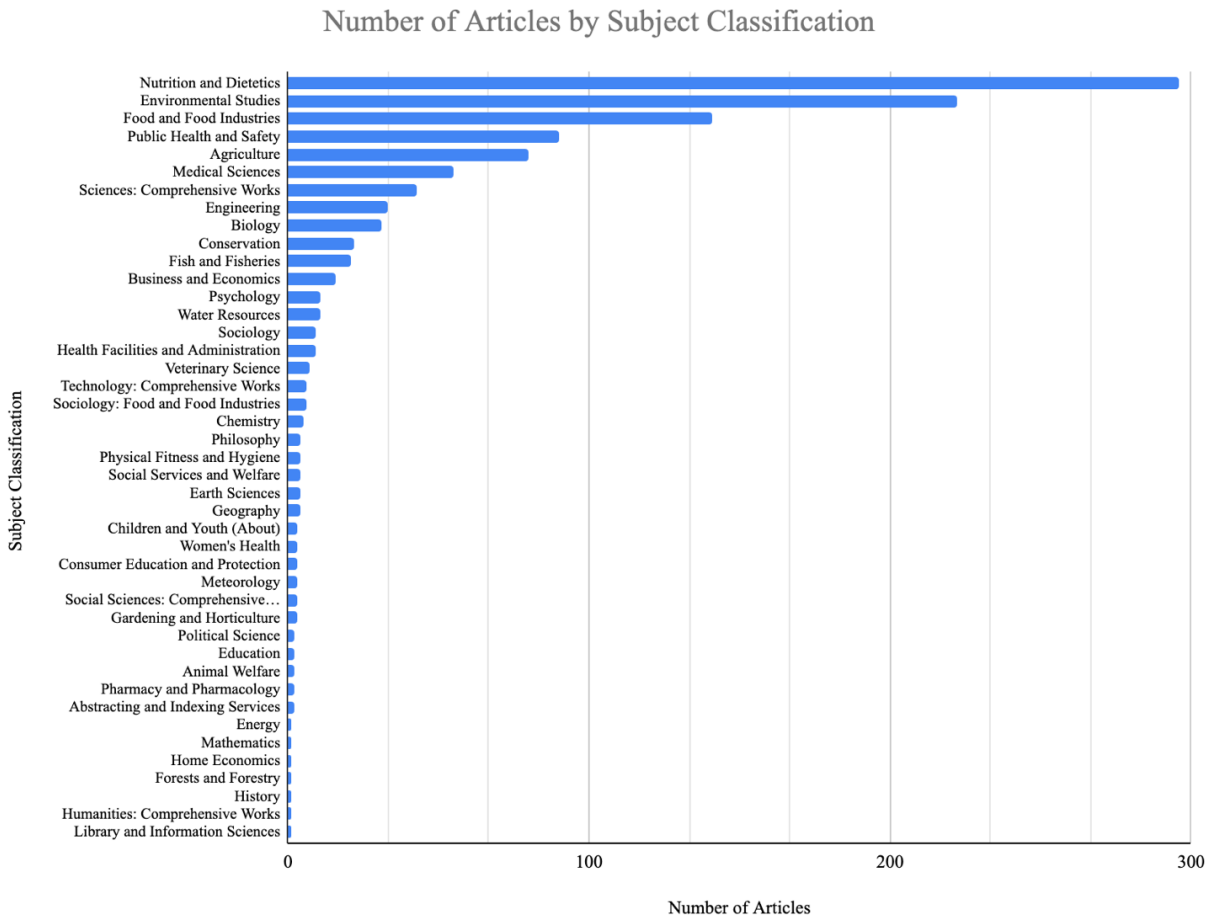

Figure 1-4. Number of articles by disciplinary classification according to Ulrich's Periodical Directory

Subject Classification Time Series Analysis

Time series analysis helps visualize the trends in subject classification over time, including which subject areas are most prominent and when and how these trends shift. These trends depict current data and are not predictive. The prominence of the top six subject classifications from the subject classification analysis, described above, is also reflected in the time series analysis. Nutrition and Dietetics emerges as a dominant subject area around 2015 and largely maintains that dominance to the present (Figure 1-5). Public

Health and Safety and Environmental Studies also rose in prominence starting around 2015. While Environmental Studies remains a prominent subject area, the number of articles per year starts declining in 2021 after 5 years of a rise in the number of articles per year. Public Health and Safety continues to rise in prominence after experiencing some dips and rises. Food and Food Industries rise around 2019, remains high though possibly slowing. Medical Sciences and Agriculture start to emerge in 2020 as more dominant subject classifications. The number of articles for each of the remaining 38 subject classification areas is between 0 - 1 until 2010. While some of these 38 subject classification areas have more articles in more recent years, they have 12 or fewer maximum publications, with most having four or fewer, and the data are highly clustered and overlapping.

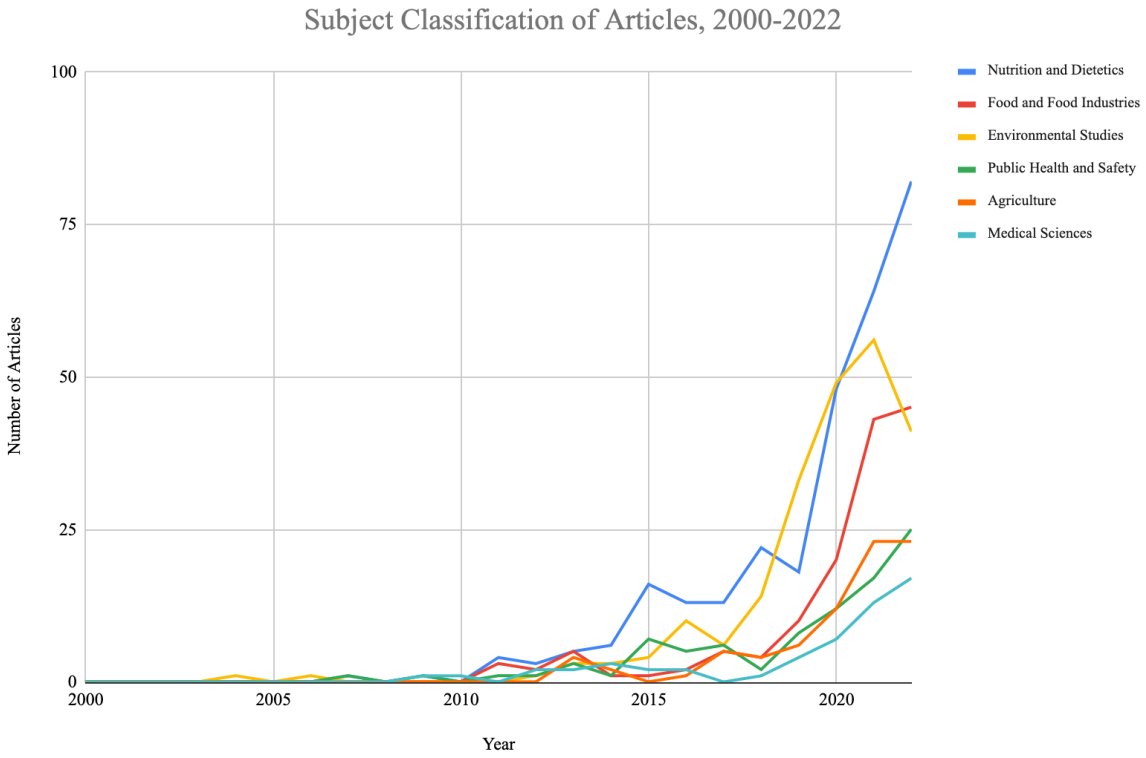

Figure 1-5. Six subject classification areas (n = 44) account for over 75% of the articles in from 2000-2022 and are depicted here in the time series analysis.

1.4.3 Topic Modeling

Based on LDA topic modeling analysis, the sustainable diets literature can be characterized by seven topic areas, identified in Table 1-3 along with the top 15 most relevant terms per topic area. The topic numbers below match the topic numbers in the pyLDAvis visualization in the supplementary materials. Table 1-3 also contains the topic labels for each topic area, which were assigned using content area knowledge and expertise and take into account both the most relevant words and a review of the articles that best represent the topic areas. Cross-referencing the articles that best represent the topic areas was a critical step in the topic labeling process as it provided additional context and nuance

for the top relevant terms. This is partially due to the fact that the most frequently used words in the corpus and the search terms were removed from the topic modeling analysis (i.e., sustainable, diet, dietary, pattern, food). Removing these words improves the ability of the model to determine how the documents are different, but it also removes some of the broader context of the articles that is important when ascribing labels to the topic areas. Topic 1, for example, is labeled, “sustainability impacts of dietary patterns,” despite the fact that sustainability, dietary, and patterns are terms that were excluded from the model and thus absent from the list of most relevant terms.

Table 1-3. Topic areas, topic labels, and top 15 most relevant terms per topic for the 7 topic LDA model.

Topic 1	Topic 2	Topic 3	Topic 4	Topic 5	Topic 6	Topic 7
Sustainability impacts of dietary patterns	**Sustainable diets and food system policy**	**Strategies for healthy and sustainable diets**	**Consumer behavior and attitudes toward plant-based meat alternatives**	**Role of traditional and/or alternative crops in sustainable diets and food systems**	**Environmental impacts of food production associated with dietary patterns**	**Sustainable reformulations of aquaculture feed**
Top 15 Most Relevant Terms						
high	sustainability	health	consumer	protein	impact	fish
consumption	system	healthy	meat	source	environmental	feed
low	policy	country	base	supply	emission	bass
environmental	nutrition	strategy	product	quality	use	protein
use	study	choice	plant	plant	production	tank
intake	environmental	make	consumption	provide	water	fillet
nutritional	well	area	meal	nutritional	reduce	pp
study	research	benefit	study	animal	footprint	affect
base	identity	increase	organic	production	reduction	level
meat	consumption	great	protein	human	greenhouse_gas	fatty_acid
ghge	use	need	show	product	change	lipid
vegetable	need	set	participant	diversity	increase	significantly
cost	social	group	milk	industry	growth	similar
score	approach	recommendation	treatment	traditional	energy	content
model	include	aim	replacement	provision	global	group

1.4.4 Topic Area Time Series Analysis

Dominant Topics Across Entire Study Period

Understanding how the sustainable diets literature is distributed across topic areas was first examined by assigning each abstract to the topic area with the highest topic weight, or the dominant topic. The topic weights represent how well the distribution of words in the abstract text matches the distribution of words in the topic areas and are

expressed as probabilities. The distribution of articles across topic areas according to the dominant topic assignment for the entire study period is depicted in Table 1-4. Topics 1 (Sustainability impacts of dietary patterns) and 2 (Sustainable diets and food system policy) each account for approximately a third of the sustainable diets publications and thus together account for a majority of the research. Topic 4, Consumer behavior and attitudes toward plant-based meat alternatives, describes approximately 13% of the research literature while the remaining topics each represent less than 10% of the sustainable diets research publications. Topic 7, Sustainable reformulations of aquaculture feed, best describes the smallest proportion of literature (approximately 3%).

Table 1-4. Distribution of publications across the seven topic areas

Topic Number and Label	**Proportion of Research**
2) Sustainable diets and food system policy	32%
1) Sustainability impacts of dietary patterns	31.2%
4) Consumer behavior and attitudes toward plant-based meat alternatives	13.2%
3) Strategies for healthy and sustainable diets	7.6%
5) Role of traditional and/or alternative crops in sustainable diets	6.3%
6) Environmental impacts of food production associated with dietary patterns	6.3%
7) Sustainable reformulations of aquaculture feed	3.3%

Dominant Topics by Time Period

Trends in the dominant topic over time were examined by calculating the proportion of papers assigned to each topic area over the five time categories (Figure 1-6). This time series analysis largely reflects the overall distribution of articles across topics for

the entire study period, though some trends emerge. Although topics 1 (Sustainability impacts of dietary patterns) and 2 (Sustainable diets and food system policy) account for a majority of research across the time periods, there is a slight downward trend in their dominance in more recent years. This can be attributed to a rise in the proportion of articles assigned to topic 4, Consumer behavior and attitudes toward plant-based meat alternatives, and a decline in the proportion of research assigned to topic 7, Sustainable reformulations of aquaculture feed.

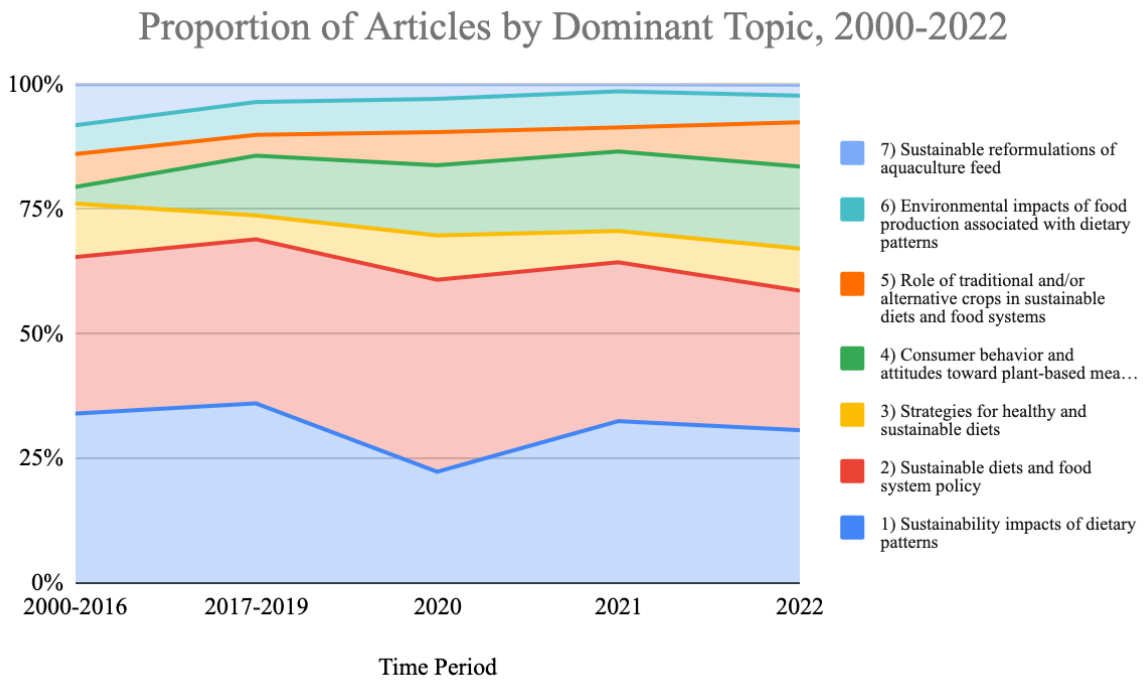

Figure 1-6. The proportion of articles by dominant topic from 2000-2022. The full topic label for topic 4 is "Consumer behavior and attitudes toward plant-based meat alternatives."

Average Topic Weights by Time Period

Trends in topic areas were further examined by averaging the topic weight for each topic across abstracts for each time period. This analysis was performed to examine more nuanced trends in relative topic dominance over time. While the dominant topic analysis provides a concise summary of the distribution of publications across the topic areas according to dominant topic areas, examining the average topic weights across abstracts reveals exactly how dominant a particular topic may be relative to other topics within an abstract. It is possible, for example, that a topic, "X," has a high relative weight, but one that is consistently and just slightly second highest behind the dominant topic area, "Y." Examining the dominant topic alone could mask this relationship and make it appear that much of the literature is characterized by topic Y and very little is characterized by topic X. The average topic weight analysis can therefore be seen as a test for this kind of relationship between the topic areas.

The average topic weight time series analysis does not reveal any unexpected relationships in the relative dominance of topics and largely reflects the dominant topic analysis. Similar to the dominant topic analysis, the average topic weight analysis revealed that topics 1 (Sustainability impacts of dietary patterns) and 2 (Sustainable diets and food system policy) consistently had the highest average topic weights while topic 7 (sustainable reformulations of aquaculture feed) had the lowest average topic weight across the five time categories. Although there are some slight shifts in average weights across years, they are relatively consistent over time. There is a slight increase in the average topic weight for Topic 4 (Consumer behavior and attitudes toward plant-based meat alternatives) over time,

while topics 6 (Environmental impacts of food production associated with dietary patterns) and 7 (sustainable reformulations of aquaculture feed) demonstrate slight downward trends.

1.4.5 FAO Mapping

Four of the seven topic areas generated by the model aligned with elements of the FAO sustainable diets framework, while three topics demonstrated more distant or vague connections, or did not align. Lastly, the petal "equity, fair trade" does not appear to have linkages to the seven topic areas that characterize the sustainable diets literature as determined by the NLP analysis. These alignments and relationships, as well as specific overlaps with the topic modeling results, are depicted and described below (Table 1-5).

Examining overlaps from the perspective of the FAO components of sustainable diets reveals that "well-being, health" is aligned with two topic areas that represent 38.7% of the sustainable diets research literature (Table 1-5). The "Biodiversity, environment, climate" component is also related to two topic areas that encompass 37.5% of the research literature. "Food and nutrient needs, food security, accessibility" is aligned with one topic area and 31.2% of the research literature. Two of the remaining components, "eco-friendly, local, seasonal foods" and "cultural heritage, skills" are each related to the same and single topic area representing 6.3% of the literature. Since some these FAO components align with more than one topic area and, in some cases, the same topic areas, these percentages are not exclusive to each of the components, nor do they total 100%. As mentioned above, the "equity, fair trade" component is not explicitly linked to any of the topic areas. The

three topics that are not explicitly aligned with the FAO components of sustainable diets: Sustainable diets and food system policy, Sustainable reformulation of aquaculture feed, and Consumer behavior and attitudes toward plant-based meat alternatives, represent 49% of the literature (32%, 3.3%, 13.2%, respectively).

Table 1-5. Alignment among the FAO sustainable diets components, the topic areas, words from the "top most relevant topic terms" (Table 1-3, generated by topic model) relevant to the FAO component, and the proportion of the sustainable diets literature represented by the topics. Note that the percentages do not total 100% as some the FAO components align with more than one topic area and, in some cases, the same topic areas.

FAO Component of Sustainable Diets	**Related Topic Area (Proportion of Research Represented by the Topic)**	**Top Most Relevant Topic Terms Relevant to Component**	**Total Proportion of Research Related to Component**
Well-being, health	(1) Sustainability impacts of dietary patterns (31.2%)	nutritional, intake, consumption	38.7%
	(3) Strategies for healthy and sustainable diets (7.6%)	health, healthy	
Biodiversity, environment, climate	(1) Sustainability impacts of dietary patterns (31.2%)	environmental, ghge	37.5%
	(6) Environmental impacts of food production associated with dietary patterns (6.3%)	environmental, emission, footprint, greenhouse_gas	
Equity, fair trade	N/A (0%)	N/A	0%
Eco-friendly, local, seasonal foods	(5) Role of traditional and/or alternative crops in sustainable diets and food systems (6.3%)	diversity, traditional, supply, source, quality	6.3%
Cultural heritage, skills	(5) Role of traditional and/or alternative crops in sustainable diets and food systems (6.3%)	diversity, traditional	6.3%
Food and nutrient needs, food security, accessibility	(1) Sustainability impacts of dietary patterns (31.2%)	nutritional, intake, consumption, cost	31.2%

1.5 Discussion

This research demonstrates that the field of sustainable diets research has grown in terms of number of publications since 2012, with the majority (66%) of sustainable diets research considered in this study published in the last three years (2020, 2021, 2022) of the study period (2000-2022). Sustainable diets research has been published in a broad range of journals (255 overall, with 252 examined in the disciplinary analysis) covering dozens of subject areas (n=44), indicating that the research touches upon a wide variety of subjects.

The majority of research, however, is concentrated in a small number of journals and subject areas. For example, the top 10% of the journals by number of publications represent over half (59%) of all the publications in the dataset and 75% of the journals in the dataset represent just one or two articles. Similarly, while the research is characterized by a wide range of subject areas, the majority of research can be characterized by just a few of these subject areas. Six subjects account for 76% of all the article counts in the analysis, and just three – Nutrition and Dietetics, Environmental Studies, and Food and Food Industries – characterize just over half (56%) of the research. While these top three subject areas have been and continue to be dominant, the other three top subjects– Public Health and Safety, Agriculture, and Medical Sciences – have been rising in prominence more recently as well. This trend suggests that the disciplinary focus, while dominated by a few subjects, is expanding and may continue to do so.

The topic modeling analysis generated seven topics that characterize the sustainable diets research considered in this study. Topic areas 1 and 2, “sustainable impacts of dietary patterns” and “sustainable diets and food system policy,” represent nearly two thirds of the

research literature considered in the study (31.2% and 32%, respectively). The remaining topics each represent less than 10% of the sustainable diets research publications, with the exception of the "consumer behavior and attitudes toward plant-based meat alternatives" topic, which represents 13.2% of the research. The time series analysis reflects this overall distribution of research across topic areas, though it reveals a slight downward trend in the dominance of topic areas 1 and 2 in recent years. This is offset by a rise in the proportion of literature related to topic 4 and a decline in the already small proportion of literature related to topic 7, "sustainable reformulations of aquaculture feed."

Examining the overlaps and gaps between the topic areas, the proportion of the sustainable diets literature represented by the topics, and the six FAO sustainable diets components sheds light on which of the FAO components receive relatively more or less attention in the research literature. Three of the FAO components, for example, each align with approximately a third of the literature: well-being, health (38.7%); biodiversity, environment, climate (37.5%); and food and nutrient needs, food security, accessibility (31.2%). In contrast, the remaining three components align with less than 10% of the research literature: ecofriendly, local, seasonal foods (6.3%); cultural heritage, skills (6.3%); and equity, fair trade (0%). It is important to note that these components receiving relatively little attention in the research literature does not necessarily mean that there are no studies exploring these topics or concepts in this dataset, but that they are too few, and perhaps too nascent in the research arena, to generate their own topics or appear more prominently in the seven topics presented here.

1.5.1 Research Implications

Given the growth in research on sustainable diets and the large number of articles considered, topic modeling presented the opportunity to perform a thematic scoping review of the literature to identify overarching trends and themes in a way that was rapid, transparent, reliable, and reproducible. In conducting this review, it was evident that human interpretation is necessary at each step of the topic modeling process, from determining the inclusion and exclusion of texts, pre-processing decisions, determining the model parameters, selecting the number of topics, labeling the topics, and interpreting the results. Researchers and others interested in using this method should be aware that although it allows for a review of literature that is much quicker than traditional, manual review, it is not a fully automated process, and that content area expertise as well as methodological proficiency is necessary to conduct a comprehensive, interpretable review.

The results of this thematic scoping review reinforce recent calls for a greater focus on equity, culture, and social processes and a more multi- or trans-disciplinary approach to food systems and sustainable diets research. A 2021 narrative review, for example, found that while sustainable diets research has focused on environment and health dimensions of sustainability, the social and economic dimensions are underrepresented in dietary pattern, food systems, sustainable agriculture, and social sustainability research. These researchers identify the need for research to address these dimensions in order to develop food systems solutions that provide healthy, affordable diets with positive, equitable socioeconomic outcomes (Nicholls & Drewnowski, 2021). A 2021 systematic review of agri-food systems research and how it relates to sustainability similarly found that while environmental

dimensions are sufficiently addressed, social, economic, and political dimensions are largely overlooked (El Bilali et al., 2021). A recent scoping review of sustainable diets metrics and findings similarly identified the need for more explicit recognition and integration of economic and social issues in research that has primarily focused on diet-climate-planetary ecology relationships (Webb et al., 2023) and a 2023 perspective piece argues that research in the sustainable diets and food systems space should address "the tension between the local and global nature of the biophysical (health, environment) and social dimensions (culture, economy)," (Biesbroek et al., 2023). Others have joined this call for incorporating sociocultural influences on food practices into sustainable diets research (Monterrosa et al., 2020) and bringing equity to the forefront of nutrition research and action (Nisbett et al., 2022).

