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Food Security in the United States: A Futures Analysis via Systems Modeling

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I am submitting herewith a thesis written by Jennifer Lynn Trumbo entitled "Food Security in the United States: A Futures Analysis via Systems Modeling." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Nutrition.

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(Original signatures are on file with official student records.)
Food Security in the United States: A Futures Analysis via Systems Modeling

A Thesis Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Jennifer Lynn Trumbo
December 2018
Abstract

Food insecurity is a pressing issue not only in developing countries, but in communities across the United States (US). Food insecurity is the lack of nutritious, sufficient, accessible, and reliable culturally-appropriate food. At least 42.2 million people across the US face food insecurity. Food insecurity has been associated with institutional barriers, gender, indigeneity, citizenship, human immunodeficiency virus (HIV) status, racialization, and poverty. Further, a lack of sufficient, nutritious food is associated with serious health outcomes. Food insecure populations have higher rates of chronic disease, mental health issues, and obesity. Considering the negative health outcomes associated with food insecurity, and its relationship with environmental, economic, political, and sociological trends, a review of the current literature was conducted, and a novel systems model was created using the Tonn methodology. This systems model defines and organizes relationships between key indicators identified via a comprehensive literature review. Data were collected from over 100 sources, scored, and analyzed from using environmental scanning and futures analysis.

Results suggested that climate change, food production infrastructure, and ecosystem health will display negative trends over time. In other words, the model predicts more intense climate change, declining food production infrastructure and ecosystem health. Trends in political climate and social inequity conditions were positive, although social inequity expected component changes remained negative. Therefore, while the model predicts decreased social inequity and improved political climate, these values were still negative in relation to food security. Sensitivity analyses revealed no unexpected effects with the removal of climate change and political climate components. Therefore, model effects were not driven solely by the trends in political climate and climate change, rather the model as a whole. Overall, policy-makers,
nutrition, and public health professionals must begin to address food insecurity in light of future
trends revealed through this and similar studies. Preparation and pro-active intervention could
reduce the risk of negative health outcomes associated with food insecurity around the world in
the next 20 years. Future studies must examine the most effective interventions and policies
targeted at vulnerable populations considering the complex relationship between environmental,
economic, political, and sociological driving factors.
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CHAPTER 1

INTRODUCTION
Very low to low food security (also known as food insecurity) is observed in societies around the world. At least 42.2 million people across the United States face food insecurity, or the lack of consistent, healthy, sufficient, available, and culturally suitable food, as previously mentioned. Poverty, institutional barriers, gender, citizenship status, HIV status, and racialization are connected to food security. In recent years, scientists have more accurately monitored food security across temporal and geographical scales. Notably, ecological studies suggest the prevalence of food insecurity among populations over time while cross-sectional studies examine subjects at one point in time. The Food and Agricultural Organization of the United Nations reports that about 795 million people are undernourished around the world. Over the last ten years, the number of undernourished individuals has decreased by around 167 million globally. This downward trend is not universal. Notably, while trends are generally negative, Africa and Oceania display positive trends. Food insecurity rates in Africa and Oceania appear to divert from the World Food Summit and Millennium Development hunger target goals.

Per Coleman-Jensen and colleagues, 12.7% of households were food insecure at some point during 2015 in the United States, despite a decrease of 1.3% from 2014 to 2015. This downward trend has occurred since the 2011 peak rate: 14.9%. In the United States, food insecurity is divided into two main categories: “low food security” and “very low food security”. Over 5%, or around 2.1 million households, are categorized as “very low food security”. This indicates that very low food-insecure people face a significant decrease in the amount and quality of food they consume. Levels of food security vary across the United States by region, state, and even county. US food insecurity rates per capita range from 4% to above 30%.

For example, Tennessee ranks at the 41st most food insecure state with a 17.1% food insecurity rate. Tennessee’s child food insecurity rate per capita is 25.7%; 8.6% higher than the
overall food insecurity rate. Proposed drivers include poverty, race, households with children, or households including someone with a disability. In particular, African American, Hispanic and American Indian households were at higher risk. Also, environmental factors like energy, food, and housing costs and unemployment rates drive Tennessee food insecurity rates. Tennessee counties with the highest food insecurity rates include Lauderdale, Haywood, Lake, Hardeman, and Shelby. These counties are in the southwest corner of Tennessee, a region also facing higher poverty rates than the rest of the state in general. The food insecurity rate has decreased since 2011, although the most-affected Tennessee counties have seen the least relief. Notably, food insecurity measures for the United States are reported per household, while global and state trends are reported per capita. Per capita measurement is a more reliable measurement because it adjusts measurements by the population in concern. This is of particular concern when comparing data sets over geographical and temporal scales.