The underrepresentation of equity, culture, and social processes may be attributed to several factors. Some research points to a lack of data and metrics on the social dimension of sustainability, as well as difficulty in defining and characterizing what is a fluid and flexible concept (Boström, 2012; Webb et al., 2023). A historical examination of the evolution of the sustainability concept suggests that it was originally rooted in agricultural sciences and ecology, and that it has only evolved more recently to consider social factors (Boyer et al., 2016). Boström (2012) suggests that making the distinction between different dimensions of sustainability risks further separating and isolating "the environment" and "the social" in management, administration, and policy rather than underscoring their intertwined nature. With regard to the lack of food system and nutrition research engagement with equity agendas, Nisbett et al. (2022) state that "equity in diets

and nutrition will never be achieved unless action *within* the food system is combined with actions *outside* of the food system, which address the deeply rooted socio-political drivers of health and nutrition inequities." Still other research suggests that homogeneity in research topics may be a result of the interest in and pursuit of research impact. This can privilege topics and disciplines that are more easily measured and fit within an investment logic mindset, and shift funding and valuation from those that are more foundational and/or where direct applications aren't as apparent (Benneworth, 2015; Williams, 2020).

Work by Nicholls & Drewnowski (2021) underscores the importance of a holistic and comprehensive understanding of both natural and social sciences, particularly as research moves into action and policy, as is currently the case with sustainable diets. They argue that as research and policy priorities shift from understanding to action, challenges involve culture, society, behavior, and institutions, yet these dimensions are underrepresented relative to natural sciences. They argue that "holistic integrated research" is not yet the standard and suggest greater emphasis on social science to address how to manage trade-offs in an equitable way. Identifying the limitations of current research thus presents a directive for future research to fill knowledge gaps and meaningfully contribute to a sustainable food system transformation. It also highlights how the shortcomings of current research may inhibit or even contradict equity and sustainability goals by preventing the understanding or weighing of trade-offs.

For example, some research concludes that dietary shifts toward more plant-based foods and away from animal-based foods are necessary to meet environmental and health goals (i.e., Aleksandrowicz et al., 2016; Springmann, Wiebe, et al., 2018). An implicit

assumption in this conclusion is that the number of livestock animals must be reduced, yet there is little discussion of how this reduction will be achieved. Similarly, there is little discussion of how to shift livestock farmers to other livelihoods or what impact this would have only local economies. There are significant equity challenges inherent in this transition. The majority of livestock keepers are in the global south, with 85% of them in sub-Saharan Africa alone. Many of them considered smallholders, or those that are operating on less two hectares (Erdaw, 2023; FAO, 2014), and family farmers who are struggling with limited access to resources, chronic hunger, high labor demands, and poverty (FAO, 2014). They also often rely on livestock as not only an important source of food, but also a form of savings, investment, and economic status, and the source of both tangible and intangible benefits (Banda & Tanganyika, 2021). Further complicating the plant-based dietary shift is additional research demonstrating that healthy diets are already unaffordable for a third of the global population (FAO, 2024) and the importance of animal-based foods in meeting nutritional needs in different contexts and populations (Beal, Ortenzi, et al., 2023; Kim et al., 2020).

The drive to shift toward more plant-based dietary patterns has also fueled the development of novel alternative proteins, such as plant-based meat substitutes and cell-based meats. While some research and industry groups suggest they can mitigate environmental, animal welfare, and public health concerns, the issues are complex. For example, research and development has largely been driven by investments from meat processing and aggregation companies. This raises questions about how this industry may contribute to the existing and concerning trends of increasing consolidation and

concentration in agribusiness (Santo et al., 2020). Significant shifts away from animal agriculture and toward alternative proteins would also entail substantial and far-reaching effects on current food producers, farm workers, and the rural communities where animal agriculture largely occurs (Santo et al., 2020). Such a massive workforce shift would not only have significant economic impacts, including the status of trade agreements and tariffs for both meat and crop markets, but also likely have implications for the well-being of farmers and farmworkers who are already struggling with poor mental health compared to other professions (Daghagh Yazd et al., 2019). Research also suggests that highly processed plant-based food alternatives are often high in fat, energy, sugar, and salt and have higher environmental footprints than minimally processed counterparts. Over reliance on these options may counteract the public health and environmental benefits of a dietary shift away from animal-based foods (Macdiarmid, 2021). These are just a few examples how current sustainable diets research may contradict the intent to support more sustainable food systems. As Webb et al. (2023) succinctly state, "to fully understand the true trade-offs that can result from dietary shifts, research must begin to incorporate all four pillars of sustainability, with specific attention on economic and social implications."

Addressing the myriad factors contributing to the underrepresentation of equity, culture, and social processes in sustainable diets research and action will likely require a variety of strategies. This may include explicitly integrating indicators and metrics linking social and economic issues to environment and health and incorporating these into modeling, life cycle assessments, and spatial analyses. Examples of such social metrics are wide ranging, and may include gender equity, child labor, farmer livelihoods, working

conditions and wellbeing, to animal welfare and female labor force participation (Webb et al., 2023). Challenges remain in collecting this data, however, given that women and child workers, migrants, and undocumented workers are often hidden from oversight, making their experiences difficult to identify and characterize (Webb et al., 2023). Other research suggests that empirical methodologies, such as ethnographic studies, in-depth qualitative interviews and surveys, can complement and address limitations of metric-oriented efforts (Monterrosa et al., 2020). Policymakers can also collaborate with local and international technical experts to conduct this work to improve feasibility and accuracy (Monterrosa et al., 2020). Nisbett et al. (2022) suggest that addressing inequities will necessarily require addressing power imbalances, improving accountability among the powerful, and elevating the voices and experiences of those who are marginalized and excluded from decision-making. They recommend utilizing a nutrition equity framework that integrates individual, social, political, commercial, cultural, and economic factors to frame research and equity action.

Adopting a multi- or transdisciplinary approach to research has also been suggested as a potential strategy. El Bilali et al. (2021) argue for overlooked social, economic, and political dimensions to be integrated into "a comprehensive, multidisciplinary agenda addressing the multifaceted (un)sustainability of [agri-food systems]" and for the adoption of a holistic approach in research that addressing the planet, people, profit and policy. Biesbroek et al. (2023) similarly argue for more interdisciplinary sustainable diets research that engages with policymakers and food system actors alike. A 2021 editorial by Schwarz et al. (2021) calls for more transdisciplinary research to support the transformation of food

systems, including research that addresses economic, ecological, and social processes within different levels of governance, addresses marginalization and inequality of places and peoples, and linking research with capacity building, education and co-learning. They recommend institutional analysis to identify drivers like regulations, property rights, power relations, market organization, information technology infrastructures, culture, and traditions to not only improve understanding of food system structures but also design effective solutions. Another recent review identified that efforts to integrate food systems approaches, such as sustainable diets and nutrition sensitive agriculture, focus on impacts rather than processes and on the negative linkages between food system components of agriculture, environment, and food, rather than actual evidence of possible positive correlations (Lamine et al., 2019). These authors suggest that studies regarding dietary change in particular overlook social processes that influence actual changes in diet which can be evidenced in recommendations for particular food intake without addressing whether and how their supply can be sufficiently and adequately distributed (Lamine et al., 2019).

1.5.2 Limitations

This study used a single database, Scopus, to conduct the literature search. Thus, research not catalogued by Scopus was not included in this study. Given that only peer-reviewed, academic literature was included, other scholarly, intellectual, and policy works not captured by these criteria but related to the topic of sustainable diets was excluded. A 2022 review of disciplinary publishing patterns, for example, found that journal articles

not only failed to capture more than half of the published works of 26 disciplines, nearly all of which are in the humanities and social sciences (Olejniczak et al., 2022). A comprehensive review and synthesis of scholarly works beyond journal articles is therefore an important area for future research. Additionally, this study used the search terms "sustainable diet" and "sustainable dietary pattern" to identify relevant research, which limit the search results to studies using this term, and may overly focus on the part of the food supply chain that addresses diet and individual diet related impacts.

Although these topic areas have some alignment with the FAO components of sustainable diets, it does not necessarily mean that these components are a good or best representation of the topic area and the literature the topics characterize, nor that the topic areas are a good or best representation of the components of sustainable diets depicted by the petals.

The three topics that do not explicitly align with the FAO components of sustainable diets (sustainable diets and food system policy, sustainable reformulation of aquaculture feed, and consumer behavior and attitudes toward plant-based meat alternatives) represent approximately half of the literature. One of these topics, sustainable diets and food system policy (representing 32% of the research), may be related to one or more of the FAO components of sustainable diets, but it does not fit neatly within this particular framework.

Similarly, while the topics related to aquaculture feed and consumer behavior are distinct topic areas in the topic model, they could be considered sub-topics in relation to the FAO sustainable diets framework. "Sustainable reformulation of aquaculture feed," for

example, could be considered a niche sub-topic of "environmental impacts of food production associated with dietary patterns" given that much of the justification for reformulating the feed for animals raised for human consumption is centered on improving the environmental sustainability of that production system (e.g., Reis et al., 2019; Sáez-Royuela et al., 2022; Weiss et al., 2020). "Consumer behavior and attitudes toward plant-based meat alternatives" could be considered a sub-topic of "strategies for healthy and sustainable diets" given that rationale for exploring plant-based meat alternatives and consumer behavior and attitudes toward them is largely to identify lower impact food products and support their consumption to improve health and sustainability outcomes (e.g., Birke Rune et al., 2022; Chezan et al., 2022; Papies et al., 2020; Trewern et al., 2022). If these two topics are considered sub-topics in the process of aligning the literature with the FAO framework, they bolster the trends described above in which the three FAO components of sustainable diets related to health, environment, and food security receive more research attention relative to the other components.

The process of assigning labels to the topics generated by the topic model revealed discrepancies between the terms that describe the topic and the articles represented by that topic, including the titles of articles. For example, while the top terms for topic 6, for example, include "production" along with terms such as environmental, impact, water, use, footprint, greenhouse_gas, emission, and reduce, the article titles indicate that the research is focused on impacts of diet and dietary patterns. The topic modeling analysis suggests that the research is focused on agricultural production, though the research titles use words that could be considered more consumer and consumption oriented. Similarly, examining

the top terms along with the article titles for topic 2 may suggest a similar tendency toward a consumption and consumer-oriented framing. This potential misalignment between research that measures food production impacts yet focuses on consumer-oriented policy may reveal both a gap and an assumption in the research and is an area for future research.

1.6 Conclusion

Using natural language processing to conduct this review presented the opportunity to perform a thematic scoping of the literature to identify overarching trends and themes in a way that was rapid, transparent, reliable, and reproducible. The body of sustainable diets research has grown over the last two decades with much of this growth occurring in the last several years. The results of this study demonstrate that although the sustainable diets body of work encompasses a wide range of subject areas, a majority of sustainable diets research can be characterized by three areas: Nutrition and Dietetics, Environmental Studies, and Food and Food Industries. Three additional subjects have risen in prominence in recent years – Public Health and Safety, Agriculture, and Medical Sciences – indicating that although the focus of the research is dominated by a few subjects, the disciplinary scope has and may continue to expand. The topic modeling analysis indicates that the FAO components of sustainable diets related to local and seasonal foods, culture, and equity receive relatively little research attention, whereas components of health, environment, and food security each align with approximately a third of the research literature. The narrow disciplinary focus of a majority of research and the imbalance in attention to the FAO components of sustainable diets suggests the need for more transdisciplinary research that

addresses areas of equity, culture, social processes, and context. Without it, trade-offs cannot be fully accounted for or considered. While focus and specificity in research is essential, sustainable diets studies that fail to acknowledge the full suite of sustainability dimensions and the broader food system in which they are situated runs the risk of inhibiting and contradicting equity and sustainability goals. This research must address the overlaps and intersections of sustainability dimensions to more holistically understand the need for, implications, and directions of sustainable diets and bolster a comprehensive, balanced body of knowledge to support a sustainable food systems transformation.

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CHAPTER 2. EXPLORING THE IMPACT OF SUSTAINABLE DIETS RESEARCH: A BIBLIOMETRIC AND ALTMETRIC ANALYSIS

2.1 Abstract

This exploratory study examines how sustainable diets knowledge is produced and what factors influence whether and which research is recognized as notable and reproduced. This study draws from the mutual aims of research impact evaluation and science of science and applies both these ongoing efforts and perspectives to the field of sustainable diets. Citation analysis was performed on 855 sustainable diets articles published between 2000-2022. High relative citation counts and moderate to strongly correlated altmetric scores reveal that a small selection of relatively homogeneous sustainable diets research articles has a high degree of influence and impact within the research community and beyond. The top 5% most cited sustainable diets research articles with high altmetric scores are more likely to be produced in high-income nations, from highly ranked academic institutions, and utilize quantitative and review methodologies than median cited articles. Articles in both top cited and median cited groups analyzed here were affiliated with research institutions predominately located in Europe and North America (compared to Africa, Asia, South America, and Oceania). Similarly, the majority of articles in both the top and median cited groups were described by two (out of seven) topic areas: sustainability impacts of dietary patterns and sustainable diets and food system policy. Articles from the first topic area were more likely to be in the top cited group than those from other topic areas. An analysis of the attention indicators that influence altmetric

scores finds that top cited articles are more likely than median cited articles to be captured and discussed in social media, news media, and policy sources. This demonstrates that a small number of homogenous articles from well-resourced nations and institutions dominate what is studied, what is highlighted and communicated in media, and what is translated into sustainable diets policy. While highly cited and visible research has made important contributions to the field of sustainable diets research, it does not reflect the breadth and extent of the available research. More work is needed to bridge the global north-south divide in research opportunities and publishing, to combat elite concentration in academia, and embrace diverse research agendas to successfully pursue a sustainable food system transformation.

2.2 Introduction

Sustainable diets have been identified as a critical part of an urgent food system transformation that is needed to meet global sustainability and human development goals (Fanzo & Miachon, 2023; Food and Agriculture Organization of the United Nations, 2018; Willett et al., 2019). According to the Food and Agriculture Organization of the United Nations (FAO), sustainable diets are those "with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources," (Burlingame & Dernini, 2012). Sustainable diets have been identified as both a driver of food system sustainability

as well as an outcome of that food system (Meybeck & Gitz, 2017). A growing body of work supports this integral role, indicating that sustainable diets have the power to both threaten and support environmental, social, and economic dimensions of food system sustainability (Canavan et al., 2017; IFPRI, 2020; Springmann et al., 2018; Willett et al., 2019; Zurek et al., 2022).

The field of sustainable diets has gathered attention in academic research and beyond in recent years. A 2024 study found demonstrated growth in the field of sustainable research, particularly since 2020 (Hricko et al., 2024/Chapter 1). Much of this work has focused on environmental and health impacts of sustainable diets (Hricko et al., 2024/Chapter 1). Research reviews suggest that dietary patterns emphasizing plant-based foods and limiting animal-based foods have improved health and environmental outcomes (Nelson et al., 2016; Reinhardt et al., 2020). A 2019 systematic review, for example, examined the impact of various dietary patterns on environmental outcomes, including water footprint, land use, and greenhouse gas emissions, and found that a plant-based diet optimized these environmental metrics (Chai et al., 2019). Additional research provides important nuance to these findings by highlighting that animal-based agriculture and consumption have notable environmental and health contributions and benefits. A 2022 study found, for example, that animal agriculture and food consumption has cultural, societal, and economic significance and can help achieve food security, though a well-managed approach that accounts for moderation in production and consumption is necessary (Leroy et al., 2022). A recent review further found that animal-based food consumption plays an important role in nutrition security, particularly in Sub-Saharan

Africa and South Asia. The review also concludes that animal agriculture can support land restoration, biodiversity, and greenhouse gas mitigation when scaled appropriately (Beal et al., 2023).

Regarding health outcomes, a 2018 systematic review determined that consuming diets high in plant-based foods was associated with a range of health metrics, including improved emotional and physical well-being, depression, quality of life, weight, diabetes management, and overall health (Toumpanakis et al., 2018). Two additional recent systematic reviews found that consumption of plant-based foods reduced cardiovascular disease and mortality and were linked to reduced blood pressure (Quek et al., 2021; Tomé-Carneiro & Visioli, 2023). It is important to note, however, that the composition of diets high in plant-based foods plays a role in the extent and direction of health outcomes. The growth in availability and consumption of highly processed plant-based foods address the desire for convenience and affordability, though they are high in fat, energy, sugar and salt and have higher environmental footprints than more minimally processed options (Macdiarmid, 2021). While consumption of diets high in healthy plant-based foods (low amounts of desserts, refined grains, and sugary snacks and drinks) are associated with a range of health benefits, including lower rates of cancer, mortality, and heart disease, diets with unhealthy plant-based foods (those that are minimized or avoided in healthy diets) are associated with higher risks of cancer, mortality, and heart disease (Thompson et al., 2023).

Institutions beyond academia, ranging from the World Bank to Bain & Company to the Rockefeller Foundation, have also turned their focus to sustainable diets (*Food System Transformation*, 2022; The Rockefeller Foundation, 2023; World Bank, 2023).

This attention is also demonstrated by numerous advisory reports focused on sustainable diets (IPES-Food, 2023; Searchinger et al., 2019). Alongside the growing attention to the field of sustainable diets research are efforts to mobilize this research into action. This is clear from initiatives to support the adoption of sustainable diets in state, national, and international advocacy and policy. Little work has been done, however, to understand the processes and practice of science within the field of sustainable diets, nor it's translation to and impact on scientific policy and advocacy. This goal of this study is thus two-fold – to address these gaps by investigating both the formation of knowledge in the field of sustainable diets and examining the impact of that research. Following the aims of both science and science and research impact evaluation, this inquiry ultimately seeks to inform decision making and investments in research and contribute to more effective policies that address complex societal challenges.

Digital data on scholarly efforts, from funding and collaborations to productivity and citations, has made it possible to explore the evolution of science itself. This has led to the emergence of the field of "science of science," or the examination of the practice of science itself. Science of science offers a quantitative look at the processes of scientific discovery, creativity, practice, and policy, and is driven by the "hypothesis that with a deeper understanding of the factors behind successful science, we can enhance the prospects of science as a whole to more effectively address societal problems," (Fortunato et al., 2018). By understanding and uncovering the mechanics of scientific practice, we can better inform research choices and support the development of more effective science policies and institutions (L. Liu et al., 2023). The goal is to harness quantitative data to

develop tools and practices that accelerate science to solve pressing socioecological problems.

The ability to use digital data to study scientific practice coexists alongside continuous efforts to evaluate and improve our understanding of research impact, or the reach and influence of a scholar's work. Many of those involved in conducting research, including academics and funders, are increasingly interested in understanding and evaluating research impact (Louder et al., 2021) and motivated by the recognition that researchers are accountable to the society that funds them (Williams, 2020). In the face of significant and pressing environmental and social challenges, research is expected to not only advance basic scientific knowledge, but also contribute to solutions to these complex problems (Louder et al., 2021). Combining the science of science with research impact evaluation is an opportunity to harness large datasets to shed light on the shared goals of understanding the practice of science and research. As well, this approach reveals the impact of that research on a range of audiences, from scholarly networks to broader society and policy makers.

2.2.1 Bibliometrics and Altmetrics in Science of Science and Research Impact

Bibliometric analysis is a methodology used in science of science to uncover research trends, patterns in collaboration, and explore the structure of scientific knowledge. It tends to utilize massive amounts of data, such as hundreds if not thousands of research records, and examines objective metrics, such as number of citations, publications, keyword and topic occurrences, which are often used and analyzed using both objective

(descriptive statistics) and subjective methods (thematic analysis). Bibliometric analysis is "useful for deciphering and mapping the cumulative scientific knowledge and evolutionary nuances of well-established fields by making sense of large volumes of unstructured data in rigorous ways" (Donthu et al., 2021). This allows scholars to develop new insights into scientific practice, including the following: research and knowledge gaps, new avenues of scientific inquiry, and their importance within the broader landscape of knowledge.

Research impact in academia has also traditionally been measured through bibliometric methods, including metrics such as number of publications and citation counts (Reed et al., 2021; Williams, 2020). Citation dynamics, in both science of science and research impact evaluation, are used to unpack interactions and patterns in research across geographic and temporal scales and "remains the dominant measurable unit of credit in science," (Fortunato et al., 2018). Despite this reliance on citation dynamics, and because of it, they have been scrutinized by many within academia over time (Fortunato et al., 2018). Although they are widely accepted, they are proxies for scholarly impact within the scientific community rather than perfect measures of research impact (Williams, 2020). Louder et al.'s (2021) work, for example, suggests that although publications in high impact factor journals have traditionally indicated success, these kinds of bibliometric measures fail to capture impact on policy. Similarly, Aksnes et al. (2019) conclude that while citations reflect elements of scientific impact and relevance and can be – and are – used as proxy of academic impact or influence in the academic community, they should be not used in isolation to evaluate research impact. They cannot alone reflect nuanced, or robust

measures of quality, nor do they capture dimensions of quality such as plausibility, originality, and societal value.

Though power and prestige in academia has traditionally focused on citations and other bibliometric measures in the scholarly system, such as journal impact factors (McKiernan et al., 2019), there is increasing recognition of the need to have and demonstrate wider societal impact (Williams & Grant, 2018). In addition to scholarly excellence, researchers are also expected to demonstrate their ability to communicate their findings to the media and beyond, influence policy and practice, or contribute to economic value (Williams, 2020). Scholars may seek to balance and combine these different fields of impact, building credibility and power within each, and thereby establishing a new form of power derived from impact itself that affords influential academics and institutions to disproportionately set and direct research agendas. As Williams (2020) describes, "actors that can successfully combine various forms of capital from different fields can translate this cumulative power into research funds, promotions, and other opportunities to influence the direction of science." Capturing these broader fields of impact as well as characteristics of researchers and their affiliated institutions can shed light on who holds positions of power in science.

Science of science joins the calls from within the research impact evaluation community to broaden the scope of indicators for measuring research impact. In a 2018 overview of science of science, Fortunato et al. (2018) liken the reliance on citation metrics and dynamics to a hierarchical system using one-dimensional currency, in which the "rich-get-richer," where research within the dominant paradigms by established scientists

continues to garner support while more junior scientists and novel ideas suppressed. They recommend addressing this by extending the range and number of indicators considered. Recommendations also include developing and including alternative metrics, or "altmetrics," such as those that capture social media and web activity, news media attention, and policy mentions to capture circulation of knowledge beyond the academic community.

Incorporating altmetrics into traditional bibliometric examinations of research offers the chance to broaden our understanding of both the import and impact of scientific practices. This is because altmetrics reveal the movement of scholarly practices into other social fields. Altmetrics were initially expected to be a faster and more granular measure of research impact than traditional bibliometric measures, such as citation analysis (Fang et al., 2020). Research suggests that altmetrics perform best as a complement to citation analysis rather than a replacement for multiple reasons. Firstly, the overall presence of altmetric data for published research remains low (Fang et al., 2020). Altmetric scores that do exist for publications may be more reflective of a journal or author(s)' science communication efforts than interest in the research that developed more independently among academic and external audiences. For examples, some journals have a strong social media presence and have strategies to actively communicate and disseminate research online, which is reflected in altmetric scores (Studenic & Ospelt, 2020). Altmetric scores are also skewed by time since publication. They immediately reflect activity following publication, whereas citation counts following publication often only increase after a certain delay. The inverse is also seen, where older articles typically have a lower altmetric

score but higher citation count (Studenic & Ospelt, 2020). Despite these limitations, altmetrics offer a look into the "broadness" of research impact, or the diversity of impact beyond the scholarly realm, and can be best used in concert with citation counts to examine different types of impact for different audiences (Bornmann, 2014).

This study draws from the mutual aims of research impact evaluation and science of science and applies both the ongoing efforts and lessons of research impact evaluation and the perspectives and digital data analysis methods from science of science.

2.2.2 Research Aims and Questions:

This study combines a science of science and research impact evaluation approach to the growing field of sustainable diets. This work aims to shed light on the practice of science itself within the field of sustainable diets research by using digital data to investigate citation dynamics, incorporate altmetrics, and assess indicators of power associated with the research institutions driving the research. This research also examines whether these indicators of power as well as characteristics of the research, such as study methodology and dominant themes, are associated with research impact. The following research questions aim to examine how sustainable diets knowledge is produced and what factors influence whether and which research is recognized as notable and reproduced.

Part 1. Which sustainable diets articles and journals have the highest scholarly impact as represented by citation count and altmetric scores?

1. How do citation counts vary among articles and journals with the sustainable diets literature? Which papers and journals receive the highest relative citation counts?
2. What are the Altmetric scores for the papers with the highest relative citation counts? What is the Altmetrics coverage rate for these papers?

Part 2. What is the relationship between traditional bibliometrics and altmetrics?

1. What is the correlation between citation counts and altmetric scores among papers deemed high performing using traditional measures of academic research impact (highest relative citation counts)?
2. How does use of altmetric attention indicators, such as policy sources and news mentions, vary between the most highly cited and median cited research? How do altmetric scores for the most highly cited research compare to those for median cited articles?

Part 3. How are measures of academic power associated with research impact as measured by citation counts? How are characteristics of the research content, such as study methodology and dominant theme, associated with research impact?

1. How are article characteristics associated with the institutions driving the research (global institutional ranking, geographic region of primary institutions, economic status of an institution's home country) associated with research impact?
2. How are study methodology, dominant research themes, and open access status associated with research impact?

2.3 Methods

2.3.1 Literature Search

These questions were answered by surveying and analyzing sustainable diets literature. A literature search was conducted using Scopus, a comprehensive database covering 330 disciplines and over 7,000 publishers (*Scopus Content*, 2024). Research databases generally only present citation count data contained within a particular database. Conducting the literature search using multiple databases would therefore introduce inconsistent and incompatible citation count data. Only a single database was therefore queried to support consistency in citation count data. In addition, expanding the search to additional databases would provide only marginal benefit due to the comprehensive nature of Scopus. For example, Scopus indexes 99% of the journals indexed by Web of Science (Singh et al., 2021).

The database search was conducted on February 8, 2023 using the terms "sustainable diet", "sustainable diets" and "sustainable dietary pattern*". The search was applied to article titles, abstracts, and keywords. The use of one or just a few key search terms or phrases is a common approach in research that aims to survey a large body of scientific work (Cooper et al., 2020). Peer-reviewed, academic literature published between 2000-2022 was included in the search to establish consistency across the type of research and academic scholarship considered. The 1,016 records identified were screened for inclusion and to eliminate duplicates in a process described in more detail in Hricko et al. (2024, forthcoming). A total of 855 articles were included in the citation analysis.

2.3.2 Citation and Altmetric Dynamics

Publication citations were examined to shed light on the relative influence of the studies within this dataset on the research community. While citations are just one metric for examining research impact and may reflect more rhetorical usefulness than actual influence, they are a widely used measure for determining the influence of academic work and research suggests that higher citation counts lead to greater reader engagement and that papers with high relative citation counts "influence the research frontier much more than their raw citation counts imply," (Teplitskiy et al., 2022). This study therefore examines the distribution of article and journal citations within this dataset and highlights the top most cited articles and journals. The determination of "most cited articles and journals" was based on the distribution of citations among the articles and journals. This study examines the top 5% most cited articles as they account for nearly half (44%, n=43) of all citations in the dataset. The top 10% most cited journals were examined as they contained 75% (n=26) of all citations in the dataset.

A second subset of the overall dataset was selected from the median most cited articles to provide a comparison group for statistical analyses to test whether characteristics of the top most cited articles differ from other articles in the dataset. The median citation count for the overall dataset was 6. Forty-one articles had this median citation count and were selected for inclusion in the comparison group. To create a comparison group with an equal sample size as the top 5% most cited articles (n=43), two additional articles were selected for inclusion: one article with a citation count just above the median citation count, or 7, and one with a citation count just below the median, or 5. Since multiple articles had

citation counts of 7, and 5, one article was randomly selected from each of these citation count groups for a total comparison group size of 43. All statistical analyses were performed using R Statistical Software (v.4.4.0, R Core Team, 2021) in R Studio (version 2024.04.1+748, Posit Software, 2024).

Altmetric scores for each of the top 5% most and median cited articles were identified using the Altmetric database. Each of the article titles was entered into the database and the corresponding Altmetric score was recorded. Seventeen attention indicators that contributed to the summary Altmetric scores for these articles were also recorded and examined. Two additional attention indicators related to citation counts ("Mendeley readers," and "citation dimension,") were excluded to avoid redundancy with the Scopus citation count data. Two more citation related attention indicators ("CiteULike," and "Connotea") were also excluded as they were very rarely used (by six and one papers, respectively) and are discontinued services. Two sample z-tests of proportions were performed to compare the frequency of use of the five most commonly used attention indicators (news outlet mentions, blogs, policy sources, X users, and Facebook pages) between the top 5% most cited article and median cited article groups. A Mann-Whitney U test was also performed to test whether the difference in the altmetric scores between the two groups was statistically significant. This test was also used to determine if the scores for the five most commonly used attention indicators were statistically significantly different between the two groups.

Both Spearman's rank and Kendall's Tau tests of correlation were used to calculate the correlation between citation counts and altmetric scores among the papers with the top

5% most cited and median cited articles. Spearman's rank correlation test generates is a widely used correlation coefficient. Due to the high number of tied rankings (i.e., the citation count=6 for 41 of the median articles), it is not possible to calculate an exact p-value. Kendall's Tau test is similar to Spearman's in that it is appropriate for data that is not normally distributed. Kendall's Tau test, however, is not as sensitive to ranking ties and was therefore used in addition to Spearman's test to triangulate the magnitude and direction of a possible association between citation counts and altmetric scores.

2.3.3 Article and Research Characteristics

A variety of article characteristics were collected and recorded to describe the dataset (Figure 2-1). These include those that reflect the resources and potential power of the affiliated research institutions (world region, institutional ranking, OECD member status) as well as characteristics of the research itself (methodological approach, topic area, open access status). They were also used to examine whether the top 5% most cited articles differed from those with the median citation counts. These characteristics are described in more detail below. Logistical regression was performed in R Studio (as described above) to assess the association of an article characteristic with the dichotomous dependent variable of being in the top 5% most cited articles or in the median cited articles. When pairwise comparisons were performed, a Benjamini-Hochberg procedure was used to control for a false positive discovery rate (Benjamini & Hochberg, 1995). In this procedure the pairwise comparison p-values are ranked in order of smallest to largest. Each p-value is compared to its Benjamini-Hochberg critical value, calculated as $(i/m)Q$ where i=rank,

m=total number of tests, and *Q*=the false discovery rate, or 0.05 for this study. The largest p-value that is less than its corresponding critical value is significant, as are all p-values smaller than it.

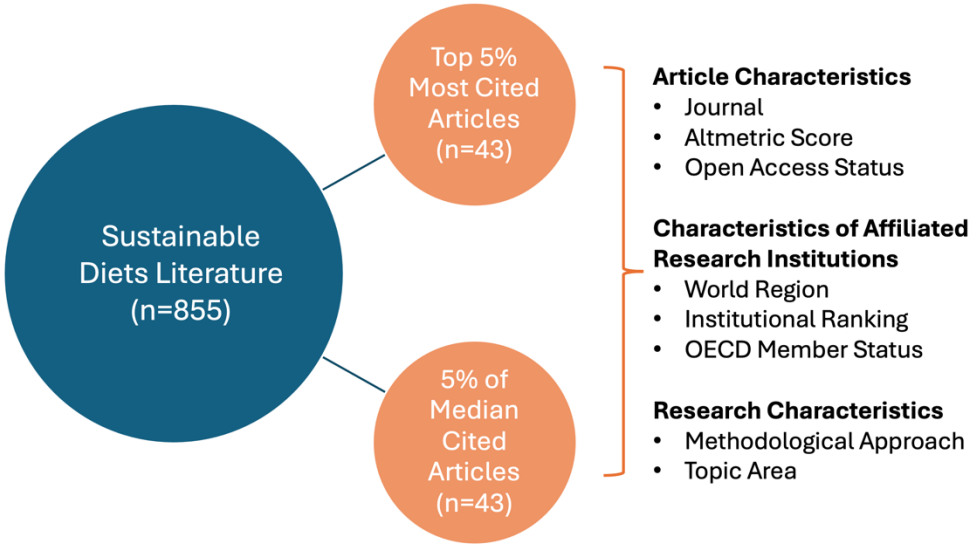

Figure 2-1. Visual representation of the data collection. The top 5% most cited and 5% of median cited articles were selected from the full sustainable diets literature dataset (n=855) used to perform the citation analysis. Article and research characteristics collected for each of the top most and median cited articles considered are displayed at right.

Institutions associated with each article were identified by examining the research affiliations of the first and last authors. This analysis examines the affiliations of these particular authors because of the roles they are often deemed to have in the research and writing process. For example, though author order in scholarly publications can vary by discipline and profession, the first position often indicates the principal author who led the writing and research. The last position often indicates a senior author or supervisor who made significant contributions to the research and manuscript (Kuper et al., 2023). The

first institutional affiliation listed for the first and last authors in each publication was recorded, including the institution name and location. The institution locations were then categorized by region using Our World in Data's six world region system (Europe, North America, Oceania, Africa, South America, Asia) (Our World in Data, 2018). Each country's Organisation for Economic Co-operation and Development (OECD) member status was also recorded. OECD member nations are those that have committed themselves to democracy and market economies, the majority of which are considered high-income countries with "very high" Human Development Index scores. OECD member status thus reflects one measure of a nation's economic development and is used in this study as an indicator of the economic wealth of the first and last author's institutional locations.

World university rankings, despite growing concerns about the undue influence of these ranking systems and the companies that produce them, have substantial influence and impact on university communities and society (Nassiri-Ansari & McCoy, 2023). To capture this influence, the world ranking of the first institutional affiliation, if it was a university, was identified and recorded for the first and last authors of each of the top 5% most cited and median cited papers. The QS World Rankings system, developed by Quacquarelli Symonds, a higher education analytics firm, was used as it is one of the oldest, most influential, and well-known ranking systems (Nassiri-Ansari & McCoy, 2023; Universities of the Netherlands, 2023). The QS ranking system sometimes uses a range to describe the rank of an institution, e.g., Tufts University's ranking is 1001-1200. In these situations, the average of the range's minimum and maximum was calculated and used to describe the institution's ranking for the purpose of statistical analyses.

The top 5% most cited and median cited articles were also categorized by study type to capture the methodological approach of the research. The study types considered and assigned were qualitative, quantitative, mixed methods, review, and unclear/other. Each article was reviewed and assigned one to one of these categories according to the methodological approach described and taken in the article. Determination of what constitutes each method was based on descriptions provided in Creswell and Plano Clark's text, "Designing and Conducting Mixed Methods Research," (2018).

The articles analyzed in this study were also assigned one of seven topic areas that describes the dominant theme in each of the papers. These seven topic areas were determined in a thematic scoping analysis using topic modeling, a natural language processing method. The methodology used to identify these topic areas is described in depth in Hricko et al. (2024, forthcoming). It was performed using the same 855 article dataset as the one used for the citation analysis in the present study. The subset of articles included in the top 5% most cited and median cited articles and analyzed in the logistical regression models were also part of the thematic scoping analysis dataset.

Lastly, the open access status of each top 5% most and median cited article was recorded. Some research indicates that open access is associated with greater overall citation counts (Bautista-Puig et al., 2020; Piwowar et al., 2018) and more diverse citations, as measured by institutions, countries, regions, fields of research, and more (C.-K. Huang et al., 2024). Other research indicates that this relationship may be limited and vary by discipline (Dorta-González et al., 2017) and influenced by factors other than open access status (Basson et al., 2021).

2.4 Results

2.4.1 Citation Count Dynamics by Article and Journal

The 855 articles in the dataset had an average of 22 citations (range=0-553, median=6). Seventy-five percent of the articles had 0-21 citations. The top 5% of most cited articles contain almost half (44%, n=43) of all the citations in the dataset, while the top 2% of most cited articles contain 29% of all the citations in the dataset. The 25% of articles with lowest citation counts had either 0 or 1 citations (n=220).

The 255 journals in the dataset had an average of 74 citations (range=0-1192). The top 10% of journals by citations (n=26) contain 75% of all citations in the dataset. The bottom 25% of journals by citations had one or no citations (n=69). Just over half of the journals in the dataset (56%, n=144) had between 0-10 citations. The top 10% of journals by citation count, the percent of total citations by journal, and the number of articles in each of these journals within this dataset are listed in the table below (Table 2-1). Of note is that the number of articles in the top 10% most cited journals varies. The journal with the second highest percentage of total journal citations, *Advances in Nutrition*, published 14 articles, whereas the fourth most cited journal, *Nutrients*, published 71. This suggests that it is not clear from the number of citations a journal has whether the impact is from a small number of highly cited papers, or from publishing a large quantity of papers. Without looking at each of the individual articles within each journal, it is also not possible to determine whether the articles are contributing evenly to the overall citation count of the journal.

Table 2-1. Top 10% of Most Cited Journals

	Journal Title	Percent of Total Journal Citations	Number of Articles in Journal
1	Public Health Nutrition	6.4	34
2	Advances in Nutrition	5.9	14
3	Appetite	5.7	25
4	Nutrients	5.4	71
5	Proceedings of the National Academy of Sciences of the United States of America	4.8	5
6	Journal of Cleaner Production	4.5	32
7	Sustainability	3.9	63
8	Foods	3.7	19
9	PLoS ONE	3.2	6
10	American Journal of Clinical Nutrition	3.0	11
11	Frontiers in Nutrition	2.9	34
12	Science of the Total Environment	2.9	15
13	Food Policy	2.9	8
14	The Lancet Planetary Health	2.7	7
15	Philosophical Transactions of the Royal Society B: Biological Sciences	2.1	1
16	Ecological Economics	1.8	7
17	Agronomy for Sustainable Development	1.8	1
18	Trends in Food Science and Technology	1.8	9
19	Aquaculture	1.7	8
20	International Journal of Life Cycle Assessment	1.5	9
21	Global Food Security	1.5	15
22	Nutrition Reviews	1.2	5
23	Nutrition Bulletin	1.1	12
24	European Journal of Clinical Nutrition	1.1	3
25	Environmental Health	0.9	2
26	Environmental Science and Policy	0.9	3

2.4.2 Citation Count and Altmetric Scores

Altmetric scores were collected for both the top 5% most cited and the median cited articles in this dataset. All top 5% most cited articles and 31 (72%) of the median 5% of articles had altmetric scores. Articles without an altmetric score were recorded as having a score of 0. Correlation tests found a moderate to strong positive correlation between altmetric scores and citation counts (Spearman's test, rho=0.68, $p<0.001$; Kendall's Tau, tau=0.5, $p<0.001$).

The use of altmetric attention indicators was also examined among the top 5% most cited and median cited articles with an altmetric score (n=43 and n=31, respectively). The frequency of use of these attention indicators is depicted in Figure 2-2, below. Five attention indicators (X users, policy sources, news outlets, Facebook pages, and blogs) are used in 50% or more of the altmetric scores of the top 5% most cited articles whereas only one attention indicator, X users, is used in at least half of the altmetrics scores of the median cited articles.

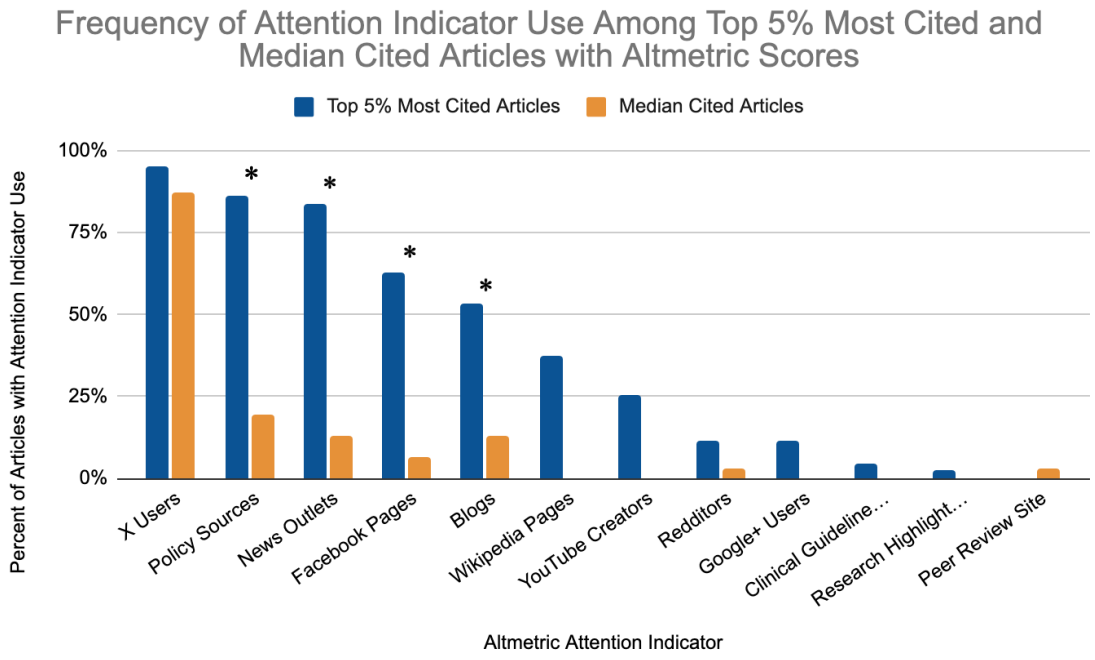

Figure 2- 2. The frequency of altmetric attention indicator use among the top most and median cited articles with altmetric scores (n=43 and n=31, respectively). The full labels for the two attenuated altmetric attention indicators are clinical guideline sources and research highlight platforms. Two-sample tests of proportions were performed on the five most used indicators (X users, policy sources, news outlets, Facebook pages, Blogs). Statistical significance is indicated with an asterisk.

The frequency of use of the five most commonly used indicators between the top 5% most cited and median cited groups was compared using two sample z-tests of proportions. Frequency of use of the X user attention indicator in the top 5% most cited group is not statistically significantly different than in the median cited group ($p=0.395$). In contrast, the frequency of use of the other four attention indicators is statistically significantly different between the two groups, with the top 5% most cited group using these attention indicators significantly more than the median cited group ($p<0.001$, Table 2-2).

Table 2-2. Results of the two sample z-tests of proportions comparing attention indicator frequency of use between the top and median cited groups.

	Articles Using Indicator (number, percent)			
Attention Indicator	**Top 5% Most Cited Article (total=43)**	**Median Cited Articles (total=31)**	**X-squared**	**p-value for two-sided test, df=1**
X users	41, 95%	27, 87%	0.72	0.395
Policy sources	37, 86%	6, 19%	30.23	<0.001
News outlet mentions	36, 84%	4, 13%	33.58	<0.001
Facebook pages	27, 63%	2, 6%	21.69	<0.001
Blogs	23, 53%	4, 13%	11.11	<0.001

There was a statistically significant difference in altmetric scores between the top 5% most cited articles (mean = 246.9, median = 72) and the median cited articles (mean=10.5, median = 4, $p < 0.001$). There were also statistically significant differences in the attention indicator scores for news outlet mentions, blogs, policy sources, X users, and Facebook pages between the two groups (Table 2-3 below).

Table 2-3. Comparison of altmetric scores and attention indicator scores between the top most and median cited articles

	Attention Indicator Scores			
Indicator	**Top 5% Most Cited Article (mean, median)**	**Median Cited Articles (mean, median)**	**W**	**p-value**
Altmetric Score	246.9, 72	10.5, 4	125.5	<0.001
News outlet mentions	20.3, 4	0.5, 0	206.5	<0.001
Blogs	3, 1	0.01, 0	488	<0.001
Policy sources	3.8, 3	0.2, 0	174.5	<0.001
X users	75.2, 18	9, 3	421	<0.001
Facebook pages	5.1, 1	0.05, 0	367	<0.001

2.4.3 Relationship Between Article Characteristics and Being a Top 5% Most Cited Article

World Region

Each article was assigned two regional affiliations: one based on the location of the first affiliation listed for the first author, and one based on the location of the first affiliation listed for the last author. The table (Table 2) below depicts the regional distribution of research articles in the top 5% most cited and median cited groups for both the first and last author affiliation. Given the small sample size and the small number of articles for numerous world regions, the regional categories were combined in the logistical regression models. Given the dominance of Europe, and then North America, as the regions with the most articles for both first and last author and both median cited and top 5% most cited groups, they were combined into one group, and Oceania, Africa, South America and Asia were combined into a second group.

Table 2- 4. Distribution of articles across six world regions based first and last author primary affiliations in both median cited and top 5% most cited groups

	First Author		**Last Author**	
Region	*Median Cited*	*Top 5% Most Cited*	*Median Cited*	*Top 5% Most Cited*
Europe	24	32	25	33
North America	7	7	8	6
Oceania	5	2	5	2
Africa	3	0	2	0
South America	2	0	1	0
Asia	2	3	0	2

The logistic regression model looking at the effect of world region on being in the top 5% most cited articles based on the first author's location found that it was not statistically significant predictor (p=0.055). For regions based on the location of the last author's primary affiliation, results were also insignificant (p=0.076).

OECD Member Status

As with regional assignments and institutional affiliations, articles were assigned two OECD classifications, one for both the first and last authors based on the location of the first listed affiliation. For the first author's primary affiliation, 95% (n=41) of the top 5% most cited articles were OECD member nations, while 81% (n=35) of the median cited articles were member nations. For the last author's primary affiliation, 98% (n=42) of the top 5% most cited articles were OECD member nations, while 86% (n=37) of the median cited articles were member nations.

The logistic regression models looking at the effect of OECD member status on being in the top 5% most cited articles based on the first author's location and the last author's location found that it was a statistically significant predictor (p=0.037 and p=0.039, respectively). The follow-on pairwise comparison using likelihood ratio tests found that, for first author affiliation, being an OECD member nation increased the odds of being in the top 5% most cited articles by a factor of 4.69 (95% CI = 1.09-32.43, p=0.038). Similarly, for the last author affiliation, being an OECD member nation increased the odds of being in the top 5% most cited articles by a factor of 6.81 (95% CI=1.094-131.788, p=0.039).