The lack of available, adequate, safe, and consistent food supply can manifest at any level in society. Yet, research suggests clear associations between the prevalence of food insecurity and health disparities. The social determinants of health theory proposes that social factors are the foundation of health inequalities. Further, Maslow’s hierarchy of needs indicates that physiological needs (most certainly including consistent access to quality foods) are most fundamental and largest in comparison with other needs. Given this connection between human physiology, social conditions, and food insecurity, how can society most efficiently decrease its occurrence? Interventions have been targeted to address social factors underlying the phenomena, consequently indirectly mitigating health issues, as will be discussed in the next section. Weiler and colleagues conducted identified the following themes linking health equity and food security: gender, HIV status, indigeneity, citizenship, racialization, institutional
barriers, and poverty. Additionally, food insecurity has been associated with disease, race/ethnicity, number and age of household members, geographical location, and income level in the United States via the recent United States Department of Agriculture Economic Research Service household survey. Cross-sectional studies have identified high rates of food insecurity in elderly populations, racial and ethnic minorities, and households with children.

Paradoxically, food insecurity has also been associated with obesity per the Food Research and Action Center. For example, Pan and colleagues identified an association between obesity and US adults in all 12 states analyzed. How could individuals consuming enough excess calories to become obese lack food? Several reasons have been suggested. Food insecurity can limit the ability to access or consume quality foods that contain less calories and more nutrients than processed food. Food insecurity can also lead to cycles of food deprivation and overeating, high stress, and fewer physical activity opportunities. Finally, food insecurity has been associated with limited healthcare access. These links can increase the likelihood of obesity in studied populations. Surely, the presence of food insecurity in a supporting web of social risk factors can lead to high allostatic load in affected individuals. Therefore, interventions addressing food insecurity are priority at local, state, and federal levels in the United States and globally.

While many studies investigating food insecurity and negative health outcomes involve large, representative populations, there are still many issues to consider. Yet, much of the NHANES data is based upon self-reported information or information gathered during interviews. Therefore, non-response, response, and recall bias could threaten internal validity. Also, because cross-sectional studies gather information at one point in time (even if it is combined over several years), the exposure data is captured with the outcome data, eliminating
the possibility of determining causation. Data collection and analysis methodologies can change over time. These changes could influence the comparability (or reliability) of the measurements. Finally, cross-sectional studies assess prevalence, not incidence, so risk ratios can’t be calculated. Such considerations should be taken into account during secondary analyses. Despite this, these studies can help inform public health and clinical professionals to assess future studies and direct resources. The following chapters will explore food security drivers and application of a novel methodology to explore the future of food security in the United States.
CHAPTER 2
LITERATURE REVIEW
Abstract

Millions of people across the United States face food insecurity each year. A lack of consistent access to sufficient safe, nutritious foods leaves individuals at a higher risk for issues with health and wellbeing. Low-income households are particularly vulnerable to food insecurity. This review explores how environmental, social, economic, and political indicators explain the past and present state of food insecurity in the United States. Researchers employ diverse methods to evaluate food insecurity. While much of current literature regards food insecurity as an individual or household phenomenon, many studies analyzed in this review use macrosystem processes like food supply and prices to quantify food insecurity. This review identified 41 food security indicators, most of which were environmental and sociological. Twenty-five percent of the studies analyzed identified potential models to explain current food insecurity based upon global trade, land use, climactic variability, yet none offered ways to forecast future trends. Furthermore, less than half addressed climate change, and none factored it into their analysis. While studies found associations between food insecurity and respective indicators, interrelationships were not discussed. The author generated a concept map to summarize critical issues and help inform future food security studies. This literature review aims to inform studies elucidating the relationship between drivers of food insecurity to better predict future trends in light of climate change.
Introduction

Globally, the United States (US) is regarded as a wealthy and successful country, yet there are many households in America that do not have enough food for healthy, productive lives. Food security describes how available, adequate, safe, and consistent food supply is in a population given financial, environmental, and social constraints. In the US, 12.7% of households were food insecure at some point during 2015. While food insecurity rates remained generally steady since 2008 (around 14%), and decreased 1.3% from 2014 to 2015, the United States Department of Agriculture (USDA) suggests that at least 42.2 million people continue to live in food-insecure households in the US. Moreover, 5% percent of these households are categorized as having very low food security. Households with very low food security must eat less food because they lack sufficient resources. Food insecurity rates are higher than the national average by household characteristics and societal factors such as race/ethnicity (e.g., black, non-Hispanics, and Hispanics), geographical location (e.g., south US), income level (e.g., income below 185% of the poverty threshold), and number and age of household members (e.g., households with children, particularly children under age 6). In particular, cross-sectional studies have identified high rates of food insecurity in elderly populations, racial and ethnic minorities, and households with children. Furthermore, food insecure individuals are more likely to experience negative health outcomes such as chronic disease, obesity, and depression.

Indeed, food insecurity decreases societal wellbeing markedly in economically disadvantaged households and groups. Therefore, understanding and assessing food security is vital. Recent studies employed targeted household surveys to assess patterns of food insecurity in communities. Yet, food insecurity is not an isolated, community-based phenomenon. It occurs within a complex, global framework that much of current research fails to address. How do
environmental, social, economic, and political indicators help researchers understand food insecurity at the macro level? The scientific community has yet to offer a comprehensive answer to this question. This narrative literature review compared indicators of food insecurity in the US to investigate how past and upcoming research could help society better predict future trends.