Institutional Ranking

Similar to the regional assignments, each article received two institutional rankings: one for the first author's primary institutional affiliation, and one for the last author's primary institutional affiliation. Descriptive statistics for this variable are shared in Table 3 below. The designation of "ranking not applicable" indicates that the first affiliation listed for the author was not an academic institution.

Table 2- 5. Descriptive statistics for the institutional ranking of the first and last author's primary affiliation

	First Author		**Last Author**	
	Median Cited	*Top 5% Most Cited*	*Median Cited*	*Top 5% Most Cited*
Ranking (mean, median, range)	486, 328, 28-1301	318, 207, 3-1401	429, 292, 28-1301	229, 207, 3-876
Number Unranked	6	3	8	3
Number Ranking Not Applicable	11	9	10	13

The logistic regression models looking at the effect of institutional ranking on being in the top 5% most cited articles based on the first author's location and the last author's location found that it was a statistically significant predictor (p=0.02 and p=0.014, respectively). The follow-on pairwise comparison using likelihood ratio tests found that, for first author affiliation, for every one unit increase in the ranking, the odds of being in the top 5% most cited articles decreased by 0.001% (OR= 0.998, (95% CI=0.996-0.9997, p=0.02)). Similarly, for every one unit increase in the ranking associated with the last author, the odds of being in the top 5% most cited articles decreased by 0.003% (OR=0.997, 95% CI=0.995-0.9995, p=0.014)). Since an increase in the ranking number would be

considered a worse ranking (i.e., the best ranking is #1), these trends indicate that as rankings improve, the odds of being in the top 5% most cited articles increases.

Methodological Approach

Each article was categorized by methodological approach and assigned to one of the following categories: qualitative, quantitative, mixed methods, review, or unclear/other. Table 4 below shows the number of articles in each of these categories by citation count group. Given the small sample size and the dominance of reviews and quantitative studies (the categories with the most articles for both median cited and top 5% most cited groups), the study categories were combined in the logistical regression models – review and quantitative remained as standalone categories, and qualitative, mixed methods, and unclear/other were combined into another group.

Table 2- 6. Number of articles in each methodological categorization for both median and top 5% most cited article groups

Methodological Approach	**Median Cited**	**Top 5% Most Cited**
Review	10	17
Quantitative	16	23
Qualitative	6	3
Mixed Methods	8	0
Unclear/Other	3	0

The logistic regression model looking at the effect of methodological approach on being in the top 5% most cited articles found that it was a statistically significant predictor ($p=0.001$). Pairwise comparisons were then calculated using likelihood ratio tests. The

effect of being a review study on the odds of being in the top 5% most cited articles compared to being a quantitative study was not statistically significant (OR=1.18, 95% CI=0.025-0.439, p=0.41)). A review study had a statistically significantly greater odds of being in the top 5% most cited articles than a qualitative, mixed methods, or unclear/other study (OR=9.63, 95% CI=0.007-0.412, p=0.004). A quantitative study also had a statistically significantly greater odds of being in the top 5% most cited articles than a qualitative, mixed methods, or unclear/other study (OR=8.15, 95% CI=0.026-0.439, p=0.001). The false positive discovery rate for multiple pairwise comparisons among methodological approaches was controlled for using the Benjamini-Hochberg procedure. Using this procedure confirmed the statistical significance of the above pairwise comparisons.

Topic Area

Each article was assigned one of seven topic areas, identified in the below table. Given the small sample size and clustering of articles around topics 1 and 2, the topic areas 3-7 were combined into one group and compared to topics 1 and 2.

Table 2- 7. Distribution of articles by topic areas and by median cited and top 5% most cited groups

Topic Area	Median Cited	Top 5% Most Cited
1. Sustainability impacts of dietary patterns	9	20
2. Sustainable diets and food system policy	17	11
3. Strategies for healthy and sustainable diets	2	1
4. Consumer behavior and attitudes toward plant-based meat alternatives	7	2
5. Role of traditional and/or alternative crops in sustainable diets and food systems	5	4
6. Environmental impacts of food production associated with dietary patterns	1	5
7. Sustainable reformulations of aquaculture feed	2	0

The logistic regression model looking at the effect of topic area on being in the top 5% most cited articles found that it was a statistically significant predictor (p=0.04). Pairwise comparisons were then calculated using likelihood ratio tests. The effect of being in topic area 1 compared to topic area 2 on the odds of being in the top 5% most cited articles was statistically significant (OR=3.43, 95% CI=0.021-0.714, p=0.018). An article in topic area 1 compared to topic areas 3-7 also had a statistically significant effect on being in the top 5% most cited articles (OR=3.15, 95% CI=0.023-0.773, p=0.023). Lastly, articles in topic area 2 compared to topic areas 3-7 did not have statistically significant effect on the odds of being in the top 5% most cited articles (OR=0.92, 95% CI=0.377-3.177, p=0.872). As with the pairwise comparisons examining methodological approach above, the Benjamini-Hochberg procedure was used to control for a false positive discovery rate for the multiple pairwise comparisons by topic area. This procedure confirmed the above statistical significance.

Open Access

Of the top 5% most cited articles, 81% (n=35) were open access. Of the median cited articles, 86% (n=37) were open access. The logistic regression model examining the effect of open access status on being in the top 5% most cited articles found that it was a statistically insignificant predictor (p=0.56).

2.5 Discussion

In this article, we examined the practice of science itself within the field of sustainable diets by investigating citation dynamics. In our citation analysis, we found that citation counts were highly skewed, with top 5% most cited articles containing nearly half (44%, n=43) of all the citations in the dataset and 25% of the articles with the lowest citation counts had either 1 or 0 citations. Similarly, the citation analysis by journal found that the top 10% of journals by citations contain 75% (n=26) of all the citations in the dataset, while the bottom 25% of journals by citation counts had just one or no citations.

In examining the relationship between citation scores and altmetric scores, we found a moderate to strong positive correlation between these two metrics. Among the 17 attention indicators used in the summary altmetric scores in this dataset, five (X users, policy sources, news outlet mentions, Facebook pages, and blogs) were used in 50% or more of the top 5% most cited article altmetric scores, while just one (X users) was used in 50% of the median cited article altmetric scores. While there was no statistically significant difference in the use of the X user attention indicator between the two groups, policy sources, news outlet mentions, Facebook pages and blogs were more frequently used

indicators in the summary altmetric scores of top 5% most cited articles compared to the median cited articles. The altmetric score among the top cited articles was also statistically significantly greater than that among the median cited articles. We also examined whether and how indicators of power associated with research institutions and characteristics of the research are associated with research impact. We examined several characteristics of the research articles that reflect the resources and power of the affiliated research institutions (world region, institutional ranking, OECD member status) as well as qualities of the research itself (methodological approach, topic area, open access status). The findings here suggest that a number of article characteristics are associated with citation counts. In particular, OECD member status, institutional ranking, methodological approach, and topic area were found to be positively associated with citation counts, while world region and open access status were not statistically significantly associated with citation counts.

2.5.1 Research Implications

As summarized above, a small number of papers receive a high degree of attention, as measured by citation counts as well as Altmetric scores, relative to the rest of the sustainable diets literature included in the dataset. Research suggests that it is this relative aspect of citation counts, compared within a subject area and topic, that provides an indicator of high research impact and influence (Teplitskiy et al., 2022). Based on traditional understanding of citation dynamics and their function in reflecting research impact, the concentration of the majority of citations in this selection of sustainable diets research among a relative few research articles suggests that they have an outsized reach

compared to the rest of the research in the dataset. Existing research indicates that while the type of citation distribution observed here is consistent with some scientific fields, it is not a universal pattern (Albarrán et al., 2011; Albarrán & Ruiz-Castillo, 2011; Brzezinski, 2015). A 2015 examination of Scopus journal articles published between 1998-2002 across 27 subject areas found a high degree of citation concentration in 14 science fields (e.g., "Chemistry," "Environmental Science," "Agricultural and Biological Sciences," "Materials Science"), though not among the remaining 13 subject areas, which included those in humanities and social sciences, formal sciences, and life sciences (Brzezinski, 2015). Previous research has also found that, on average, 2% of the most highly cited articles in a field account for approximately 13.5% of all the citations within that field (Albarrán et al., 2011; Albarrán & Ruiz-Castillo, 2011). The citation concentration observed in the present study follows a similar trend, yet demonstrates a greater degree of concentration, with 2% of sustainable diets articles accounting for 29% of citations in this field. This is particularly notable as a recent 2024 study found, contrary to earlier findings, a decreasing trend in citation concentration (Kozlowski et al., 2024). The authors identify a decline in the number of uncited articles as primary driver of the increasingly scattered citation distribution.

Since open access status can aid in reducing barriers to research access by making research visible and available to a wider audience, it may follow that open access articles receive a greater number of citations and thus attention (Bautista-Puig et al., 2020; Piwowar et al., 2018). This study, however, did not find that OA status influenced the odds of being in the top 5% most cited articles compared to median cited articles. This follows other

research, such as that by Dorta-González et al. (2017) suggesting that this relationship may be limited and vary by discipline. Additional research suggests that citation counts are influenced more by factors other than open access status (Basson et al., 2021), which is consistent with the findings of this study. Given the small sample size in this study, however, and the fact that nearly all articles were open access, these findings may not be generalizable to the broader sustainable diets literature.

Nutrients and *Sustainability* are within the top 10% of most cited journals. What makes them notable is the number of articles they published within this dataset, approximately double the next highest number of articles. This suggests that these journals' influence/impact could be related to the volume of publications rather than publication of highly cited articles. These results warrant a closer look at the patterns of publication and the articles published by these journals before deeming certain journals higher impact than others.

Altmetrics seek to reflect broader impacts than citation count alone by measuring the reach of publications to media, society, and policy (Bornmann, 2014). Numerous studies examine whether altmetrics can supplement or supplant the traditional citation count metric as a research impact evaluation system (e.g., Cho, 2021). Some research suggests that altmetrics may best serve as a complement to traditional citation count metrics rather than a replacement. This is due to overall low coverage rates of altmetric scores (Fang et al., 2020) and the way that scores may be more reflective of author communication and outreach efforts than independent interest in the research (Studenic & Ospelt, 2020).

Used together with citation count data, though, altmetrics may shed light on other audiences reached by academic research (Arroyo-Machado & Torres-Salinas, 2023).

Research over the past decade has explored the role of altmetrics by examining the correlation between citation counts and altmetric scores, finding inconsistent and varied results. Numerous research studies found weak or nonexistent correlations between citations and altmetric indicators (Bornmann, 2015; Costas et al., 2015; de Winter, 2015; C. L. Liu et al., 2013; Rosenkrantz et al., 2017). This type of relationship could indicate that altmetrics capture different dimensions of impact than citation counts (Dinsmore et al., 2014). Other studies, however, have found moderate or high degrees of correlation, indicating that altmetrics may not provide substantial additional or alternative information than citation counts (Sud & Thelwall, 2014). For example, an earlier study examined the correlation between altmetric scores and citation counts for 20,000 randomly selected publications from the Web of Science and found a moderate positive correlation. They highlighted the uncertain value and meaning of altmetrics as an area for future research (Zahedi et al., 2014). Other studies are consistent with this finding (e.g., Huang et al., 2018). The moderate to strong positive correlation between altmetrics and citation count revealed in this study is in line with these findings and calls into question the extent to which altmetrics provide an alternative measure of impact in this sample of the sustainable diets literature.

Another interpretation of a moderate to strong positive correlation is that higher social media use, a measure captured by altmetrics, leads to higher visibility, research dissemination, and citation counts. A 2019 study (Smith et al.) in the field of

gastroenterology found a strong association between social media exposure and citation counts. Two additional studies go farther, concluding that the positive correlation suggests that researchers should actively use social media to increase the visibility and reach of their work as well as increase the number of citations in their field (Bardus et al., 2020; Ouchi et al., 2019). The results of the present study support the role of social media use in generating and boosting altmetric scores, though these dynamics are nuanced. For example, the finding that the use of the most frequently used attention indicator in both groups, the X user attention indicator, does not statistically significantly differ between the top and median cited groups suggests that it may be an important factor influencing altmetric scores of both highly cited and median cited articles. The average number of X users was statistically significantly greater in the top 5% most cited group (mean=75.2 users) compared to the median group (mean=9 users), indicating that greater use of this platform may elevate visibility, influence the number of citations, and contribute to the statistically significantly greater altmetric scores of the top 5% most cited group compared to the median cited group.

As noted above, however, the relationship between the X user and other social media indicators and altmetrics are nuanced and focusing on this indicator alone paints an incomplete picture of the altmetric scores in this study. For example, the X user attention indicator is the only indicator that is used in at least half of the altmetric scores (87% of articles) in the median cited article group, with all other indicators considered here used in less than 25% of the median article group. In comparison, five indicators (X users, policy sources, news outlets, Facebook pages, and blogs) are used in 50% or more of the altmetric

scores of the top 5% most cited articles, with an additional two, Wikipedia pages and YouTube creators, used in at least 25% or more of the scores. This suggests that while use of the X platform may be the driver behind getting established on the altmetric scoreboard, it is a combination of X use, a mix of indicators such as policy sources, traditional news media, blogs, and Wikipedia, and other social media platform use (i.e., Facebook and YouTube) that drives some articles to the top of the scoreboard.

These findings shed additional light on the dynamics that may be driving the moderate to strong positive correlation between citation counts and altmetric scores in the sustainable diets literature. While altmetrics may not provide an entirely distinct measurement of impact, they may reflect that the use of social media, particularly X use, could be increasing the visibility and dissemination of this research and contributing to higher citation counts. The higher altmetric scores of the most highly cited sustainable diets literature are also driven by additional factors, such as policy and news mentions, as well as a broader range in the type of social media use. Whether this correlation between citation counts and altmetric scores applies to the sustainable diets body of work beyond the subset of articles considered here warrants additional research.

While more research can shed light on the citation count and altmetric dynamics across the entire body of sustainable diets research, this work demonstrates that highly cited articles are more highly visible in spheres inside and outside of academia, including social and news media and policy, due to significantly higher altmetric scores, higher altmetric attention indicator scores for all of the top five most used indicators, and greater use of all five of the most commonly used attention indicators compared to the median cited articles.

The findings of this research also suggest that these articles differ from those with lower citation counts and altmetric scores, including that the top 5% most cited research originates in nations with higher economic and human development (as determined by OECD member status) and from higher ranked academic institutions. In addition, although the results of the world region analyses were insignificant, the effect sizes and trends indicate that additional research and greater sample sizes may be worth exploring to better understand the effect of region on the odds of being a top cited research article. Furthermore, the descriptive statistics demonstrate that there are simply very few research articles generated by first and last authors in regions outside of Europe and North America, regardless of whether the research article is in the top 5% most cited or median cited articles.

These findings may reflect the reality that well-resourced nations and research institutions (to the extent that global rankings can reflect this) are potentially better able to support not just scientific research, but the dissemination and promotion of that research as well. This is likely enabled through institutional social media platforms, communications professionals, and government and policy liaisons. The dominance of this highly cited research in academia, news media, social media, and policy has implications for future knowledge creation and its applied use, such as in policy or program design. The high altmetric scores and citation counts indicate, for example, that this research is likely to garner a high degree of respect and value within academia. Research suggests that articles with high relative citation counts within a field, such as in sustainable diets, are perceived as higher quality and more deserving of time and attention investment. They also generate

greater reader engagement and more likely than less cited research to influence future research directions (Teplitskiy et al., 2022). Furthermore, the objectives, findings, implications, and recommendations of this research are much more likely to be captured and communicated by formal media channels, discussed on social media platforms, and thus shared with the public, influencing public awareness, opinion, and knowledge of sustainable diets and food systems. The higher degree of attention in policy sources also indicates that this research is more likely to be influencing conversations around and the direction of policies on sustainable diets and food systems. Collectively, this paints a clear picture showing that a small number of highly cited sustainable diets research articles from highly ranked research institutions in the global north are dominating what we study, what we know, and what policies are formed.

These trends align with existing research demonstrating inequalities in publishing and information sharing between the global north and global south and highlights the need for more equity in research and publishing across world regions, income levels, and institutions. In development studies, for example, research has demonstrated a similar phenomenon, where the majority of research on development and development policies in the global south (defined by the authors as developing countries) is conducted in the global north. The authors acknowledge that while this may be attributable to better research skills, networks, funding, and resources in the north, it is also likely a result of cultural and professional exclusivity. They argue that this exclusion restricts the plurality and richness of academic dialogues and diminishes southern researchers valuable first-hand knowledge and call for a more inclusive research environment (Amarante et al., 2022). Related

research additionally finds that development articles written by northern-based researchers have higher citation count than those by southern-based researchers (or those in the World Bank's classification of low, lower-middle, and upper-middle income countries, or LMICs) (Amarante & Zurbrigg, 2022). Both studies suggest that north-south research collaborations, which appear to be on the rise, may improve academic isolation of southern scholars.

In addition, a study of researcher diversity in the field of ecology found that more than 75% of top publishing authors were from United States, United Kingdom, Australia, Germany, and Canada and that those from the global south were "strikingly underrepresented." The study authors argue that enhancing diversity and inclusion at the author, leadership, and society level is essential to developing solutions in conservation science (Maas et al., 2021). One of the findings of a recent study examining the research on nature's mental health effects was that the literature is dominated by western world perspectives and is almost entirely conducted in westernized nations. The authors recommend that future work take a more culturally pluralistic and inclusive approach and suggest that doing may be necessary in identifying and pursuing sustainability pathways and action to support planetary health, or interwoven human and ecosystem health (Gallegos-Riofrío et al., 2022). Research also suggests that citation concentration among a small number of scientists is on the rise across natural, medical, and agricultural sciences. These scientists are also increasingly affiliated with high-ranking academic institutions in western Europe and Australasia, while the United States has seen a slight decline in this "elite concentration" (Nielsen & Andersen, 2021).

Taken together, this research aligns with the findings of the present study and sheds light on the extent of the challenges facing equity and diversity in academic research and publishing. As this broader research literature suggests, however, north-south research collaborations may aid in bridging some of these divides. Articles within the top 5% most cited research highlight some areas that may present opportunities for sustainable diets research collaborations that bridge the global north-south divide or present opportunities for leadership from areas outside of prestigious global north institutions. Auestad & Fulgoni (2015), for example, call for more research that explores culturally sensitive dietary preferences and real-world challenges such as cost-constraints. Behrens et al. (2017) identify that additional research on country specific individual dietary data is needed, particularly among disadvantaged groups, to translate results on the environmental impact of dietary recommendations. Jones et al. (2016) state that the scope of the literature needs to be broadened to include LMICs to reveal how regional differences affect sustainability outcomes and to ensure that alternative dietary recommendations are economically, culturally, and nutritionally appropriate for diverse populations around the world. Even more recent research that does examine country specific dietary shifts to mitigate climate and water crises concludes that future research needs to consider the social, economic, ecological, and agronomic feasibility of dietary shifts, especially in low- and middle-income countries, as well as a broader scope of impacts, including livelihoods and environmental impacts such as land availability and biodiversity (Kim et al., 2020).

Furthermore, these areas for future research may best explored using qualitative or mixed method approaches, presenting an opportunity to break out of the review and

quantitative research dominance paradigm present in sustainable diets research. As summarized above, the top cited articles with the highest altmetric scores are more likely to utilize quantitative research and review methodologies than median cited articles. These methodologies, as compared to qualitative, mixed method, and other studies, were also dominant across both citation groups. Although the literature comparing the breadth and impact of quantitative research compared to qualitative and other types of research is somewhat limited, some examples from the medical field and bibliometrics exist. For example, an analysis of the impact of qualitative and quantitative articles in the *British Journal of Medicine* using bibliometrics and altmetrics found that while there were substantially more quantitative studies, both study types have high impact and neither was found to be consistently superior, suggesting study type is not a main driver of impact (Retrouvey et al., 2020). An earlier comprehensive review of factors affecting citation counts found that review papers receive more citations than research papers and intervention studies. The review also found that research suggests study design is associated with citations, with randomized trials, systematic reviews, and meta-analyses having higher citations than behavioral studies, observational studies, and case reports (Tahamtan et al., 2016). The present study contributes to this understanding of factors that affect citation counts and suggests that methodological approach is a factor to consider in sustainable diets research. Areas for future research suggested by articles from the top 5% most cited literature present opportunities to expand this methodological concentration.

Lastly, descriptive statistics of topic areas reveal that topic areas 1 (sustainability impacts of dietary patterns) and 2 (sustainable diets and food system policy) describe the

majority of research in both the top 5% most cited and median cited article groups, indicating their overall dominance across the research considered here. Furthermore, articles in topic area 1 were more likely to be in the top 5% most cited group than articles in topic area 2 or articles in topic areas 3-7. The fact that certain methodologies are more likely to be highly cited and visible, and that a few research topics dominate the research literature, may reflect the tendency toward the densification of research and knowledge and patterns in problem selection. For example, research suggests that when scholars select a research topic, they often favor those that are within their current expertise and collaboration networks. This narrowing of research inquiry, or densification, may limit the range of future research (Fortunato et al., 2018). The sociology of science also suggests that the question of which research challenges to work on is shaped by what Fortunato et al. (2018) identify as "an ongoing tension between productive tradition and risky innovation" based on the works of Bourdieu (1975) and Kuhn (1970). Scientists may often appear highly productive by steadily publishing on a focused research agenda. This narrow agenda may limit the ability of the researcher, however, and those influenced by their works, to sense and seek out new opportunities and ideas that test and grow the bounds of their field. For the field of sustainable diets, this densification may be limiting the range of challenges, and solutions, are considered and explored in pursuit of a sustainable food system transformation.

Homogeneity in study methodology in the top cited and most visible research, and in research topic across the samples considered here, may also reflect the pursuit of research impact itself. The interest in and pursuit of research impact itself can also

contribute to a narrowing in the range of acceptable topics and approaches by privileging those disciplines and topics that are more easily measured. This may detract from funding and valuation of disciplines and inquiry that are more foundational, innovative, and/or where real-world applications aren't as readily apparent (Williams, 2020). This can exacerbate sway toward disciplines that fit more neatly within an investment logic, such as scenarios where researchers or research institutions have direct relationships with companies, such as spin-offs and the biotech and pharmaceutical sectors (Benneworth, 2015). Despite these challenges, determining and measuring research impact can improve accountability, establish evidence that particular research efforts are worth the investment of time and resources, and contribute to broader societal, environmental, and economic goals (Henrick et al., 2017 and Pitt et al., 2018 in Louder et al., 2021). This should be balanced, however, with the pursuit of diverse research objectives and methods and the need to support and elevate diverse forms of and topics in research.

2.5.2 Limitations

This research utilized a single database, Scopus, to conduct the literature search and citation analysis. Articles not included in Scopus are therefore excluded from this study, as are citation counts beyond those recorded in Scopus. A 2021comparison of Web of Science and Scopus, however, found that Scopus was better suited for evaluating research results (Pranckutė, 2021). The author concluded that this due to its wider and more inclusive content coverage, user friendly interface, single subscription format that eliminates confusion and/or additional restrictions on content accessibility, and extensive availability

of information on institutions, authors, and serials. In addition, recent research comparing different research databases and sources for citation data suggests a high correlation in citation counts between Google Scholar, Scopus, and Web of Science (Martín-Martín et al., 2018). Although Google Scholar could be considered a superset of Web of Science and Scopus data sets, most of the citations found by GS were from sources other than journals non-journal sources (48-65%). Given that the present study focused on journal sources, these additional citations captured by Google Scholar are not of immediate interest. The study authors also concluded that using Google Scholar for research evaluations would be unlikely to result in substantially different results due to the high degree of overlap between Google Scholar, Web of Science, and Scopus.

It is also important to note that assessing the impact of research on policy and practice is not a straightforward task despite the growing interest in research impact evaluation. There are many different understandings of what research impact is and how it can be measured, complicating the process of identifying and measuring impact (Louder et al., 2021). Furthermore, the relationship between research and impact is non-linear, hard to track, and occurs over different, and frequently unknowable, timescales (Pitt et al., 2018, Posner et al., 2020, and Posner & Cvitanovic, 2019 in Louder et al., 2021). This paper focuses on citation dynamics and altmetrics as one way of measuring impact within scholarly circles and broader, non-academic spheres.

Lastly, the comparison of top cited articles to median cited articles in this study can only shed light on the relationships between these two sub-groups of the sustainable diets literature. It does not describe whether any of the patterns that emerged, or those that failed

to be revealed, exist in other parts of the data set or research literature. The trends that did emerge, however, indicate areas for further and deeper investigation.

2.6 Conclusion

If citation dynamics are used to reflect or demonstrate research impact in the field of sustainable diets, as in common in academia, then they are likely to capture just a subset of the sustainable diets literature that is demonstrably different than other, less cited research. The results of this research find that top cited sustainable diets research articles are more likely to be from higher income nations and highly ranked research institutions, and that, overall, sustainable diets research is predominately generated in Europe and North America. Top cited articles are also more likely to be quantitative or review studies and characterized by one topic area, sustainability impacts of dietary patterns. Overall, two (out of seven) research topics dominate the literature. If citation counts are used as a measure of value in literature searches for research reviews, summaries, or to inform future research directions, then only a small range of perspectives will be included. Namely, research from lower-income nations, less prestigious academic institutions, using qualitative, mixed method, or other methodologies are likely to be excluded. Furthermore, since citation counts and altmetric scores have a moderate to strong positive correlation, the influence of highly cited works, with their particular characteristics, may reach beyond academia to public and policy spheres. The analysis of altmetric indicators performed here demonstrates that highly cited articles are more likely to be present in social media, news media, and policy. This suggests that only certain methodological and topical areas of

sustainable diets research from highly resourced institutions in the global north are making their way into the content disseminated and consumed on this topic. Given that this research is more highly visible and influential, it is likely playing an outsized role in media, advisory reports, and policy. A small number of homogenous studies are thus dominating what is studied, what is communicated to academic and public audiences, and what is translated into policy discussions and decisions worldwide. While the top cited, high altmetric score research may very well be high quality and make important contributions to the field of sustainable diets, it does not provide a complete picture of the research that exists and explicitly excludes some researchers and research methods. Those conducting literature reviews, synthesizing research into landscape reports, or formulating policy recommendations must remain mindful of these dynamics and actively seek to include diverse research and perspectives. In addition, future work should focus on bridging the global north-south divide in research opportunities and publishing, to address elite concentration in scholarly work, and to pursue diverse research agendas to fully explore all pathways to a sustainable food future.

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CHAPTER 3. SUSTAINABLE DIETS RESEARCH AIMS AND RECOMMENDATIONS FOCUS MORE ON DOWNSTREAM OUTCOMES AND IMPACTS THAN MID- AND UPSTREAM DETERMINANTS

3.1 Abstract

Sustainable diets have been proposed as a pathway toward achieving a sustainable food systems transformation necessary to support planetary health. The field of sustainable diets research continues to grow in breadth and depth as it is increasingly translated into policy and strategy implementation. This study presents a timely and comprehensive examination of the existing knowledge base to determine what this research seeks to address and the mechanisms it proposes to leverage for change. It also examines where these efforts are situated within an upstream-downstream gradient of food system components and influences, where upstream indicates recognition of underlying social and structural contexts, and downstream indicates a greater focus on outcomes, impacts, beliefs, and behaviors. A content analysis was performed on the top 5% most cited and median cited peer-reviewed, academic sustainable diets articles (n=86). This study finds that the objectives and recommendations of these sustainable diets publications focus more on downstream food systems outcomes and impacts than mid- and upstream food system influences and drivers. Among the outcomes and impacts studied, dietary outcomes, environment, nutrition, and health impacts receive relatively frequent attention while food security, social equity, and economic impacts rarely or only occasionally receive attention in the sustainable diets literature.

The absence of a statistically significant difference in the upstream-downstream focus of the research objectives and future research recommendations between top cited and median cited articles indicates some consistency across the literature. Top and median cited articles are equally as likely to make general recommendations, though median cited articles are more likely to focus on upstream, midstream, and downstream categories. This indicates that median cited articles may provide greater detail and specificity in their general recommendations and focus more on understudied mid- and upstream food system components. The lack of attention to median cited articles in media and policy in comparison to top cited articles may result in the minimization of the voices and ideas driving less cited research. This may not only limit progress toward achieving sustainable food systems, but also reinforce elite concentration in research and knowledge given that median cited articles are more likely to be from lower-income countries, less prestigious universities, and use qualitative and mixed methods than top cited research.

The sustainable diets studies examined here have contributed to a robust body of knowledge on the environmental and health consequences of dietary patterns necessary for establishing the imperative for food systems change. Given the lack of focus on understudied mid- and upstream factors, however, including but not limited to cross-cutting issues of governance and resilience, drivers such as globalization and trade, population and income growth and distribution, food supply chains, and food environments, these findings highlight the opportunity for a shift in research within the field. Failing to do so comes at the risk of distracting from opportunities to leverage impactful, effective upstream strategies as well as limiting the effectiveness of downstream focused solutions. More

attention to sociocultural influences on food practices and the intersections of sustainability dimensions, particularly social and economic dimensions, may also help to provide a more complete perspective on what sustainable diets may entail and how they can be achieved.

Keywords

Sustainable diets, food systems, planetary health, food system framework, content analysis

3.2 Introduction

Sustainable food systems are necessary to support planetary health, or the interlinked health of human and natural systems (Herrero et al., 2021). They have the power to influence human health, which is facing multiple challenges from food insecurity, malnutrition, to diet-related chronic disease (Fanzo et al., 2022). Yet food systems threaten and are threatened by a changing global environment (Willett et al., 2019). Sustainable diets have been proposed as a necessary component, and outcome, of a sustainable food system, and a pathway toward achieving it (FAO & WHO, 2019). Sustainable diets were defined in 2010 by the United Nations Food and Agriculture Organization as those "with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources," (Burlingame & Dernini, 2012).

Sustainable diets have received growing attention in academic research within the last decade and most notably since 2020 (Hricko, Demarest, et al., 2024/Chapter 1). This study found that sustainable diets research has thus far largely focused on the areas of environmental studies and nutrition and dietetics. While the focus has expanded to other areas (e.g., public health and safety, food industries, medical sciences, and agriculture), interdisciplinary approaches and elements of sustainable diets such as culture, equity, and social processes remain understudied (Hricko et al., 2024/Chapter 1). Multiple additional studies find a similar trend in agri-food systems research more broadly, in which the environmental dimension of sustainability is a primary focus while social, economic, and political dimensions are insufficiently addressed and warrant more research attention (Biesbroek et al., 2023; El Bilali et al., 2021; Nicholls & Drewnowski, 2021; Webb et al., 2023).

Efforts to further synthesize and summarize sustainable diets research are often either highly specific to a particular outcome or impact, or high-level reviews that lack granularity. For example, systematic reviews of sustainable diets research are narrowly focused on particular topics, such as consumer behavior (Biasini et al., 2021), consumer perceptions (van Bussel et al., 2022), and environmental footprints (Chai et al., 2019). In contrast, a recent thematic scoping review found that sustainable diets research is broadly focused on two areas: sustainability impacts of dietary patterns and sustainable diets and food system policy (Hricko et al., 2024/Chapter 1). While these efforts appraise discrete impacts and shed light on broad themes within the research, there is a critical lack of a comprehensive yet detailed understanding of what sustainable diets research publications

seek to address and what they recommend for both research and action. Without this stock-taking, it's impossible to fully grasp the implications, consequences, and trade-offs of both the research and recommended actions to support sustainable diets and food systems (Nicholls & Drewnowski, 2021).

Despite these shortcomings in research and analysis, attention to sustainable diets as both a challenge and solution to mounting environmental and health crises continues to grow outside of academia. This is evident in proposed and achieved adoption of sustainability considerations in dietary recommendations (Dietary Guidelines Advisory Committee, 2020; FAO, 2024) and in public food procurement reform efforts (Swensson & Tartanac, 2020). It is also evident in the marketing of at-home meal kits (e.g., Hungryroot) and popular health and wellness media outlets such as Healthline and Medical News Today (Mayer, 2023; *Hungryroot*, 2024; Johnson & Holland, 2019). The need to comprehensively understand sustainable diets, including knowledge gaps and areas for future research and action, is necessary and timely given the increasingly urgent calls to address planetary health, the growing body of research on sustainable diets, and the desire to harness sustainable diets for action.

The "upstream-downstream" metaphor offers a framework for assessing where influences, actions, and actors are located within a system and how they interact. This metaphor is frequently used in public health research and has been called the field's "defining metaphor" (Dorfman & Krasnow, 2014). It is often used to differentiate between "upstream" and "downstream" influences on health, where upstream implies using systems theory, acknowledging underlying social and structural contexts, and advocating for and

using policies and programs to improve health. In contrast, downstream implies a focus on individual health outcomes, beliefs, and behavior that historically did not account for factors that shape an individual's context, environment, and actions (McMahon, 2022). The terms are also often applied to the study of social determinants of health, or "nonmedical factors influencing health, including health-related knowledge, beliefs, or behaviors," (Braveman et al., 2011). As these authors point out, this definition focuses on downstream factors, or those that are close in space and time to health effects and relatively apparent. They are influenced by upstream social determinants as well, which can be described as the underlying causes that initiate causal pathways to health effects via downstream factors and are often relatively distant to health effects in space and time (Braveman et al., 2011). This recognition of multiple layers of influences, from upstream to downstream, is also apparent in the World Health Organization's framing of the social determinants of health created in the context of achieving health equity and social justice (CSDH, 2008).

Downstream determinants are often easier to study compared to upstream determinants, which are frequently complex, difficult to disentangle, and challenging to parse because of the time and space that separates them from their more visible effects (Braveman et al., 2011). Furthermore, looking toward upstream levers of change, such as tackling policies related to issues like taxes, poverty, and nutrition, is often challenged by political and bureaucratic resistance (Hahn, 2021). Focusing research and attention on easier to study downstream determinants, however, comes "at the risk of failing to address fundamental causes" and missing potentially more important, effective opportunities for improving outcomes and equity (Braveman et al., 2011). Hahn (2021) also makes the case

for focusing on upstream factors to achieve greater impact, describing the power of upstream efforts as multiplied as they "are likely to have a greater cascading array of downstream consequences" than focusing on a single downstream cause alone. There is growing recognition of the power of upstream influences within a system on affecting change in outcomes and impacts. The United States Department of Health and Human Services (HHS) Healthy People 2030 initiative, for example, identifies national public health objectives guided by social determinants of health (HHS, n.d.). Similarly, a 2023 perspective piece calls for a public policy agenda that focuses on upstream social determinants or root causes of population health, such as socioeconomic, cultural, political, and cultural contexts, in order to improve downstream health effects, consequences, and inequities (Ray et al., 2023).

The use of the metaphor has filtered into the sustainable diets literature as well. Though rarely accompanied by a clear definition, the terms are often used to characterize, describe, and communicate where strategies and influences exist within the food system and supply chain. For example, in a study presenting new food system typologies, Marshall et al. (2021) use the terms more generally to describe "…well-documented upstream and downstream influences on food systems." They also apply the terms to describe the supply chain, as in "…the well-documented influence of supermarkets in driving upstream changes in food supply chains, including farming, distribution, and processing." In a study of frameworks used for food systems analysis, Brouwer et al. (2020) uses the term upstream to indicates producers and downstream to indicate consumers. (Ruben et al.,

2021), meanwhile, use the term midstream to describe "…agents in charge of transport, storage, processing, and retail."

3.2.1 Research Aims and Questions

The present study proposes to apply the "upstream-downstream" metaphor more systematically to sustainable diets literature to describe where the research objectives and recommendations are situated within the food system and shed light on what levers are suggested for change. This study examines and compares two subsets of the sustainable diets literature – the most highly cited and median cited articles – to allow for a close read and detailed review of the contents of the research. Citation counts are often used as a proxy for research impact in academia (Reed et al., 2021; Williams, 2020), albeit a contested and incomplete one (Aksnes et al., 2019; Louder et al., 2021; Williams, 2020). A recent bibliometric analysis of peer-reviewed, academic sustainable diets articles published between 2000-2022 found that the top 5% most cited sustainable diets research articles (n=43) contained nearly half of all the citations considered in the study (n=855) (Hricko, Belarmino, et al., 2024/Chapter 2). Research suggests that it is this high relative citation count within a subject and topic area rather than raw counts that indicates high research impact and influence (Teplitskiy et al., 2022). A second comparison group (also n=43) was drawn from the median cited articles to test whether the top cited research differs from other sustainable diets literature. Such an understanding is important to assess given that previous research (Chapter 2), highlights that highly cited articles receive greater attention in media and policy realms.

These top and median cited articles were also moderately to strongly correlated with altmetric scores, a newer, alternative method that seeks to assess research reach and impact in news media, social media, policy, and governance documents, indicating influence beyond academia (Hricko, Belarmino, et al., 2024/Chapter 2). Previous analysis of both the full dataset of sustainable diets articles (n=855) and the subsequent bibliometric analysis of the top and median cited research articles (n=86) shed light on the thematic and disciplinary trends over time as well as citation dynamics and knowledge production. However, this study did not examine the content of the articles outside of the abstracts, focused on identifying broad themes and disciplinary emphasis, and highlighted article and research characteristics, such as author affiliations and methodological approach, that do not describe the content of the research itself (Hricko, Belarmino, et al., 2024/Chapter 2; Hricko, Demarest, et al., 2024, Chapter 1). These 86 sustainable diets articles were thus included for analysis in the present study for deeper content analysis.

This research applies the upstream-downstream metaphor as gradient to the Food Systems Framework depicted in Figure 3-1 (below), where the outermost layer, or component category, of the visual (drivers) is considered the furthest upstream along with cross-cutting issues (not pictured in the figure), the inner layers (food supply chains and food environments) are considered midstream, and the innermost layers (individual factors, outcomes, and impacts) are considered downstream. Research objectives and recommendations identified in the top and median cited sustainable diets articles are mapped onto these component categories and the sub-components they contain to examine where on this gradient the research is focused. This Food Systems Framework is used as it

was recently developed (2020, and updated in 2023) by a wide range of stakeholders to describe complex food systems in a visually direct way and to guide decision making and action (The Food Systems Dashboard, 2023). It is part of the Food Systems Dashboard, a tool that brings data across public and private spheres together to describe food systems and guide decision makers in identifying challenges as well as levers for change (*About the Food Systems Dashboard*, 2024). A 2020 commentary describes the origins and intentions of the Dashboard and the corresponding Framework in greater depth, including the various actors and organizations that contributed to its development (Fanzo et al., 2020).

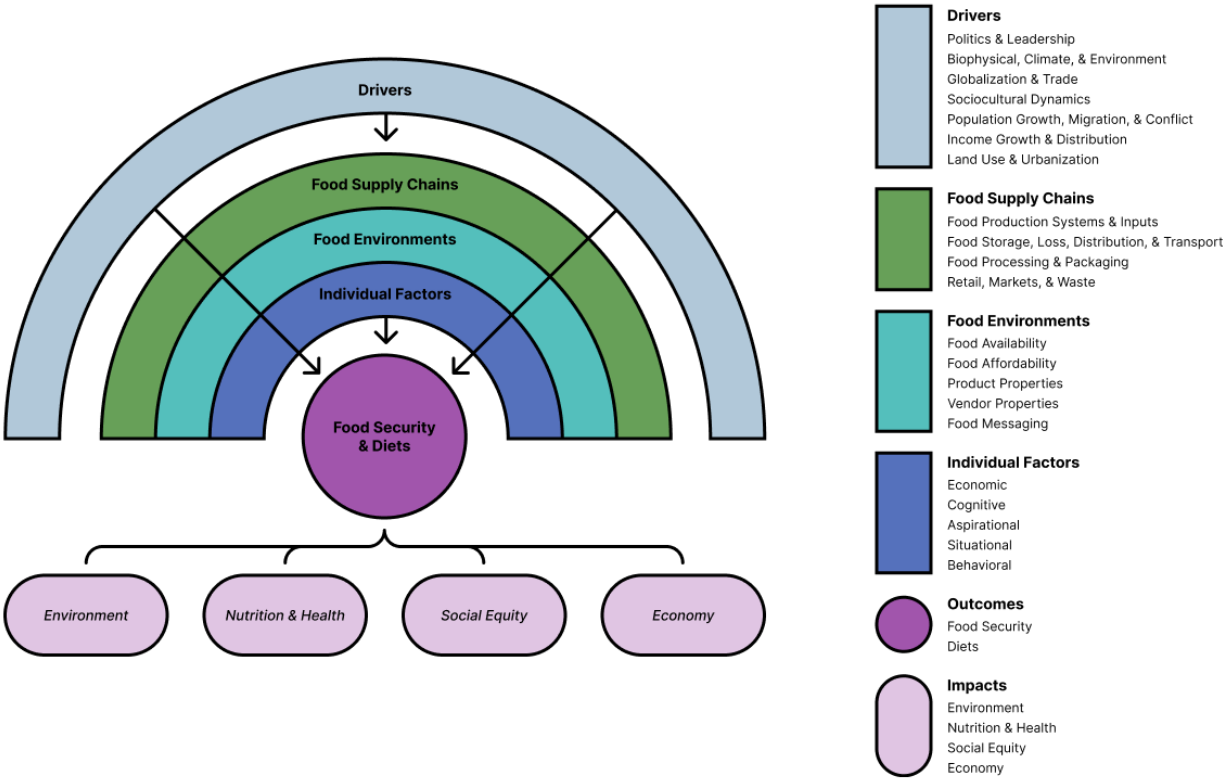

Figure 3-1. Food Systems Framework developed by the Food Systems Dashboard (used with permission, The Food Systems Dashboard, 2023).

The following research questions seek to address the aims of this study:

1. How do the research objectives and recommendations from the top 5% most highly cited and median cited sustainable diets publications align with the various components of food systems as described by the Food Systems Dashboard's Food System Framework?
2. How are the research objectives and recommendations distributed among the upstream, midstream, and downstream components? How does this differ between the top 5% most cited and median cited articles?
3. Which elements of the Food Systems Framework's outcomes and impacts receive relatively more and less attention? What research and knowledge gaps are revealed?

3.3 Methods

3.3.1 Literature Search and Article Selection

The search for sustainable diets research literature was conducted on February 8, 2023 using Scopus, a database that includes research from 330 disciplines and more than 7,000 publishers (*Scopus Content*, 2024). The terms "sustainable diet", "sustainable diets", and "sustainable dietary pattern*" were used to search the article titles, abstracts, and keywords of peer-reviewed, academic literature published between 2000-2022. The 1,016 records identified in the search were then manually screened for duplicates and inclusion using a process detailed in Hricko et al. (2024/Chapter 1). After screening, 855 articles were considered in the full sustainable diets literature dataset. As described above, the top 5% most cited articles (n=43) were found to contain almost half of all citations in the

dataset (44%) and to be moderately to strongly correlated with altmetric scores, an alternative indicator of impact that seeks to capture the circulation of knowledge beyond academia (Hricko, Belarmino, et al., 2024/Chapter 2). These 43 articles were thus selected for inclusion in this analysis.

The second subset of articles was selected from the median cited research to provide a comparison group. The 41 articles with the median citation count for the full dataset (median=6) were included in the comparison group. Two additional articles were selected to create sample size equal to the top cited group. One article was randomly selected from the group of articles with citation counts just above the median (citation count=7), and one from the group just below the median (citation count=5).

3.3.2 Content Analysis

The articles were imported into NVivo, the qualitative data analysis software program (Lumivero Pty Ltd, Release 14.23.3), for coding and analysis. First, the author (CH) and a committee member (EB) randomly selected a subset of the top cited articles (n=5) to establish agreement on coding research objectives and recommendations. The author then coded the articles in a multi-step process using NVivo. The articles were first reviewed to identify research objectives and recommendations guided by a grounded theory approach (Charmaz, 2006; Charmaz & Belgrave, 2012; Cohen et al., 1969). The review of each article included a close read of the abstract to identify and code the stated research objectives. Any recommendations that were included in the abstract were also coded. Recommendations were coded as either “future research” if they specifically

mentioned further analysis and/or future study, or as "general recommendation" if they related to the application of the research to policy, action, strategy, or change beyond future research.

The full discussion and conclusion sections of each article were then reviewed for additional or more detailed recommendations. If an article did not clearly delineate a discussion section or had a combined "results and discussion" section, the results and any subsequent sections were reviewed for recommendations. In order to inclusively capture recommendations across disciplines and journals, "soft" and "hard" recommendations were both included. A "soft" recommendation often included phrases such as "should consider", "would benefit", "could be used", "can inform", "can contribute", "is warranted". "Hard" recommendations could be considered those that used phrases like "are required", "is necessary", "must ensure", "will require", "has to be supported". All the above phrasings were considered recommendations and coded into "future research" or "general recommendations," as indicated.

In the next step in the analysis, the first author developed a structural coding framework based on the component categories and sub-components of food systems as depicted in the Food Systems Framework (Figure 3-1) designed by the creators of the Food Systems Dashboard (The Food Systems Dashboard, 2023). Each objective and study recommendation was reviewed and coded to the relevant and corresponding components of the food system as described in the Framework (Figure 3-1). Text identified as an objective or recommendation was coded to as many areas of the food system framework as necessary to capture the content. If it was unclear which or how many components of

the Framework were relevant to the coded text, the text immediately surrounding the objective, future research, or general recommendation was reviewed. Each of the food system component categories (e.g., Drivers, Food Supply Chains, Food Environments) are described in more detail elsewhere (*Food Systems Dashboard*, 2024). Not included in the visual representation are two Cross-Cutting Issue components: “Governance” and “Resilience and Sustainability". The words “sustainable” and “sustainability” occur with high frequency across the articles and coded text given that “sustainable diets” is the research topic under analysis here. To avoid redundancy, only mentions of resiliency were coded to the crossing-cutting issue component Resilience and Sustainability.

Some content that emerged from the data did not explicitly map to the framework. In these instances, the first author used the code that was most appropriate. All mentions of social or cultural factors or dynamics, unless clearly identified as related to equity (and therefore coded as Impacts: Social Equity), were thus coded to Drivers: Sociocultural Dynamics. Animal welfare was also coded to Drivers: Sociocultural Dynamics, as were mentions of food preference, acceptability, and/or desirability. Mention of non-market food systems were coded under Food Supply Chains: Food Storage, Loss, Distribution, & Transport as well as Food Environments: Food Availability. Food system policy, including dietary guidelines, were coded to Drivers: Politics and Leadership. Text specifically relating to dietary guidelines was also coded to Food Environments: Food Messaging. In addition, three original codes were created and applied based on recurrent themes in the data: Improved measurements, metrics, indicators; Multi-disciplinary collaborations and/or research; and More data, research (general).