**Selection Methods**

Several approaches were followed to ensure adequate representation and high-quality review of the literature on food security indicators. Firstly, records were identified through comprehensive database searches of EBSCO, Google Scholar, Library of Congress, PUBMED, University of Tennessee OneSearch and Web of Science. Results were limited to human-subjects, peer-reviewed primary research articles published since 2013 in English. Secondary data analyses through statistical approaches, conceptual frameworks and models were considered for analysis. Search terms used to generate articles included food insecurity or food security combined with any of the following words: access, agriculture, ecosystem, economics, environment, equity, indicator, policy, political, price, public policy, risk, societal, society, socioeconomic, trade, United States, or USA. Secondly, reference sections of review articles located during this process were reviewed for additional primary research articles.

Evaluation of articles considered the following criteria: research objectives, study design, independent and dependent variables, sampling techniques, manipulation of the independent variable, collection of dependent variables, statistical analyses, study findings, and limitations. Studies identified through the initial database search that did not contain original data collection or analysis (i.e., reviews or commentaries) were immediately excluded but were reviewed for additional resources and comparison. Studies with research objectives that were not related to the landscape of food security in the US were excluded. Global studies were considered if results
were applicable to the US. Literature complying with selected criteria were analyzed, evaluated, and synthesized within and among the following focus areas: environment, economics, politics, and sociology. The author then speculated upon potential future applications of insights resulting from the literature review, particularly modeling approaches. This review presented a perspective regarding what, how, when, and why particular indicators are used to describe food insecurity for stakeholders, policymakers, public health officials, and individuals invested in society’s future.

**Review of Literature**

Food insecurity disproportionately affects adults and children in low socioeconomic strata in the US. Researchers recognize that factors like the environment, economics, politics, and sociological factors contribute to this problem. Yet, the scientific community struggles to describe, quantify, and depict the etiology and trajectory of food insecurity. Most notably, the complex relationships between these factors are still unclear. Current literature focuses on the metrics and indicators of food security. These indicators within environmental, economic, policy, and sociological contexts can help scientists begin to resolve the interdependencies of food insecurity on national and global scales.

**Environmental Drivers**

Vermeulen and colleagues suggested that the environment (i.e., one’s surroundings, including factors like climate, organisms, and soil) plays a substantial role in food availability, and consequently, food security. Human and ecosystem responses to climate variability are interconnected. In addition, fluctuating ecosystem health decreases food security. As such, food crops must receive adequate water and nutrients to produce sufficient yield. Ultimately, according to Vermeulen and colleagues, agriculture drives food security and environmental changes through greenhouse gas emissions, water quality degradation, and water use.
Poppy and colleagues proposed a methodology to investigate how food security can be understood in an environmental context. The authors paired the ecosystems services and policy response frameworks to elucidate how ecosystems relate to food supply. In particular, the authors examined how several ecosystem services (e.g., water, biomass, pollinators) benefit food security at individual, household, and community levels. This approach was particularly useful because it incorporated data at various temporal and spatial scales from organism to ecosystem processes. Moreover, potential tradeoffs between measures to protect ecosystems and increase food supply were identified. Poppy and colleagues predicted that areas with high population growth (i.e., high birth rates) would be most vulnerable to food insecurity and environmental degradation because of climate variability. During validation with Malawian data, this study reported lack of accurate agricultural statistics. Perhaps a case study using a more reliable dataset would verify that their methodology yields realistic, consistent results. This study suggested that local data would help nationwide estimates of food insecurity accurately inform policies and initiatives.

Nelson and colleagues investigated the relationship between climate variables and food insecurity. The authors focused on how vulnerable food security in the US Southeast and North Atlantic were to climate variability based on historically and archaeologically documented cases from year 1000 to the 1900s. Nelson and colleagues quantified food shortage through availability of food, diversity of available, accessible food, and health of food resources. The authors evaluated the contribution of domestic animal and farming practices, historical records, and textual evidence. This study qualified climactic challenge replicating past events by temperatures, sea ice occurrence, and storminess. Variables were qualitatively ranked by contribution to food shortage based on expert knowledge. Food shortage was proportional to the intensity of vulnerability in many climate challenges. Food shortage effects did not display a
significant pattern in the Southeastern US. Despite its focus on climate, this study examined a limited amount of climate challenges. It would be useful to see how changes in the growing season, albedo (the whiteness of a land surface, often reflected by the amount of snow cover), amount of sunshine and amount of participation would affect food security. In addition, it would be useful to compare these findings to other regions within the US. This analysis was limited to large-scale ecosystem processes, unlike the methodology proposed by Poppy and colleagues. Nonetheless, this study estimated potential climate conditions from a large, robust data set.