3.3.3 Frequency Categories

Frequency labels were assigned once all objective and recommendation codes were mapped to the Food Systems Framework components and/or the original codes created for the recurrent themes that arose in the data. The number of articles referencing a particular component category and sub-component was represented as a percentage of all the articles in the group. For example, if 10 out of 43 top cited articles had objectives that were coded to the component category "drivers," this was calculated as a frequency of 23%. Component categories and sub-components were then grouped into frequency categories to describe how often articles reference the food system components and sub-components along the upstream-downstream gradient: rarely, or coded in 0-25% of articles; occasionally, or coded in 26-50% of articles; often, or coded in 51-75% of articles; and very frequently, or coded in 76-100% of articles (Table 3-1).

Table 3-1. Categories to describe how frequently articles reference food system components and sub-components.

Frequency Categories	**Percent of articles that reference a component or sub-component**
Rarely	0-25%
Occasionally	26-50%
Often	51-75%
Very frequently	76-100%

3.3.4 Upstream-Downstream Comparison Between Citation Groups

The frequency of upstream-downstream categorization of objectives, future research recommendations, and general recommendations was compared between the top 5% most cited and median cited groups to determine if there are differences in research focus in these groups. Upstream, midstream, and downstream frequencies for objectives and recommendations for each group were determined by aggregating the Food System Framework component data to these highest-level categories. For example, the upstream category encompasses cross-cutting issues and drivers. The number of top cited articles containing an objective referencing a cross-cutting issue(s) and/or driver(s) were counted (n=10) and represented as a percentage of the overall number of articles in this group containing an objective (n=43), or 23%. These frequencies were calculated and compared using a two-sample z-test of proportions for each upstream-downstream category and each sample group (top and median cited) for objectives, future research recommendations, and general recommendations. The proportion of articles with objectives, future research recommendations, and general recommendations were also compared between the two groups using a two-sample z-test of proportions. A binomial exact test was used to test for difference when the number of articles without an objective, future research recommendation, general recommendation, or reference to a component was between 0-5. Statistical tests were performed using R Statistical Software (v.4.4.0, R Core Team, 2021) in R Studio (version 2024.04.1+748, Posit Software, 2024).

3.4 Results

The results of the multistep coding process are presented in Tables 3-2 and 3-3. Note that each article could be coded to multiple component categories and sub-components.

Table 3-2. Research objectives, future research and general recommendations from the 43 most highly cited sustainable diets publications were mapped onto components of the Food Systems Framework. N represents the number of articles containing a component or sub-component.

		Objectives		**Future Research**		**General Recommendations**	
		Articles		**Articles**		**Articles**	
		N	**%**	**N**	**%**	**N**	**%**
	TOTAL	43	100%	30	70%	42	97%
	Framework Component						
Upstream	*Cross-Cutting Issues*	*0*	*0%*	*1*	*3%*	*3*	*7%*
	Resilience	0	0%	1	3%	0	0%
	Governance	0	0%	0	0%	3	7%
	Drivers	*10*	*23%*	*11*	*37%*	*17*	*40%*
	Politics & Leadership	4	9%	5	17%	15	36%
	Biophysical, Climate, & Environment	1	2%	1	3%	2	5%
	Globalization & Trade	1	2%	0	0%	1	2%
	Sociocultural Dynamics	5	12%	7	23%	10	24%
	Population Growth Migration, & Conflict	3	7%	1	3%	0	0%
	Income Growth & Distribution	3	7%	1	3%	2	5%
	Land Use & Urbanization	2	5%	0	0%	0	0%
Midstream	*Food Supply Chains*	*11*	*26%*	*12*	*40%*	*15*	*36%*
	Food Production Systems & Inputs	6	14%	7	23%	13	31%
	Food Storage, Loss, Distribution, & Transport	0	0%	3	10%	2	5%
	Food Processing & Packaging	2	5%	5	17%	3	7%
	Retail, Markets, & Waste	1	2%	4	13%	5	12%
	Food Environments	*11*	*26%*	*10*	*33%*	*13*	*31%*
	Food Availability	3	7%	4	13%	6	14%
	Food Affordability	6	14%	5	17%	6	14%
	Product Properties	1	2%	6	20%	2	5%
	Vendor Properties	1	2%	1	3%	2	5%
	Food Messaging	4	9%	5	17%	10	24%
Downstream	*Individual Factors*	*15*	*35%*	*8*	*27%*	*15*	*36%*
	Economic	4	9%	2	7%	2	5%

	Cognitive	3	7%	2	7%	9	21%
	Aspirational	3	7%	0	0%	2	5%
	Situational	2	5%	2	7%	3	7%
	Behavioral	13	30%	4	13%	15	36%
	Outcomes	*41*	*95%*	*27*	*90%*	*21*	*50%*
	Food Security	7	16%	2	7%	9	21%
	Diets	40	93%	27	90%	20	48%
	Impacts	*40*	*93%*	*25*	*83%*	*18*	*43%*
	Environment	39	91%	21	70%	16	38%
	Nutrition & Health	33	77%	21	70%	14	33%
	Social Equity	4	9%	8	27%	8	19%
	Economy	9	21%	11	37%	5	12%
Other	*Other Categories*						
	Improved measurements, metrics, indicators	2	5%	9	30%	6	14%
	More data, research (general)	0	0%	9	30%	8	19%
	Multi-disciplinary collaborations and/or research	1	2%	2	7%	7	17%

Table 3-3. Research objectives, future research and general recommendations from the 43 median cited sustainable diets publications were mapped onto components of the Food Systems Framework. N represents the number of articles containing a component or sub-component.

		Objectives		**Future Research**		**General Recommendations**	
		Articles		**Articles**		**Articles**	
		N	**%**	**N**	**%**	**N**	**%**
	TOTAL	43	100%	29	67%	41	95%
	Framework Component						
Upstream	*Cross-Cutting Issues*	*1*	*2%*	*1*	*3%*	*10*	*24%*
	Resilience	0	0%	0	0%	2	5%
	Governance	1	2%	1	3%	9	22%
	Drivers	*16*	*37%*	*16*	*55%*	*28*	*68%*
	Politics & Leadership	11	26%	9	31%	24	59%
	Biophysical, Climate, & Environment	0	0%	2	7%	1	2%
	Globalization & Trade	0	0%	0	0%	1	2%
	Sociocultural Dynamics	8	19%	11	38%	16	39%
	Population Growth Migration, & Conflict	2	5%	2	7%	2	5%
	Income Growth & Distribution	0	0%	1	3%	0	0%
	Land Use & Urbanization	0	0%	1	3%	1	2%
Midstream	*Food Supply Chains*	*8*	*19%*	*12*	*41%*	*26*	*63%*
	Food Production Systems & Inputs	8	19%	10	34%	22	54%

	Food Storage, Loss, Distribution, & Transport	1	2%	2	7%	5	12%
	Food Processing & Packaging	2	5%	4	14%	11	27%
	Retail, Markets, & Waste	1	2%	5	17%	15	37%
	Food Environments	*18*	*42%*	*17*	*59%*	*32*	*78%*
	Food Availability	0	0%	5	17%	13	32%
	Food Affordability	4	9%	3	10%	12	29%
	Product Properties	2	5%	4	14%	12	29%
	Vendor Properties	0	0%	1	3%	3	7%
	Food Messaging	13	30%	12	41%	29	71%
Downstream	*Individual Factors*	*23*	*53%*	*13*	*45%*	*32*	*78%*
	Economic	0	0%	2	7%	3	7%
	Cognitive	11	26%	7	24%	16	39%
	Aspirational	1	2%	2	7%	5	12%
	Situational	3	7%	2	7%	8	20%
	Behavioral	21	49%	13	45%	30	73%
	Outcomes	*41*	*95%*	*25*	*86%*	*36*	*88%*
	Food Security	4	9%	0	0%	3	7%
	Diets	41	95%	25	86%	36	88%
	Impacts	*41*	*95%*	*23*	*79%*	*38*	*93%*
	Environment	39	91%	17	59%	35	85%
	Nutrition & Health	33	77%	21	72%	32	78%
	Social Equity	1	2%	2	7%	7	17%
	Economy	10	23%	10	34%	12	29%
Other	*Other Categories*						
	Improved measurements, metrics, indicators	0	0%	6	21%	2	5%
	More data, research (general)	1	2%	9	31%	2	5%
	Multi-disciplinary collaborations and/or research	1	2%	4	14%	11	27%

3.4.1 Objectives: Overview

Research objectives were identified in each of the articles considered in this study. Examining the frequency with which the top 5% most cited sustainable diets research objectives reference the different food systems component categories reveals a trend in which the frequency of mentions increases while moving from upstream to downstream categories. Upstream categories (drivers and cross-cutting issues) are mentioned rarely, or

in 25% or fewer articles. Midstream categories (food supply chains and food environments) are mentioned occasionally, or in between 26-50% of articles, and downstream categories are mentioned occasionally (individual factors) and very frequently (outcomes and impacts), or more than 76% of the time (Figure 3-2).

The research objectives in the median cited sustainable diets research articles follow a similar trend in which the frequency of mentions increases from upstream to downstream categories. The upstream categories are rarely mentioned (cross-cutting issues, 2% of articles) or occasionally mentioned (drivers, 37% of articles). Similarly, midstream categories are rarely (food supply chains, 19% of articles) or occasionally mentioned (food environments, 42% of articles). Downstream categories are either often (individual factors, 53% of articles) or very frequently mentioned (impacts and outcomes, each in 95% of articles) (Figure 3-3).

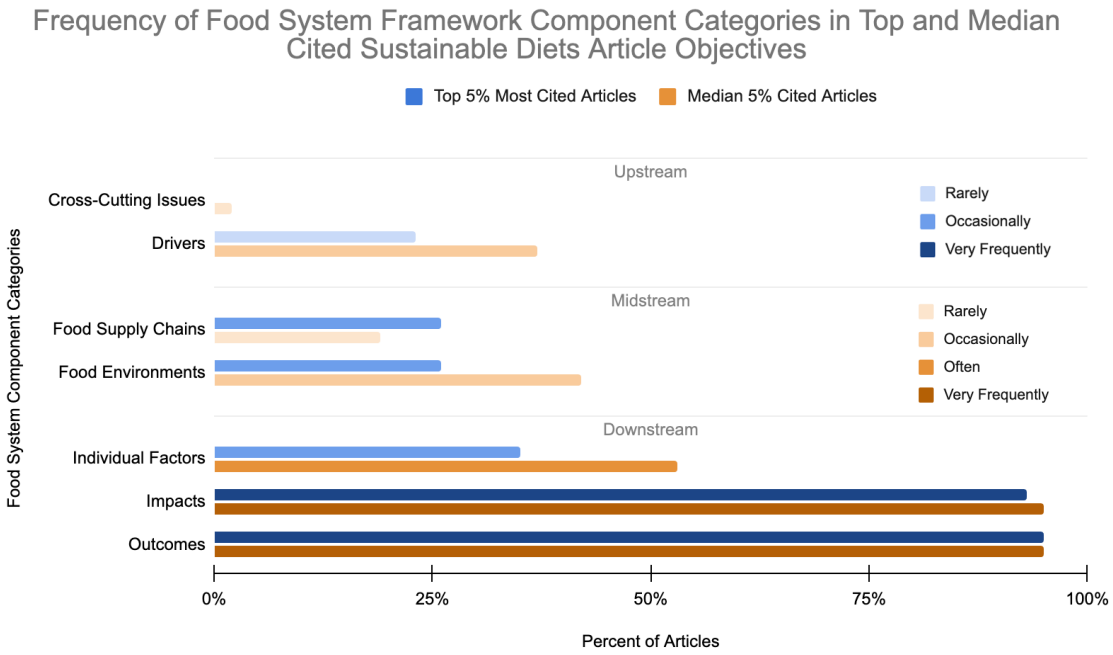

Figure 3-2. Frequency with which upstream, midstream, and downstream food system framework component categories are mentioned in the objectives of top and median cited sustainable diets research articles.

Objectives: Sub-Component Categories Among Top 5% Most Cited Articles

The sub-components of the drivers category are mentioned rarely, in 2-12% of articles. Similarly, sub-components of food supply chains and food environments are mentioned rarely, appearing in between 0-14% of articles and 2-15% of articles, respectively. One sub-component of individual factors, behavioral, was referenced occasionally (30% of articles), while the remaining sub-components were mentioned rarely in 9% of fewer articles. Among the two outcomes sub-components, diets were referenced very frequently in 93% of articles, while food security was mentioned rarely, in 16% of articles. Attention to the impact sub-components was similarly uneven, with environment and nutrition and health mentioned very frequently in 91% and 77% of articles,

respectively, and social equity and economy mentioned rarely in 9% and 21% of articles. Text coded to the original codes ("other" in Table 3-2 above) appeared rarely in 5% or fewer articles.

Objectives: Sub-Component Categories Among Median Cited Articles

The sub-components of the cross-cutting issues category are mentioned rarely, in 0-2% of articles. Most sub-components of the drivers category are mentioned rarely, from 0-19%, except for politics & leadership, which is occasionally referenced in 26% of articles. Sub-components of food supply chains are similarly mentioned rarely (2-19% of articles). The food messaging sub-component of food environments is referenced in 30% of articles, while the other sub-components are rarely mentioned (0-9% of articles). Two sub-components of individual factors, cognitive and behavioral, are mentioned occasionally (26% and 49% of articles, respectively), while the rest are rarely mentioned (0-7% of articles). Among the outcomes sub-components, diets are referenced very frequently in 95% of articles, while food security is rarely mentioned (9% of articles). The environment and nutrition & health sub-components of impacts are mentioned very frequently, in 91% and 77% of articles, respectively, while social equity and economy are mentioned rarely (2% and 23% of articles, respectively). Text coded to original codes in "other categories" appeared rarely in 0-2% of articles.

3.4.2 Objectives: Text Examples

Objectives from top cited articles coded to the diets and environment sub-components were often explicitly about measuring or quantifying environmental impacts of dietary patterns. For example, "We systematically review the evidence on changes in GHG emissions, land use, and water use, from shifting current dietary intakes to environmentally sustainable dietary patterns," (Aleksandrowicz et al., 2016). Objectives coded to the nutrition and health sub-component of impacts often overlapped with environment impacts (e.g., Macdiarmid et al., 2012), as well as other less frequently referenced food system components, such as affordability (Masset et al., 2014) and animal welfare (Clonan et al., 2015).

Objectives from median cited articles similarly focused on examining and measuring the environmental and health impacts of various dietary patterns and food groups (e.g. Comerford et al., 2021; Jarmul et al., 2019; Kraak, 2022; Ridoutt et al., 2021; Wood et al., 2019). Other articles were focused on consumer attitudes, perceptions, and perceptions toward topics such as sustainable diets (Banovic & Barone, 2021), particular foods groups (de Boer et al., 2020; Ladaru et al., 2020), behaviors to reduce climate impacts (Cologna et al., 2022), eco-labels (Neumayr & Moosauer, 2021), and food system transformation (Dengerink et al., 2021). Several studies were more focused on developing or examining summary scores or indices for measuring sustainable diets (e.g., Bjørnarå et al., 2019; Shamah-Levy et al., 2020), while others focused on exploring and evaluating the contribution of specific foods to healthy sustainable diets, such as seafood (Bogard et al., 2019), edible seaweed (Butcher et al., 2020), indigenous fruits and vegetables (Cogill,

2015), and neglected and underutilized crops (Mudau et al., 2022). Some studies were more theoretical in nature, exploring conceptual frameworks for sustainable diets (Claasen et al., 2015), examining what constitutes a good diet (Lang, 2021), and defining social and economic dimensions of food systems (Comerford et al., 2020).

3.4.3 Future Research Recommendations: Overview

Future research recommendations were often mentioned and appeared in 70% of the top 5% most cited articles. The frequency with which the top 5% most cited sustainable diets future research recommendations reference the different food system component categories reveals a trend similar to that above with the research objectives. Moving from upstream to downstream component categories aligns with a rise in frequency of mentions (Figure 3-3, below). The upstream category of cross-cutting issues is mentioned rarely, in 3% of articles that reference future research recommendations (or "articles" for the remainder of this section), while drivers are mentioned occasionally in 37% of these articles. Midstream categories are mentioned occasionally, with food environments mentioned in 33% and food supply chains in 40% of the articles. The downstream category individual factors is similarly mentioned occasionally (27% of articles), while impacts and outcomes are mentioned very frequently (83% and 90% of articles, respectively).

Similar to the top 5% most cited articles, future research recommendations appeared often and were identified in 67% of the median cited research articles. As with the top 5% most cited articles, the frequency with which the future research recommendations in the median cited articles reference the food system component

categories demonstrates a trend in which frequency generally increases when moving from upstream to downstream categories, though this trend is less defined (Figure 3-3). While the upstream category of cross-cutting issues was rarely referenced (3% of articles with future recommendations), the drivers category was often mentioned in 55% of these articles. Among midstream categories, food supply chains was referenced occasionally in 41% of articles, while food environments was often referenced (59% of articles). Downstream component categories were mentioned occasionally (individual factors in 45% of articles) and very frequently (outcomes and impacts in 86% and 79% of articles, respectively).

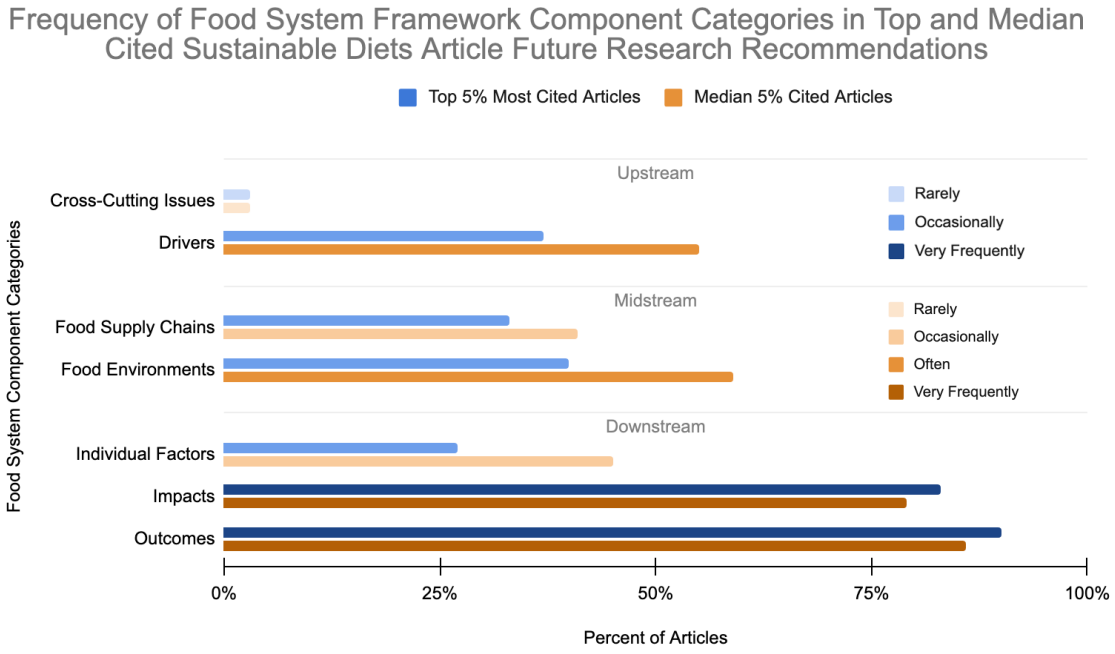

Figure 3-3. Frequency with which upstream, midstream, and downstream food system framework component categories are mentioned in the future research recommendations of top and median cited sustainable diets research articles.

Future Research Recommendations: Sub-Component Categories Among Top 5% Most Cited Articles

The sub-components of the upstream category of crossing-cutting issues are mentioned rarely, in 3% or fewer articles. Sub-components of drivers are similarly mentioned rarely, in 0-23% of articles. The sub-components of the midstream categories food supply chains and food environments are also all mentioned rarely, in between 10-23% and 3-20% of articles. The sub-components of the downstream category individual factors were mentioned rarely, in 0-13% of articles. While the food security sub-component of outcomes was rarely mentioned, in 7% of articles, diets were mentioned very frequently in 90% of articles. Sub-components of impacts were mentioned occasionally and often, with social equity and economy occasionally mentioned in 27% and 37% of articles, and environment and nutrition and health each often mentioned in 70% of articles. Text coded to the original code "multidisciplinary collaborations and/or research" appeared rarely, in 7% of articles, while the other two original codes, improved measurements, metrics, indicators and more data, research (general), were each occasionally mentioned in 30% of articles.

Future Research Recommendations: Sub-Component Categories Among Median Cited Articles

The sub-components of the upstream category cross-cutting issues were mentioned rarely (0-3% of articles with future research recommendations), as were most of the sub-components of drivers (0-7% of articles), though the politics & leadership and sociocultural dynamics sub-components of drivers were mentioned occasionally (31% and 38% of

articles, respectively). Most of the sub-components of the midstream categories were mentioned rarely, though the food production systems & inputs sub-component of food supply chains was mentioned occasionally (34% of articles) as was the food messaging sub-component of food environments (41% of articles). The sub-components of downstream categories were mentioned from rarely to very frequently. Sub-components of individual factors were referenced rarely (7-24% of articles), though the behavioral sub-component was mentioned occasionally (45% of articles). The diets sub-component of outcomes was mentioned very frequently (86% of articles) while food security wasn't referenced at all. The impact sub-components were referenced rarely (social equity in 7% of articles), occasionally (economy in 34% of articles), and often (environment in 59% of articles and nutrition & health in 72% of articles). Among the original codes, more data and research (general) was referenced occasionally in 31% of articles, while the other codes were mentioned rarely.

3.4.4 Future Research Recommendations: Text Examples

Future research recommendations coded to the environment impact were often related to the perceived need for additional research on the impacts of specific food items, and particularly high protein foods, "Identifying food species diversity in diets is a useful first step toward sustainability assessment of diets. Adding additional estimates on the environmental impact or ecosystem services (40) of the species consumed (e.g., chicken vs. beef vs. pork) would allow for better assessment and modeling of the sustainability of the diet. Such assessment will improve assessment of the environmental and natural

resource impacts from agricultural production or from extraction from natural ecosystems (41)," (Lachat et al., 2018). There were also often connections made between the need for data on the environmental impacts of food items and supporting sustainable dietary patterns or dietary choices (e.g., Clune et al., 2017). While a few of the future research recommendations were focused on optimizing the nutritional content of a particular food item, such as pulses (e.g., Margier et al., 2018), most addressed the human health – diet connection more broadly. For example, "However, further work should be aimed at verifying the health benefits of reducing meat and dairy consumption in real-life settings, and addressing the effect of reduced meat and dairy consumption on micronutrient consumption in vulnerable subgroups of the population," (Scarborough et al., 2012).

Future research recommendations that combined numerous often and very frequently referenced food system components, such as environment and nutrition and health impacts and dietary outcomes, usually called for more comprehensive, holistic research (e.g., González-García et al., 2018). For example, "Many studies point to the need for a far more complete assessment of the environmental, social, and economic impacts of foods and diets. Research needs cut across multiple fields, including agriculture, nutrition, animal science, environment, social sciences, and economics," (Auestad & Fulgoni, 2015).

3.4.5 General Recommendations: Overview

General recommendations were mentioned very frequently, appearing in all but one (98%) of the top 5% most cited articles. The general recommendations in this citation group also reference the various upstream and downstream food system category components

relatively evenly: all but one of the categories from upstream to downstream were occasionally referenced, or in 26-50% of articles that mentioned general recommendations (or "articles" for the remainder of this section). Cross-cutting issues were mentioned rarely, in 7% of articles (Figure 3-4).