West and colleagues suggested techniques to limit agriculture’s negative effects on the environment and food security. Current cropland is producing half of what is realistically attainable. West used past data to predict routes to increase crop yield, particularly in low-performing areas. In the US, West and colleagues predicted that an 8% reduction in excess irrigation, 11% reduction in excess nitrogen, and 4% reduction in excess phosphorus used in fertilizers would balance crop yield with ecosystem health. This approach could substantially reduce agriculture’s effect on the environment and increase food security if completed in combination with similar reductions in Brazil, Pakistan, China, India, and Indonesia. A 13% decrease in nitrous oxide, a greenhouse gas produced naturally by some crops (particularly wheat, maize, and rice) would aid in balancing the caloric needs of the US with environmental concerns, as well. This study emphasized the heterogeneity of challenges and opportunities for improving food security and environmental health around the world. Indeed, in the US resources are not distributed evenly. Therefore, Nelson and colleagues and Poppy and colleagues suggested that large-scale models must be informed by trends in small-scale models. Unlike Nelson and colleagues, this work and Poppy and colleagues did not assess climate extremes, but attempted to determine how to balance food security with environmental health.
One limitation of the above-mentioned studies is the quality of data. Many agricultural and environmental statistics are limited, especially in areas where food is most insecure. In addition, models can not represent every intricacy of real conditions and scenarios, especially at larger scales. If conditions change outside of set assumptions, models, and frameworks can predict trends far from real-life outcomes. For instance, environmental variables can differ seasonally and spatially. Despite this, research has begun to tease apart both current relationships between the environment and food security, and potential future trends and tradeoffs considering climate variability. Environmental variables increase and decrease food yield and quality; two factors that impact food security.

**Sociological Drivers**

Food insecurity is a human problem. Resources have driven populations to travel, fight, and farm for generations. Indeed, societal factors drive how people can access food in their communities. Social conditions such as social networking, mobility, storage, equal access to diverse food supplies influence the likelihood of food insecurity. Social institutions, structures, and trends not only drive, but respond to changing food resources. Research has explored how community and individual factors, barriers, and initiatives modulate the phenomenon of food insecurity in the US. For example, gender, racialization, poverty, citizenship, and institutional barriers increase health inequity related to food insecurity. The following studies elaborate on these topics, as well as policies to address them in the future.

Headey investigated how sociological factors correlate with food security and nutrition. Measures of poverty level through asset ownership, consistent access to clean water, sanitation, electricity, medically attended births, vaccinations, fertility rate and secondary and tertiary education were retrieved from Demographic Health Surveys. Headey constructed dynamic
regression and fixed effects modeling to predict food security outcomes based upon these variables. Results suggested differing trends by country, with most notable increases in food security related to both favorable health, education, and fertility trends and well-documented nutrition programs. Yet, their methodology did not consider potential interdependencies between variables that could increase the potential for confounding in Headey’s analysis. In addition, Headey did not conduct a sensitivity analysis. This makes it difficult to determine how the inclusion of different independent variables influenced model outcomes. Like Poppy and colleagues, Headey suggested increased availability of agricultural data would help build more responsive, predictive models. In contrast to West and colleagues and Poppy and colleagues, Headey suggested that more “nation-level” data were needed to inform food security models particularly in developing nations.

Jablonski and colleagues conducted a secondary analysis on data resulting from a food security assessment survey in Colorado, US. The authors aimed to determine what factors increase and decrease food security at community and population levels. Factors included food retail access, transportation, community food assistance, locally grown food access, cost, and time and education. The authors analyzed data on a population level, and produced the following clusters to ensure that effects were not being minimized through their analysis technique: food engaged and secure, away from home price conscious fruit and vegetable eaters, food secure with inconvenient access to fruits and vegetables, compromised consumers (low-income large households with no transportation who do not participate in food assistance programs), and single and food insecure. Results suggested that there is much heterogeneity between clusters of food security. In particular, access to food was particularly influential for the “single and food insecure” cluster’s food security while cost was a greater factor for those in the “compromised
consumer” group. Education and transportation barriers were evident for all food insecure groups. Therefore, when analyzing food insecurity trends and tailoring policies and interventions, it is important to take into account patterns within population subgroups.

Weiler and colleagues identified crosscutting themes relating health equity and food security through a meta-analysis. Social themes include gender, racialization, indigeneity, poverty, citizenship, institutional barriers, and HIV status. Short-term processes to address food insecurity through improved health equity included addressing gender equality and structural racism and promoting soil fertility and healthy school food systems. Weiler and colleagues generated a conceptual framework linking food system processes to differential health impacts through sociological factors. The study focused mostly on local-level actions and interventions, compared with the previously discussed population-level studies. Weiler and colleagues identified a lack of research focused on intercultural food systems. In addition, this study did not include grey literature, which could have yielded a broader perspective of sociological factors than peer literature alone.

Societal factors increase or decrease vulnerability of populations to food insecurity. In particular, societal inequity increases the chance of food insecurity in populations and communities. In addition, sociological factors influence population responses to interventions and food environments. Studies analyzed local and population level data, yet often do not consider heterogeneity within communities. Research suggests that addressing sociological inequities could decrease food insecurity in the US.

**Economic Drivers**

One of the most apparent causes of food insecurity is the lack of financial resources to purchase food, nutritious or otherwise. Accordingly, economic conditions play an important part
of food insecurity in the US. Low-income households, communities, and populations are more likely to experience food insecurity and the resulting health and sociological disparities. With an increasing global population over the past few decades, food supply must increase to meet demand. While international food trade has increased globally during this time, food supply is not being met in many areas for several reasons. This recent research on the relationship between food insecurity and economic conditions yields insight into future trends.

Zhang and colleagues investigated how food prices and food security related among low-income American households with children. The authors conducted a secondary data analysis of longitudinal observations that defined food security by USDA guidelines and US cost of living data. This study found that higher food prices were significantly associated with increased risk of food insecurity within the study population (containing almost 28,000 participants). Notably, increased beverage prices had the opposite effect upon the risk of food insecurity. This suggests that effects of food prices on food security are not homogenous. Further research should be conducted to see why an increase in beverage prices was protective compared to prices of vegetables, fruit, and fast foods. This study was conducted in a metropolitan area on limited food items using prior data. Like Weiler and colleagues suggested, this study does not take into account the cultural differences in food intake and food type. In addition, housing and other prices likely complicate the relationship between food prices and food security. Despite these limitations, Zhang and colleagues concluded that variable food supply (estimated by food prices), increased food insecurity, particularly in low-income areas.

Brown and colleagues expanded on Zhang and colleague’s perspective by exploring global trade possibilities. The authors used modeling techniques to simulate how the globalization of agricultural markets influences food security via land use patterns. Maximized
global food production (or the balance of food supply with demand) relies upon efficient use of land in fertile areas. This concept\textsuperscript{39} discounts potential small gains from use of marginal land, in contrast to recommendations by West and colleagues\textsuperscript{32}. Brown and colleagues suggested how to balance maximized global food production with global food security and other ecosystem services.\textsuperscript{39} The study concluded that globalized food production systems yield more food from less land than regionally based systems. The globalized system yielded more homogenous, stable production levels.\textsuperscript{39} Negative effects on globalized trade of food included abandoned productive land, and inefficient land uses. The study suggested that while complete globalization is impossible, regional land use systems present more significant risks than a partially globalized system. Regional production was more sensitive to internal and external factors. In an effort to meet global food demand and improve ecosystem services and efficiencies, Brown and colleagues\textsuperscript{39}, like West and colleagues\textsuperscript{32}, suggested that land use intensity and function should be matched to local conditions, internal and external factors.

Suweis and colleagues\textsuperscript{40} explored how the globalization of food production effects food prices. The authors employed a modeling approach\textsuperscript{40} on secondary data from the past 25 years to evaluate global food security vulnerabilities considering changes in food supply and trade in a process similar to Nelson and colleagues.\textsuperscript{31} The study developed a theoretical framework to assess how population growth influences the availability of food calories to meet country-specific demand.\textsuperscript{40} The US was categorized as a food exporter; other categories included net importer, no effect of trade, and food scarce. Results indicated that most vulnerable countries to food trade changes were most often considered “food scarce”.\textsuperscript{40} Therefore, in the past 25 years, food security was most impacted by trade dependency in importing countries. Overall, the study suggested that the resilience of the global food security is declining under increasing population
size and becoming particularly vulnerable to food supply instability. Study findings aligned with Brown and colleagues, in that more globalized areas are more stable than those focused on regional trade, such as the “food scarce” countries.

Brown and colleagues, Suweis and colleagues and Zhang and colleagues approached the economics of food security in separate ways. Yet, these studies have come to similar conclusions. While many factors can be considered to indicate how economics affect food security, demand is increasing globally. Increased globalization of food production increases food availability. Areas with low food security are particularly vulnerable to changes in food prices, supply, and trade. Efforts should be taken to increase trade options for regionally focused food production markets. These models did not attempt to forecast potential changes in economic status in relation to food security. Future studies should address this gap in research.

Public Policy Drivers

Countries around the world have attempted to address issues with food insecurity through public policies and initiatives. Many such policies depend upon the interaction between environmental, sociological, and economic factors like those previously discussed to be successful. Current attempts at influencing the incidence of food insecurity are examined to reveal insights about the relationships between these factors.

Kaiser analyzed how Title IV of the Food, Conservation, and Energy Act of 2008 approaches food insecurity through produce availability in low-income houses. Title IV provides provisions for Supplemental Nutrition Assistance Program (SNAP), and other food grants and programs. Kaiser suggested that while subsidies offered through this law increase food supply and accessibility, they increase production of already overproduced crops (i.e., corn, wheat, grain) used in highly processed foods. Instead, subsidies should be focused on diverse
crop types most often used in nutrient-rich foods to better address access to nutritionally
healthful foods. In addition, Kaiser (2013) suggested investment in training and incentives
courage a wide-spread transition to production of fruits and vegetables (although this may
translate to improved diet quality rather than increased food security). Brown and colleagues
and West and colleagues suggested a food supply most focused on national needs and local
conditions to meet food demand. Kaiser proposed SNAP restructuring to include more farmer’s
markets, which could address nutritional quality and accessibility of food. Low-income
communities may be most impacted through local efforts such as community supported
agriculture projects. While Title VI provides funds, it does not support infrastructure or training
necessary to start and continue projects. These projects, while directly focused at the
community level, could impact food supply and demand on a large scale, and limit vulnerability
to global trade crises.