General recommendations were mentioned very frequently in nearly all or 95% of the median cited articles. In contrast to the top 5% most cited group, the general recommendations in the median cited group follow the trends from objectives and future research recommendations in which the frequency of references to component categories increases when moving from upstream to downstream categories. Upstream categories are mentioned rarely (cross-cutting issues in 24% of articles) and often (drivers in 68% of articles). Midstream categories are mentioned often (food supply chains in 63% of articles) and very frequently (food environments in 78% of articles). Downstream categories were all mentioned very frequently (individual factors in 78% of articles, impacts in 93% of articles, and outcomes in 88% of articles) (Figure 3-4).

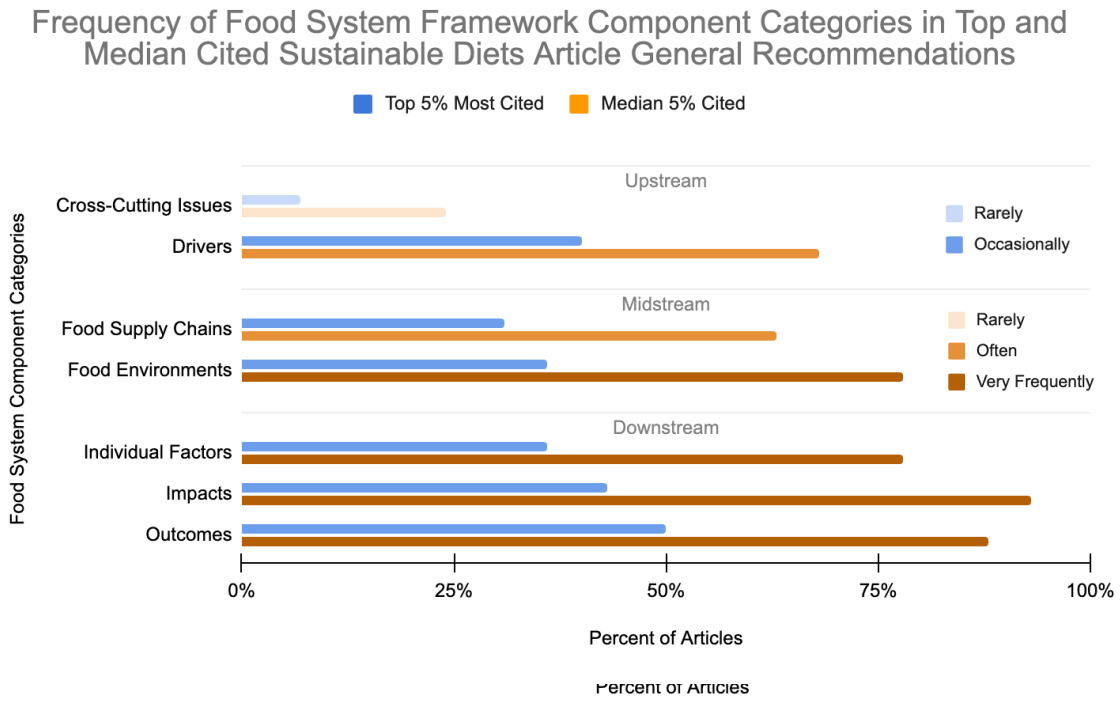

Figure 3-4. Frequency with which upstream, midstream, and downstream food system framework component categories are mentioned in the general recommendations of top and median cited sustainable diets research articles.

General Recommendations: Sub-Component Categories Among Top 5% Most Cited Articles

Most of the sub-components of upstream categories are rarely mentioned. Sub-components of the cross-cutting issues category are in 0-7% of articles. Most of the sub-components of the drivers category are mentioned rarely, in 0-24%, though one sub-component, politics and leadership, was occasionally referenced in 36% of articles. Similarly, most sub-components of the midstream categories are mentioned rarely. Sub-components of food environments are rarely mentioned, in 5-24% of articles. Most sub-components in the food supply chains are rarely mentioned (5-12% of articles), though the food production systems and inputs sub-component is occasionally mentioned (31% of

articles). The sub-components are mentioned either rarely or occasionally among the downstream categories as well. For the individual factors category, behavioral factors are mentioned occasionally (36% of articles), while the rest of the sub-components are mentioned rarely (5-21% of articles). In the outcomes category, diets are occasionally mentioned (48% of articles) while food security is rarely mentioned (21% of articles). Environment and nutrition and health impacts are occasionally mentioned (38% and 33% of articles, respectively), while social equity and economy are rarely mentioned (12% and 19%, respectively). Text coded to the original codes appeared rarely (14-17% of articles).

General Recommendations: Sub-Component Categories Among Median Cited Articles

Most of the sub-components of the upstream categories are rarely mentioned in the general recommendations among the median cited articles. The politics & leadership sub-component of drivers was often mentioned, however (59% of articles), and sociocultural dynamics was occasionally mentioned (39% of articles). Among the midstream category of food supply chains, food storage, loss distribution & transportation was mentioned rarely (12% of articles), while food processing & packaging and retail, markets & waste were mentioned occasionally (27% and 37% of articles, respectively), and food production systems & inputs were often mentioned (54% of articles). Similar variation in references to the sub-components of the food environments category were observed. Vendor properties was mentioned rarely (7% of articles), food availability, food affordability, and product properties were each mentioned occasionally (32%, 29% and 29% of articles, respectively), and food messaging was referenced often (71% of articles).

There was variation in the references to the sub-components of the downstream category individual factors as well. Some were mentioned rarely, while the cognitive sub-component was referenced occasionally (39% of articles) and the behavioral sub-component was often mentioned (73% of articles). The diets sub-component of outcomes was mentioned very frequently (88% of articles) while food security was rarely mentioned (7% of articles). Environment and nutrition & health sub-components of impacts were very frequently referenced (85% and 78% of articles, respectively), while economy was occasionally referenced (29% of articles), and social equity was rarely mentioned (17% of articles). One of the original codes, multi-disciplinary collaborations and/or research, was occasionally referenced (27% of articles), while the other original codes were rarely mentioned (0-5% of articles).

3.4.6 General Recommendations: Text Examples

The politics and leadership references (sub-component of upstream drivers) of top cited articles are often quite general, simply mentioning "policy implications" (Aleksandrowicz et al., 2016) or "getting the concept of sustainability on the political agenda" (Berry et al., 2015). Others are specifically related to a discussion of dietary guidelines (e.g., Clonan et al. 2015). Others include dietary guidelines among other strategies, including food environment modifications and taxation to deter over consumption (e.g., Donati et al., 2016 and Gephart et al., 2021). Among the median cited articles, these recommendations often offer detailed steps for policy advocacy and design, such as in the successful promotion of sustainable diets within the healthcare system

(Alberdi & Begiristain-Zubillaga, 2021), specific policy and government body actions in support of alternative proteins (Kraak, 2022), and multiple strategies for promoting healthy, sustainable diets during disruptive events like global pandemics (Martinelli et al., 2020).

References in top cited and median cited articles to the food production system and inputs sub-component of the midstream food supply chains category are often related to the acknowledgement of environmental impacts, particular of meat production (e.g., Auestad & Fulgoni, 2015; de Boer et al., 2006; Dwivedi et al., 2017; González-García et al., 2018). According to Henchion et al. (2017), for example, "it is clear that the way we produce and consume protein has significant impacts on the environment and on human and animal health which necessitate action." Production methods, such as adoption eco-friendly practices (Berry et al., 2015), designing diverse cropping (Dwivedi et al., 2017), improved management and technological interventions (Gephart et al., 2021; Henchion et al., 2017), and efficiency increases are also mentioned (El Bilali et al., 2021; Godfray et al., 2010). Median cited articles also outline practices, methods, and strategies to support the production of local, indigenous foods (Cogill, 2015; Maroyi, 2018) and food systems (Gallegos-Riofrío et al., 2021), neglected and underutilized crops (Mudau et al., 2022), and specific products, like seafood (Bogard et al., 2019) and seaweeds (Butcher et al., 2020).

The behavioral sub-component of the downstream individual factors category in top cited and median cited articles is largely comprised of recommendations oriented around consumer adoption of sustainable dietary patterns, particularly those that are high in plant-based and low in animal-based foods (e.g., Aleksandrowicz et al., 2016).

González-García et al. (2018) conclude, for example, that their "results confirm that a reduction in the carbon footprint of daily diets requires a reduction in the consumption of meat and dairy products, since both can be considered as the environmental hotspots in terms of GHG emissions." A wide variety of mechanisms and strategies are mentioned to achieve this behavior change, such as targeting meat consumption reductions among specific populations (e.g., males (Clonan et al., 2015) and young adults (Donati et al., 2016)), changes to built and retail environments (Clonan et al., 2015), using footprint calculations to guide meal planning (Clune et al., 2017), capitalizing on health concerns and culinary traditions like the Mediterranean diet (de Boer et al., 2006; Dernini et al., 2017), and social, education and awareness campaigns (Downs et al., 2022; González-García et al., 2018).

3.4.7 Upstream-Downstream Comparison Between Citation Groups

The proportion of articles with objectives, future recommendations, and general recommendations was compared between the top 5% most cited and median cited groups. The proportion of articles with objectives was the same in both groups (43 out of 43 articles, or 100%), thus no statistical test was performed. A two-sample z-test of proportions did not find a statistically significant difference in future recommendations between the groups ($p=1$). A binomial exact test was used to test for difference in general recommendations due to the very small number of articles without any general recommendations, and no statistically significant difference was found ($p=0.400$; Table 3-4).

The proportion of articles that reference upstream, midstream, and downstream food system components for each of the objectives, future research recommendations, and general recommendation coding groups was also compared between the top 5% most cited and median cited groups using a two-sample z-test of proportions. A binomial exact test was used to test for difference when the number of articles without a reference was between 0-5. Among the objectives, there was no statistically significant difference in the proportion of articles that mentioned upstream, midstream, or downstream food system components (Table 3-4). Similarly, there was no statistically significant difference in the proportion of articles that mentioned upstream, midstream, or downstream food system components when examining future research recommendations (Table 3-4). Among the general recommendations, however, several differences were found. The proportion of articles referencing upstream factors was statistically significantly different between the citation groups ($p=0.011$), with a greater proportion of the median cited articles group referencing upstream components than the top 5% cited articles group. Similarly, there was a statistically significant difference in the proportion of articles referencing midstream and downstream components between the two citation groups ($p<0.001$ for both comparisons). A greater proportion of median cited articles referenced midstream components and downstream components than the top 5% most cited articles (Table 3-4).

Table 3-4. Results of the two-sample z-test of proportions comparing references to upstream, midstream, and downstream food system components between the top 5% most cited articles and median cited articles groups for objectives, future research recommendations, and general recommendations. An asterisk in the left column denotes a case where a binomial exact test was performed due to the small number of articles without a reference (between 0-5).

Objectives				
	Top 5% Most Cited	**Median Cited**	**X-squared**	**p-value for two-sided test, df=1**
Articles with Objectives	43, 100%	43, 100%	N/A	N/A
With Upstream References (N, %)	10, 23%	16, 37%	1.38	0.24
With Midstream References (N, %)	20, 47%	24, 56%	0.42	0.52
With Downstream References (N, %)	43, 100%	43, 100%	N/A	N/A
Future Research Recommendations				
	Top 5% Most Cited	**Median Cited**	**X-squared**	**p-value for two-sided test, df=1**
Articles with Future Research Recommendations	30, 70%	29, 67%	0	1
With Upstream References (N, %)	11, 37%	16, 55%	1.36	0.24
With Midstream References (N, %)	17, 57%	22, 76%	1.64	0.2
With Downstream References (N, %) *	28, 93%	27, 93%	N/A	0.649
General Recommendations				
	Top 5% Most Cited	**Median Cited**	**X-squared**	**p-value for two-sided test, df=1**
Articles with General Recommendations *	42, 98%	41, 95%	N/A	0.400
With Upstream References (N, %)	17, 40%	29, 71%	6.51	0.011
With Midstream References (N, %)	19, 45%	37, 90%	17.15	<0.001
With Downstream References (N, %)	21, 50%	39, 95%	18.89	<0.001

3.5 Discussion

This study aims to address the gap in sustainable diets research synthesis by examining what sustainable diets research publications seek to address, what mechanisms these publications propose to leverage for change, and where these efforts are situated within an upstream-downstream food systems paradigm using the Food Systems Dashboard's Food System Framework. This research demonstrates that the objectives and future research recommendations of both highly cited and median cited sustainable diets publications generally follow a trend wherein the frequency with which articles reference food system components increases from upstream to midstream to downstream components. In general, the sustainable diets research studied here very frequently focuses on downstream components of food systems, such as outcomes and impacts, while midstream components, such as food environments and food supply chains, often or occasionally receive attention in the literature, and upstream components such as food system drivers and cross-cutting issues are rarely, occasionally, or often addressed. The general recommendations among the top 5% most cited articles were more evenly distributed across the food system component categories, with upstream, midstream, and downstream recommendations appearing occasionally or rarely, in the case of cross-cutting issues.

There were no statistically significant differences in the frequency with which the top and median cited article groups stated objectives or made future research or general recommendations. There were also no statistically significant differences in the frequency with which the citation groups referenced upstream, midstream, or downstream

components in their objectives and future research recommendations. The median cited articles, however, referenced upstream, midstream, and downstream components in the general recommendations more than the top cited articles. Overall, this suggests that while the top cited and median cited articles are just as likely to make general recommendations, the median cited article recommendations are more detailed and specific across the upstream-downstream gradient and more likely to address upstream, midstream, and downstream components of the food system than top cited research.

This study also found a similar trend in research attention to the sub-components of these upstream-downstream food systems component categories, with nearly all upstream and midstream sub-components rarely or occasionally receiving attention, and just a few downstream sub-components (behavioral and cognitive factors, dietary outcomes, and environment and nutrition and health impacts) receiving occasional, often, or very frequent attention in the research.

3.5.1 Research Implications

These results highlight that the objectives and future research recommendations of sustainable diets literature are focused more on downstream than mid- and upstream components of food systems. While these samples are small segments of the full body of work, the lack of a statistically significant difference in the upstream-downstream focus of objectives and future research recommendations between the top and median cited groups indicates consistency in the research across citation counts and visibility levels. Although top cited and median cited articles were just as likely to make general recommendations

overall, the general recommendations in median cited articles were found to address upstream, midstream, and downstream components more frequently than top cited articles. This indicates that median cited articles are more likely to address understudied upstream and midstream food system components in their recommendations than top cited articles. The consistency of this pattern across the upstream-downstream gradient also suggests that this may reflect a greater level of detail and specificity within the median cited article general recommendations. This is reinforced by the trend observed in the general recommendations of the top cited articles where components across the upstream-downstream gradient are addressed more evenly and only occasionally at most.

The difference in general recommendation focus and detail between the two citation groups adds to the differences identified in Chapter 2, which finds that these same highly cited articles are more likely to be from highly ranked institutions in well-resourced nations, use quantitative and review methodologies, focus on one topic area, and are more often captured and communicated by news and social media and appear in more policy sources than the median cited articles (Hricko et al., 2024/Chapter 2). This demonstrates that the more detailed recommendations for attention to and action in understudied upstream and midstream areas of the food system in median cited articles are less likely to appear in news media, be discussed in social media, communicated to the public, and translated to policy than the highly studied downstream outcomes and impacts oriented recommendations in top cited research. Media and policy thus continue on the well-worn path of describing and discussing downstream food system outcomes and impacts while the more detailed upstream and midstream recommendations from less cited research are

largely absent. This dynamic may be silencing the ideas and voices behind this less cited research. This has significant implications, including both the stifling of progress in achieving sustainable diets and food systems, and reinforcing elite concentration of knowledge and power in academia.

The 16 years of sustainable diets research analyzed here, spanning from 2006-2022, contributes to a robust and well-established evidence base that identifies and examines downstream environmental and health consequences of our current dietary patterns and food system. This research has provided critical foundational knowledge in our understanding of the scope and severity of the environmental and health challenges faced and created by the food system, from greenhouse gas emissions and freshwater water use to adequate nutrition and chronic diseases (e.g., Kim et al., 2020; Payne et al., 2016; Springmann et al., 2018). Research on behavioral factors has also brought awareness and attention to the potential role of individual food choices in influencing dietary shifts toward more sustainable options and a variety of mechanisms to support this behavior change (i.e., changes to retail environments, taxation, messaging and awareness campaigns) (Aleksandrowicz et al., 2016; Clonan et al., 2015; Dernini et al., 2017; Downs et al., 2022). This has been essential in establishing the imperative and building support for change.

After nearly two decades of this focused work, however, the time has come to shift attention not only to other, less studied outcomes and impacts, but to understudied mid- and upstream food system drivers. This involves elevating existing, less visible research, such as the median cited articles studied here, that has already begun extending beyond the familiar downstream outcomes and impacts. Future research can also seek to

address multiple mid- and upstream levels of influence together to collectively represent a systems approach. As indicated by the Food Systems Framework, these include a range wide range of cross-cutting issues (e.g., governance and resilience), drivers (e.g., globalization and trade, sociocultural dynamics, income growth and distribution), food supply chains (e.g., food storage, loss distribution and transport and food processing and packaging), and food environments (e.g., food availability and affordability, product and vendor properties, messaging).

Continuing along with the same downstream focused research agenda may risk overlooking or missing opportunities to investigate, understand, and advocate for midstream and upstream strategies and solutions to sustainable diets challenges. Taking the same approach in future research may present fewer challenges, as research suggests that downstream factors may be easier to study as they tend to be more visible and present the need for immediate attention (Braveman et al., 2011). It may also be easily justifiable given that understanding downstream outcomes and impacts of a system, such as sustainable diets and food systems, is important in outlining and describing the extent of symptoms and results of challenges. Continuing, however, to direct attention predominately toward these downstream factors while understudying mid- and upstream factors risks distracting from fundamental root causes driving and contributing to food system challenges. It may also lead to missed opportunities to uncover, study, and implement more impactful, effective strategies that can have a multiplying effect on improving equitable outcomes (Braveman et al., 2011; Hahn, 2021).

Furthermore, the emphasis on downstream outcomes and impacts of food systems in the current sustainable diets literature may be influencing the direction of future research efforts. The downstream emphasis was consistent in future research recommendations across citation groups, though research suggests that it is publications with high relative citation counts within a subject area that indicate higher research impact and influence (Teplitskiy et al., 2022). This research is perceived as higher quality, more worthwhile of time and attention investment, garners more meaningful engagement from readers, and can have a more substantial influence on the research frontier than less cited works (Teplitskiy et al., 2022). The greater media and policy attention to these articles, as evident in their higher altmetric attention indicator scores (Hricko et al., 2024/Chapter 2), may also contribute to a self-reinforcing cycle in which studies that focus on and recommend more research on downstream components of the food system receive greater relative scholarly attention, generate more media and policy buzz, and fuel more research and attention to these downstream topics. Further contributing to this dynamic is the tendency among scholars to favor research questions and topics within their current scope and networks, leading to a densification of scholarly inquiry (Fortunato et al., 2018).

The need for more attention to additional down-, mid-, and upstream food system influences is underscored by calls for greater attention to the intersections of health and environment with social and economic dimensions, sociocultural influences on food practices, and social equity in sustainable diets and food systems research (Biesbroek et al., 2023; Monterrosa et al., 2020; Nisbett et al., 2022). A narrative review, for example, found that although sustainable diets research has focused on environment and health,

social and economic dimensions of sustainability are broadly understudied in sustainable food systems literature and must be addressed to develop positive, equitable food systems strategies and solutions (Nicholls & Drewnowski, 2021). Webb et al. (2023) similarly identified the need for greater recognition and integration of economic and social issues in a scoping review of sustainable diets metrics. There are also broader recommendations for more multi-disciplinary approaches to food systems research. Biesbrook et al. (2023) call for more interdisciplinary sustainable diets research that engages with food systems actors, including policymakers. Similarly, El Bilali et al. (2021) argue in a systematic review for more attention to and integration of the overlooked social, economic, and political dimensions of sustainability in a research agenda that holistically addresses an agri-food system that is inherently multi-disciplinary.

The overall need for greater attention to multiple components and layers of food systems demonstrated by the results presented here is reflected in some of the research considered in this content analysis. For example, Jones et al. (2016) suggest partnerships between researchers and stakeholders to collaboratively identify food system elements, leverage points, and areas for evaluation to better track sustainability measures over time and scales. They also recommend integrating environmental, health, and social dimensions across contexts and scales to more comprehensively understand barriers and opportunities in food systems transformations. Similarly, Johnston et al. (2014) state that "promoting sustainable diets will require an inclusive approach that reflects multidisciplinary determinants," including interdependent agriculture, food, nutrition, health, culture, and environment dimensions. Dernini et al. (2017) recommend more interdisciplinary

collaborations in addition to government, academia, private sector, civil society and mass media cooperation while de Boer et al. (2006) suggest multidisciplinary analyses of the drivers influencing protein sources in diets are needed to develop policy options to support an animal to plant protein transition. Others call for a greater involvement of a variety of stakeholders, including a range of actors from nation states, civil society, and the private sector, to support sustainable food systems (Gephart et al., 2021; Henchion et al., 2017).

It is also important to note that the process of coding objectives and recommendations that reference environmental impacts revealed a subtle but notable nuance in how sustainable diets impacts are framed in the research literature. This nuance became apparent when determining whether environmental impacts are a result of diets (a downstream sub-component of outcomes) or of food production systems (a midstream sub-component of food supply chains). The first author coded according to the language used by the publication authors. For example, if authors stated that the objective was to model the environmental impact of diets, it was coded as such (i.e., to outcomes and diets, and environment and impacts). While this accurately represents the stated intent of the publication, it fails to capture that study authors were measuring the environmental impacts associated with food production. This is reflected in the fact that diets are mentioned more frequently in the sustainable diets research than food production systems and inputs. For example, among top cited research objectives and future research recommendations, food production systems and inputs are mentioned rarely in 14% 23% of articles whereas diets are very frequently mentioned in 93% and 90% of articles, respectively. This is less

apparent in general recommendations where both food production systems and inputs and diets are each only occasionally mentioned, in 31% and 48% of articles, respectively.

While there is a clear and direct correlation between food that is produced and food that is consumed, these are arguably two separate processes that are often indistinguishable in the research literature. When a research study is framed as modeling the impacts of diets, subsequent recommendations logically suggest focusing on these downstream levers, suggesting dietary change to decrease impacts. The mechanism is presumably through supply-demand market dynamics, though this rarely is this explicitly stated. Examining the general recommendations coded to politics and leadership, the most frequently mentioned sub-component of the generally under-referenced drivers, indicates that even when upstream tools, such as policy, are utilized, they are often still ultimately focused on downstream dietary choices. For example, one of the articles with general recommendations coded to politics and leadership discusses the need to incorporate nutritional, animal welfare, and environmental considerations of sustainable diets into dietary guidelines to increase public awareness and influence their behavior (Clonan et al., 2015). Others also mention dietary guidelines as policy tool for influencing dietary choice, as well as adjusting food environments and introducing taxation measures to change dietary patterns (Donati et al., 2016; Gephart et al., 2021).