Aliaga and Chaves-Dos-Santos investigated how the Rome Declaration within the 1996
World Summit affected food and nutrition insecurity in several countries. In particular, the
authors analyzed the impact of public initiatives stemming from this declaration on
socioeconomic indicators of food insecurity. Notably, least developed countries were more likely
to have food security policies, although the US and Canada have specific policies, such as the
previously discussed Title IV of the Food, Conservation, and Energy Act of 2008. Only 66% of
countries involved in the 1996 World Summit possessed any type of food security policy at the
time of analysis. This suggests that public initiatives must be supported by stakeholders to
continue after institution. Aliaga and Chaves-Dos-Santos considered studies written in several
languages, considering different approaches to meet food demand. International cooperation can
aid in assumption of new public initiatives, as well.
Fox and colleagues examined the sociological drivers of stakeholder commitment in successful food security policy. The authors piloted an assessment tool to the United Nations to see how nutrition policy agendas can be balanced with priorities and motivations of stakeholders. Political leaders generally support food security programs; yet designated funds are often not sufficient. Factors used to evaluate stakeholder commitment included focusing events, competing priorities, policy community cohesion, political transitions, external/global influences, and viable policy alternatives. These factors were organized by problem, policy and politics streams. Fox and colleagues found that, generally, political stakeholders are not directly opposed to reform of food security policy. The study suggested that instead, supporting current programs, capitalizing on focusing events, strengthening stakeholder cohesions, working with mass and social media, and building a consensus among stakeholders would help further food security policies overall. Like Aliaga and Chaves-Dos-Santos, Fox and colleagues found that the largest potential and desire for programs was associated with developing countries.

Successful food security policies depend upon cooperation between several stakeholders and an ideal set of conditions. Countries are more likely to introduce policies to improve food security when they are experiencing widespread food insecurity, yet the US has introduced policies including the Food, Conservation, and Energy Act of 2008. Title IV of the Food, Conservation, and Energy Act of 2008 supports several programs that can help low-income households meet their food nutrition needs, yet many improvements can be made to better address national food security issues.

**Conclusions and Future Study**

Food insecurity is a significant issue for millions of households in the US. Low-income households are at higher risk for food insecurity. Health issues related to food insecurity make it
even more important to understand how it fits into the societal picture. As explored in this review, food insecurity is linked to environmental, economic, sociological, and public policy issues. Analysis revealed the complex atmosphere surrounding the phenomenon of food insecurity. Many issues are highly interconnected and interdependent. Despite this, several themes and evaluation methods are discussed below.\textsuperscript{7-20}

**Limitations, Gaps, and Opportunities**

Studies used a variety of methods to delve into the problem of food insecurity. Only one study collected primary data.\textsuperscript{35} The remaining studies gathered and analyzed data using modeling or other notable methods (Table 2-1).\textsuperscript{a} Because of these methods, studies were limited to available data at the time of analysis. As discussed previously, secondary data analyses are limited by the quantity and quality of information available.\textsuperscript{31,40} In addition, models are limited by the data the authors use to pilot, parameterize, and ability to control for uncertainty.\textsuperscript{30} Moreover, assumptions must be included to convert complex real-life situations into mathematically driven scenarios. Despite these limitations, numerous data sources exist that yielded scientifically sound results in the reviewed studies, including the Food and Agriculture Organization of the United States.\textsuperscript{32,40} Model-based studies yielded predictions of past and current food insecurity variables based upon secondary data and constructed frameworks. Other analyses provided associations between food insecurity and a variety of variables.\textsuperscript{30,31,39,40} Both types of analyses helped clarify the etiology of food insecurity in different, valuable ways, but all studies supported the indicators the authors presented.

While most studies evaluated food security via food supply, prices or accessibility, several\textsuperscript{30,32,34,40} approached food security by analyzing nutritional content per capita. Out of 41

\textsuperscript{a} All tables and figures are located in the appendices at the end of each chapter.
indicators, there were 14 and 12 environmental and sociological indicators respectively (Figure 2-1). There were eight economic and seven public policy related indicators. Higher indicators could suggest a larger amount of research done in those areas. In fact, this could represent more heterogeneous effects on food insecurity. Notably, many indicators incorporate similar data sources so the abundance of indicators in a particular category does not necessarily represent heterogeneity. Perhaps a lower number of indicators could indicate either established indicators (i.e., economic driver) or little research in a food insecurity context (i.e., public policy driver). In addition, some factors were especially similar (e.g., food availability and food supply); their evaluation methods were different, so they were categorized as separate indicators (community cohesion versus policy community cohesion). 

The socioecological model, which proposes that a lack of food, shelter, safety, and security directly impact an individual’s well-being, supports the prevalence of sociological indicators. In other words, as the number of “risk factors” increase proportionately, the more a person, household, or population lacks in life. The indicators identified in this review span several levels of the socioecological model (Figure 1-2). The model emphasizes that while food insecurity can be viewed as an individual problem, it is very much interconnected with interpersonal, community, and policy conditions.

No studies suggested future trends in food security based upon current data. In addition, only 42% addressed climate change, none factored it into their analysis. Food production contributes almost 30% of global anthropogenic greenhouse gases per year. Indeed, meeting food demand could magnify the effects of climate change. Reduction in biodiversity and biome health, an increase in pathogens and altered use of fertilizers via climate change could decrease food supply under increasing food demand. In addition, climate change could decrease crop
yield through temperature and precipitation variability.\textsuperscript{31} This issue cannot be ignored in future research, as it could dramatically increase food insecurity around the world.

**Future Perspectives**

Food insecurity is born from the complex relationships between many factors at many levels. Despite numerous studies, these relationships are still not well-understood. Models seek to understand food security in the context of a changing world at different resolutions. Yet, the author could not locate any that attempt to understand the future of food security in the shadow of climate change. Nonetheless, this review suggests several critical areas under environmental, economic, sociological, and public policy drivers including: ecosystem degradation, climate variability, global trade, supply reliability, and infrastructure stability. A concept map was constructed to highlight several main themes that were evident in the literature (Figure 2-3). This map could help guide future investigation of inter- and intra-relationships between indicators (including climate change) and food security.

Future studies must take into account the heterogeneity intrinsic to environmental, economic, political, and sociological drivers.\textsuperscript{15,35} Current studies suggest that reliable data resolution at both fine and coarse spatial and temporal resolutions could help inform food security models.\textsuperscript{50} Consistent with this, transparent data collection methodology with awareness of cultural, and regional intricacies can be particularly useful for small-scale models.\textsuperscript{34} Large scale models predicting future trends can benefit from data with high credibility and reliability.

Despite the limitations and gaps in current research, the studies examined have provided a solid framework for future research in food insecurity. This literature review consolidated information on methodologies, indicators, and relationships between and among indicators of food insecurity in the US. This work could support future research to conceptualize and model
how the environment, economics, sociology, and public policy interplay within the phenomenon of food insecurity. More research is needed to fully grasp these intricate relationships and more accurately forecast future trends considering the effects of climate change.
Appendix