This distinction between the impacts of diets and the impacts of food production is subtle but has the potential to meaningfully shift how strategies and solutions are formulated. Framing this type of research as modeling the impacts of food production introduces space to acknowledge that changing the impacts also involves changes further

upstream. This finding aligns with an agri-food systems literature and framework analysis, which found that efforts to integrate multiple approaches to food systems challenges, such as sustainable diets and nutrition sensitive agriculture, tend to focus on impacts rather than processes (Lamine et al., 2019). In doing so, they tend to overlook the essential social and ecological processes that influence system changes and transitions. This was especially the case in sustainable diets studies that recommend specific dietary shifts or patterns without addressing if and how they can be adequately supported through food production. The authors recommend combining qualitative and quantitative methodologies and shifting from impact assessments to transdisciplinary process-based approaches that involve a wide range of researchers and agrifood transformation actors in order to develop and enact a sustainable and just transition (Lamine et al., 2019). Focusing singularly on diets and impacts can preclude the acknowledgement, integration and study of mid- and upstream factors that influence not just diets but also food production. Without addressing these mid- and upstream factors, the effectiveness of dietary change strategies may be limited. It may also narrow the scope of strategies and solutions considered, and prevents a thorough analysis and consideration of trade-offs, limitations, and unintended consequences of such actions.

3.5.2 Limitations

It is important to note that the top cited and median cited research examined in this study may not be representative of the broader sustainable diets literature. The top cited articles were selected, however, not because they are representative but because they are correlated with high altmetric scores and thus likely to be more visible and influential. The

inclusion of a comparison group comprised of median cited articles, although a small sample size, also aimed to provide more insight into the extent to which the top cited articles are representative of the literature.

The selection of articles included in this study was based on a literature search that used a small selection of similar search terms to query the research database: “sustainable diet”, “sustainable diets”, and “sustainable dietary pattern*”. Relevant research that does not use these terms would therefore be excluded from consideration in the broader dataset and thus the subset of articles examined here. In addition, while coder agreement between CH and EB was established using a subset of articles in the first step of the coding process to identify research objectives and recommendations, all subsequent coding was performed by one coder, CH. This individual coding may therefore reflect potential biases of the first author.

Some limitations were also revealed in the framework itself. Some topics that arose during the coding process did not have an obvious home in the framework. For example, neither animal welfare nor concepts of food acceptability, preferences, or desirability are explicitly mentioned in the framework. Animal welfare was coded to sociocultural dynamics under the drivers category given that it has been considered a sociocultural outcome by, for example, the Food and Agriculture Organization of the United Nations (FAO, 2018). Food desire is mentioned in the framework description of sociocultural dynamics, and references to preference, acceptability, and/or desirability were thus coded to this component. In addition, the framework does not recognize non-market food systems, such as sharing networks, charitable giving, and food aid. Although only one study in the

dataset considered here mentioned non-market food exchange systems in the objectives or recommendations (Barosh et al., 2014), it highlighted the absence of these exchanges systems in the framework. Despite this absence, non-market systems are an important element of food security and food systems and are an important yet underrecognized component of the food system (Bliss, 2019).

3.6 Conclusion

This study examines the aims and recommendations of highly and median cited sustainable diets literature through a content analysis to shed light on what knowledge this body of work seeks to uncover, what topics it proposes for future studies, and how it recommends addressing food systems challenges. The research objectives and recommendations are mapped to an upstream-downstream gradient overlaid on the Food Systems Dashboard's Food System Framework to identify what levers are suggested for change and where they are situated on the upstream-downstream spectrum. This study finds that sustainable diets research objectives and recommendations largely focus on downstream outcomes and impacts rather than mid- and upstream food system influences and drivers. Top cited and median cited articles follow similar trends in the upstream-downstream focus of their research objectives and future research recommendations, indicating consistency in this focus across the broader literature.

While top and median cited articles are equally likely to make general recommendations, the median cited articles more often reference food system components across the upstream, midstream, and downstream categories in their general

recommendations compared to top cited articles. This indicates that they are more likely than top cited articles to focus on understudied mid- and upstream factors and also more likely to be detailed and specific in these recommendations. Median cited articles receive less attention in media and policy spheres than top cited research, suggesting that the recommendations and voices behind this less cited research may be minimized. Given that median cited research is more likely to originate in lower-income countries, from less prestigious academic institutions, use qualitative or mixed method, and make mid- and upstream recommendations than top cited research, the lack of attention to this work may result not only in reinforcing elite concentration in knowledge and power, but also in stifling progress toward a sustainable food system transformation.

This study also finds that among the outcomes and impacts examined, dietary outcomes and environment, nutrition and health impacts are studied more frequently than food security, social equity, and economic impacts. These results highlight the need for greater attention to these understudied outcomes and impacts, and to mid- and upstream food systems components to support sustainable diets and food systems more broadly. This involves elevating existing research that is already making this shift and focusing future research on cross-cutting issues of governance and resilience, drivers such as globalization and trade, sociocultural dynamics, and population and income growth and distribution, food supply chains, and food environments. These findings are bolstered by calls from both the literature reviewed in this analysis and beyond for greater focus on sociocultural influences on food practices, greater attention to the intersections of sustainability dimensions, particularly social and economic dimensions, and the need for holistic and

transdisciplinary systems thinking across sectors and stakeholders to develop and enact effective strategies for a sustainable food system. Continuing to focus on downstream factors risks overlooking and failing to address root causes, missing opportunities to study and utilize impactful upstream solutions, and limiting the effectiveness of any downstream strategies that are implemented.

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CONCLUSION

The aim of this dissertation was to improve understanding of sustainable diets knowledge, shed light on research gaps and strengths, and assess the capacity of this research to holistically support sustainable food systems for planetary health. This dissertation accomplishes this through a comprehensive review of sustainable diets literature, analyzing knowledge creation and reproduction within this field, and examining how the existing literature approaches research inquiry and recommends action along an upstream-downstream framing of food system components and influences. In other words, this work looks at what the research says, who is driving it, how it is repeated, and what it recommends for study and action. In this concluding chapter, I will summarize the findings of this work, critique the capacity of sustainable diets research to address food systems challenges, and highlight opportunities to support a sustainable food future.

4.1 Sustainable Diets Research Strengths

This dissertation research reveals that the field of sustainable diets is growing in breadth and depth, particularly in the last several years. While environment, nutrition, and health have received the majority of research attention thus far, analysis from Chapter 1 indicates that the scope is widening to include additional disciplines, including public health and safety, agriculture, and medical sciences. Chapter 3 results similarly indicate a strong research focus on dietary outcomes and environment, health, and nutrition impacts. Together, these results demonstrate that there is robust research on the environmental and health consequences of our current dietary patterns and food system.

This knowledge is essential in understanding the scope and severity of current food system impacts and helps establish the imperative for change.

4.2 Sustainable Diets Research Gaps and Limitations

This dissertation also reveals gaps in and limitations of existing research. Chapter 1 highlights the need for greater focus on several understudied topics, including local and seasonal foods, culture, equity, and social processes and contexts. These findings are further supported and informed by the in-depth content analysis conducted in Chapter 3. These results find that highly cited sustainable diets research articles very frequently focus on and recommend study and action on downstream outcomes and impacts compared to mid- and upstream factors, such as food system drivers, food supply chains, food environments. In addition, closer examination of downstream outcomes and impacts indicates that food security, social equity, and economic impacts are rarely or only occasionally studied while dietary outcomes and environment, nutrition, and health impacts are occasionally to very frequently the focus of sustainable diets research aims and recommendations.

Failure to understand the full scope of food system challenges by only focusing on some impacts while overlooking others may inhibit or contradict the goal of this work to support sustainability and planetary health. Without accounting for the full range of impacts and influences, trade-offs and consequences cannot be fully assessed. As a 2023 scoping review on the planetary health impacts of dietary patterns suggests, research must incorporate all elements of sustainability, and particularly economic and social

impacts, in order to fully understand trade-offs resulting from dietary shifts (Webb et al., 2023). Nicholls & Drewnowski (2021) similarly underscore the importance of a yet unrealized holistic research approach to sustainable diets that integrates natural and social sciences in order to equitably assess and manage trade-offs.

Furthermore, while focusing predominately on downstream food system components and influences may address some of symptoms of food system challenges, it does so at the risk of distracting from and overlooking upstream root causes contributing to these challenges. Downstream factors are often easier to study than those that are upstream because they tend to be closer in time and proximity to their more observable effects (Braveman et al., 2011). Focusing on upstream factors, however, may be more likely to effectively improve outcomes and equity as they address fundamental causes (Braveman et al., 2011) and have greater impact because of their potential to have ripple down effects on multiple downstream factors (Hahn, 2021). Addressing upstream levers for change is not without complications, however, as it often involves policies mired in political and bureaucratic resistance (Hahn, 2021).

The bibliometric and altmetric analysis of sustainable diets literature in Chapter 2 also identified several research limitations. This Chapter first establishes that the most highly cited research articles are likely to have a high degree of influence both within and beyond the research community due to their high relative citation counts and moderately to strongly correlated altmetric scores. This Chapter then highlights how these highly cited articles are more likely to use quantitative and review methodologies and be published by authors affiliated with highly ranked academic institutions based in high-

income countries than median cited articles. Both highly cited and median cited articles are associated with research institutions that are predominately located Europe and North America. The majority of these articles are also best described by two topic areas – sustainable diets and food system policy and sustainability impacts of dietary patterns. In addition, as discussed above, Chapter 3 highlights how the most highly cited articles more frequently focus on downstream food systems outcomes and impacts than mid-and upstream factors of cross-cutting issues, drivers, food supply chains, and food environments.

There are numerous challenges associated with these findings. For example, relying on citation counts as a reflection of quality when identifying research articles to inform future research directions or literature reviews may capture only a subset of perspectives and voices. Specifically, those affiliated with less prestigious academic institutions based in lower-income nations and using qualitative and mixed methods research approaches are likely to be excluded while those from high income, highly ranked institutions and using quantitative and review methods are more likely to be included.

In addition, if highly cited research is in fact more visible and influential than less cited research in news and social media, web activity, and policy documents, then it may play an outsized role in media, public opinion, and policy and advisory report formulation. Considering the results of Chapter 3 in this dynamic suggests that highly cited sustainable diets research, which very frequently addresses downstream outcomes and impacts while rarely focusing on mid- and upstream drivers, cross-cutting issues,

food supply chains, and food environments, may be more likely to circulate within and beyond academic networks. These knowledge creation and reproduction dynamics may perpetuate inequities in research opportunities and publishing, elite concentration in research, and limit the ability of scholars and others to consider a full scope of options in pursuing sustainable food systems.

4.3 Opportunities for Sustainable Diets Research to Better Support Sustainable Food Systems and Planetary Health

Several strategies may support the expansion of sustainable diets research to incorporate understudied areas of culture, equity, social processes, economics, and upstream food systems factors, such as food system drivers, food supply chains, food environments. For example, research can incorporate social and economic metrics and indicators into environment and health studies, including life cycle assessments, models, and spatial analyses (Webb et al., 2023). These metric-focused studies can also be complemented by methodologies such as surveys, qualitative interviews, and ethnographic studies (Monterrosa et al., 2020). Establishing collaborations between researchers, technical experts, and policymakers may support the feasibility and strength of efforts to combine metric-oriented and other empirical methodologies (Monterrosa et al., 2020). Additional research suggests adopting equity-based frameworks that integrate multiple factors, ranging from individual, social, and political to commercial, cultural, and economic (Nisbett et al., 2022). Transdisciplinary research efforts may also offer opportunities to integrate quantitative and qualitative approaches and move from impact

assessments toward participatory process-based examinations that support sustainable food systems (Lamine et al., 2019).

Improving equity in research opportunities and publishing, combatting elite concentration in research, and reducing homogeneity in study methodology will also involve a range of strategies. One of these may involve establishing and supporting north-south research collaborations. These collaborations may enhance the plurality and richness of academic exchanges, elevate the valuable first-hand contributions of southern researchers, reduce academic isolation of southern scholars, and promote a more inclusive scholarly environment (Amarante et al., 2022; Amarante & Zurbrigg, 2022). Elite citation concentration, or the concentration of citations among a few scientists, and reducing the western world's domination of research publications will likely involve enhancing diversity and inclusion at multiple levels, from author to leadership to society (Maas et al., 2021). Lastly, supporting diverse research topics and reducing methodological homogeneity may require acknowledging the role that research impact pursuit has in narrowing research questions, topics, and approaches to those that are more easily measured. The emphasis on maximizing research impact should be balanced alongside the pursuit of diverse research topics and methods to combat bias toward those that appeal to investment logic (Benneworth, 2015; Williams, 2020).

4.4 Final Thoughts

This dissertation sought to tell an increasingly complex story about what sustainable diets research contributes to knowledge and actions in support of sustainable

food systems. It also aimed to uncover gaps and limitations in the literature to highlight areas of caution, inform a research agenda, and identify strategies that support a more equitable, holistic, and complete vision for sustainable diets. This concluding chapter summarizes and synthesizes the collective findings of this three chapter effort and highlights a range of opportunities for sustainable diets researchers and collaborators to consider in the pursuit of a sustainable food system necessary for planetary health.

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APPENDIX A: Chapter 1 Supplementary Materials

Topic Modeling Method:

Following the topic modeling framework described by Asmussen & Møller (2019), pre-processing steps were performed prior to running the LDA model. These steps included loading the papers into the analysis program and cleaning the data. This included tokenizing the abstracts, or breaking the string of text into individual words, referred to as "tokens." Pre-processing also included converting text to lowercase and removing all punctuation, numerical values and symbols, URLs and special characters. Words, or tokens, were then lemmatized, or reduced to common base form, i.e., agricultural to agriculture, changing to change. Bigram and trigram models were created in which a pair or trio of consecutive words were assigned as a token to maintain sequencing, i.e. "grocery store" to "grocerystore." Stopwords, or common non-topical English words (i.e., a, an, the, is, are, by, for, from, that, with), were removed.

It is also common practice to remove both very rare and very frequent words as they will be uninformative for the model, though there is no standard for determining what constitutes rare and frequent. Words that are used too rarely do not show how documents are similar, whereas words used very frequently will not show how documents differ. This study follows the precedent of Asmussen & Møller (2019) and Suominen & Toivanen (2016) by removing words that occur only once in the corpus (n=2,746). For frequently used words, this study follows the work of Cooper et al. (2020) by removing the search terms used to conduct the literature search (sustainable, diet, dietary, pattern), and Asmussen & Møller (2019) by removing words that provide little contextual information

or insight into the dataset, such as words that frequently appear as section headers in abstracts (abstract, cab_abstract, background, introduction, objective, purpose, method, result, conclusion). This study also follows examples set by Székely & vom Brocke (2017), Carter et al. (2016), and Mimno (2012) by removing words that appear very frequently. Words that appeared in more than 80% of the documents (sustainable, diet, and food) were identified for exclusion, recognizing that two of the three words were already removed due to being search terms. The final dictionary for the model contains 3,829 words.

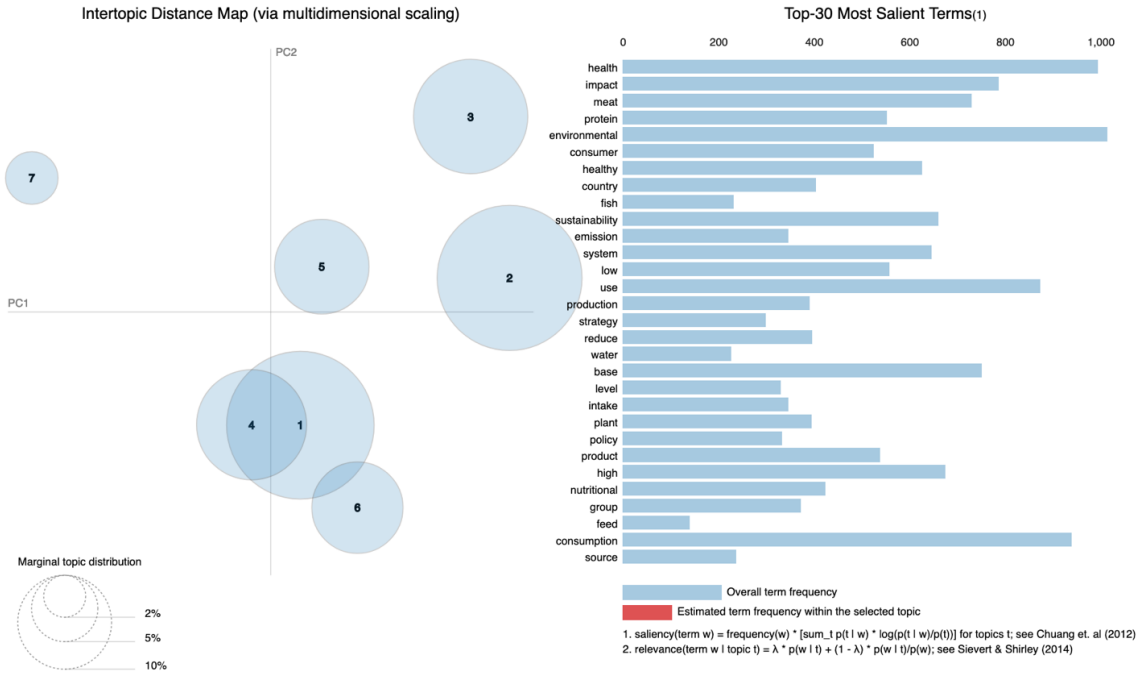
The LDA topic modeling technique uses unsupervised classification to generate topics. One of the key steps in this method is determining the optimal number of topics to include in the model. The "right" number of topics can vary depending on the context and content of the dataset. A higher number of topics can be used for a more detailed understanding of the data, while a lower number of topics provides a more general overview (Asmussen & Møller, 2019). To estimate the optimal number of topics in this work, a cross-validation method was applied. Although Asmussen & Møller's (2019) framework for using topic modelling in literature reviews suggests using perplexity as a cross-validation metric to evaluate the topic model, this study instead uses coherence scores. Perplexity is a metric used in information and language models in which a lower score indicates a better model (Asmussen & Møller, 2019). Perplexity indicates how well the model can predict the distribution of the remaining words in a document after observing a portion of it and can be used to quantitatively evaluate the strength of an LDA model (Blei & Lafferty, 2007). In contrast, coherence is a measure of how well the words relate to each other and reflects how humans intuitively determine what makes a topic coherent,

with a higher score indicating a better model with topics that are consistent, clear, and relevant. Stevens et al. (2012) note that perplexity does not always capture semantically interpretable topics and instead use coherence measures to evaluate model strength, and Chang et al., (2009) found that optimizing perplexity is often negatively correlated with human interpretability. This study therefore uses coherence scores to determine the optimal number of topics that are semantically interpretable.

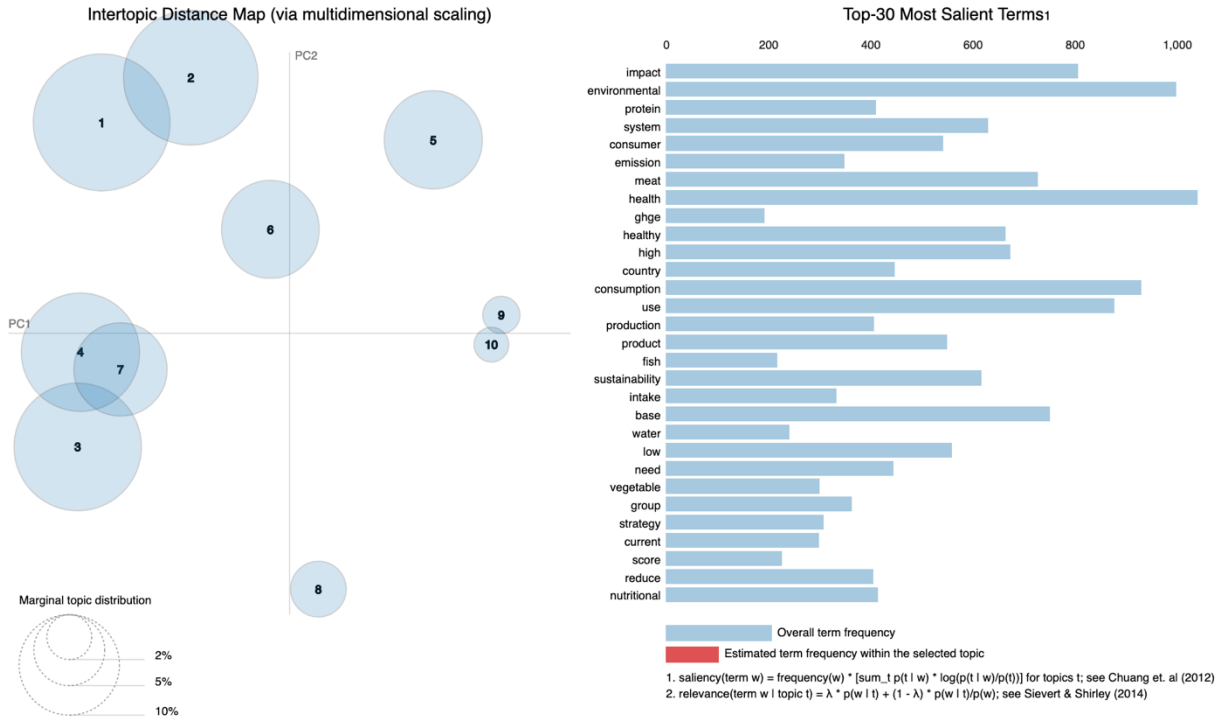
In addition to coherence scores, this study incorporated topic visualization and content area knowledge in the selection of topics. Gensim's pyLDAVis tool, a commonly used interactive visualization tool for LDA models (Mabey, 2015; Sievert & Shirley, 2014), was used to visualize the data. In this visualization plot, each bubble represents a topic. The size of the bubble represents the prevalence of the topic with the prevalence increasing along with the size of the bubble. A plot with large, non-overlapping bubbles scattered throughout the plot (versus a plot with small, overlapping, clustered bubbles) indicates a good topic model.

Identifying an appropriate number of topics was thus a balance between maximizing the coherence score, examining the topic visualization, and optimizing specificity and useability, or finding a useable number of topics that are precise. Coherence scores were calculated for models ranging from 1 to 20 topics (1, 2, 3, 4… 19, 20 topics). To optimize the number of passes, or the number of times the topic model runs through the entire corpus, the coherence scores were calculated at 10, 25, 50, and 100 passes. The default settings were used for the alpha eta hyperparameters. The model with 7 topics at 100 passes had the highest coherence score. This model was cross validated with the

pyLDAviz visualization, which indicated some overlap in topics and some clustering, though the topics were reasonably well dispersed and relatively comparable in size (Supplemental Figure 1-1). The 7 topic model limited overlap and maximized distribution of the bubbles across the quadrants compared to other models. An example of this comparison is demonstrated by viewing the pyLDAviz of a 10 topic model (Supplemental Figure 1-2), which shows a higher degree of overlap in topics and a greater differential in the bubble size. This, combined with the coherence score analysis and a review of the topic areas using content knowledge, suggests there is marginal benefit to increasing the number of topics, and that clarity may worsen in doing so.



Supplemental Figure 1- 1. Figure 1. pyLDAvis depicting the overlap, dispersion, and clustering for the 7 topic model selected for this analysis. Although there is some overlap in the bubbles, particularly for topics 1 and 4, and some clustering toward the lower right quadrant, they are dispersed and relatively comparable in size.



Supplemental Figure 1- 2. Figure 2. pyLDAvis depicting the overlap, dispersion, and clustering for a 10 topic model. There is a higher degree of overlap and greater differential in bubble size compared to the 7 topic model (Figure 2). There is also some clustering of the topics in the top left quadrant.

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