Table 2-1: Food security indicators. Main indicators and associated drivers of the analyzed studies. FAO: Food and Agriculture Organization of the United States. N2O: nitrous oxide.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Driver</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand sensitivity</td>
<td>Economics</td>
<td>39</td>
</tr>
<tr>
<td>Food overabundance</td>
<td>Economics</td>
<td>40</td>
</tr>
<tr>
<td>Food prices</td>
<td>Economics</td>
<td>40</td>
</tr>
<tr>
<td>Food prices</td>
<td>Economics</td>
<td>35</td>
</tr>
<tr>
<td>Global trade</td>
<td>Economics</td>
<td>30</td>
</tr>
<tr>
<td>Productive ability</td>
<td>Economics</td>
<td>39</td>
</tr>
<tr>
<td>Trade reactivity</td>
<td>Economics</td>
<td>40</td>
</tr>
<tr>
<td>Variation in competition</td>
<td>Economics</td>
<td>39</td>
</tr>
<tr>
<td>Climate challenges</td>
<td>Environment</td>
<td>31</td>
</tr>
<tr>
<td>Crop allocation</td>
<td>Environment</td>
<td>32</td>
</tr>
<tr>
<td>Dietary energy supply</td>
<td>Environment</td>
<td>30</td>
</tr>
<tr>
<td>Ecosystem health</td>
<td>Environment</td>
<td>31</td>
</tr>
<tr>
<td>Excess fertilization</td>
<td>Environment</td>
<td>32</td>
</tr>
<tr>
<td>Food availability</td>
<td>Environment</td>
<td>31</td>
</tr>
<tr>
<td>Food availability</td>
<td>Environment</td>
<td>41</td>
</tr>
<tr>
<td>Food diversity</td>
<td>Environment</td>
<td>31</td>
</tr>
<tr>
<td>Land use change</td>
<td>Environment</td>
<td>30</td>
</tr>
<tr>
<td>N2O release</td>
<td>Environment</td>
<td>32</td>
</tr>
<tr>
<td>Resource availability</td>
<td>Environment</td>
<td>30</td>
</tr>
<tr>
<td>Indicator</td>
<td>Driver</td>
<td>Reference</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>--------------</td>
<td>-----------</td>
</tr>
<tr>
<td>Water availability</td>
<td>Environment</td>
<td>30</td>
</tr>
<tr>
<td>Community advocacy</td>
<td>Public policy</td>
<td>41</td>
</tr>
<tr>
<td>Policy community cohesion</td>
<td>Public policy</td>
<td>44</td>
</tr>
<tr>
<td>Political climate</td>
<td>Public policy</td>
<td>43</td>
</tr>
<tr>
<td>Political commitment</td>
<td>Public policy</td>
<td>44</td>
</tr>
<tr>
<td>Program sustainability</td>
<td>Public policy</td>
<td>41</td>
</tr>
<tr>
<td>Public initiatives</td>
<td>Public policy</td>
<td>43</td>
</tr>
<tr>
<td>Public initiatives</td>
<td>Public policy</td>
<td>41</td>
</tr>
<tr>
<td>Asset ownership</td>
<td>Sociological</td>
<td>34</td>
</tr>
<tr>
<td>Climate change</td>
<td>Sociological</td>
<td>15</td>
</tr>
<tr>
<td>Community cohesion</td>
<td>Sociological</td>
<td>30</td>
</tr>
<tr>
<td>Education</td>
<td>Sociological</td>
<td>34</td>
</tr>
<tr>
<td>Equal access</td>
<td>Sociological</td>
<td>31</td>
</tr>
<tr>
<td>Fertility rates</td>
<td>Sociological</td>
<td>34</td>
</tr>
<tr>
<td>Food accessibility</td>
<td>Sociological</td>
<td>35</td>
</tr>
<tr>
<td>Food storage</td>
<td>Sociological</td>
<td>31</td>
</tr>
<tr>
<td>Health equality</td>
<td>Sociological</td>
<td>15</td>
</tr>
<tr>
<td>Health services</td>
<td>Sociological</td>
<td>34</td>
</tr>
<tr>
<td>Institutional barriers</td>
<td>Sociological</td>
<td>15</td>
</tr>
<tr>
<td>Occupation</td>
<td>Sociological</td>
<td>15</td>
</tr>
</tbody>
</table>
Table 2-1. Continued.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Driver</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social connections</td>
<td>Sociological</td>
<td>31</td>
</tr>
<tr>
<td>Transportation</td>
<td>Sociological</td>
<td>31</td>
</tr>
</tbody>
</table>
Figure 2-1: Abundance of food security indicators by driver. This chart displays the total number of food security indicators organized by their respective drivers. Some indicators overlap within drivers but are evaluated differently. Refer to Table 2-1 for more information.
Figure 2-2: Socioecological model. The socioecological model addresses the dynamic relationship between people and their environment on many levels. At the individual level, factors include sex, age, health, and genetic predispositions. The microsystem level includes relationships with other people, such as family and peers. Mass media, local politics, neighbors, work environments are in the ecosystem level. The mesosystem is the interface between ecosystem and microsystem levels. The macrosystem includes general policies, cultural attitudes, history, economic conditions, and practices. This review illustrated that food insecurity issues span the entire socioecological model. Adapted from data in Bronfenbrenner, U. (1979). The ecology of human development: Experiments by nature and design. Cambridge, Mass.: Harvard University Press.
Figure 2-3: Food insecurity concept map. Critical issues within environmental, economic, public policy, and social drivers identified through the literature review.
CHAPTER 3

FOOD SECURITY IN THE UNITED STATES: A FUTURES ANALYSIS VIA SYSTEMS MODELING
A version of this chapter is under review for publication in Public Health Nutrition.

Abstract

Contemporary modeling techniques are uniquely capable (yet underutilized) tools to synthesize currently available data on both food security and climate change. Therefore, the objective of this study was twofold: to create a novel systems model of food security and quantify and project future trends in the US considering the potentially devastating effects of climate change. The research team employed environmental scanning to assess data quantitatively. Relationships were visualized by a novel systems model. The research team used the Tonn methodology to aggregate results through this systems model. Sensitivity analyses were conducted to reveal any unexpected impacts of components upon one another and the systems model in its entirety. This systems model defined and organized relationships between key indicators identified via literature review, focusing on trends in the US. Data were collected, scored, and analyzed from over 100 peer-reviewed, grey literature, and industry resources. Results suggested that food security, climate change, food production infrastructure, and ecosystem health could exhibit negative trends over time. In contrast, political climate and social inequity conditions could exhibit positive trends. Sensitivity analyses revealed no unexpected impacts of climate change and political climate components, suggesting that these components were primary, although not exclusive, drivers of model outcomes. Resources should focus on areas with the most negative trends (e.g., ecosystem health and food production infrastructure), and with broad model impacts. Intervention could limit the risk of negative health outcomes associated with food insecurity in the next 20 years.
Introduction

Very low to low food security (also known as “food insecurity”) is observed in societies around the world, including the US.¹ In fact, at least 15.6 million households across the US face food insecurity, or the lack of consistent, healthy, sufficient, available, and culturally suitable food.² In recent years, scientists have more accurately monitored food security across temporal and geographical scales. The most recent analysis, per Coleman-Jensen and colleagues², found that in 2016, 12.3% of American households were food insecure. Notably, the prevalence of food security varied across the US by region, state, and even county. US food insecurity rates per household ranged from 5.6% to above 38% based upon income in 2016.² More specifically, the United States Department of Agriculture (USDA) divides food insecurity into two main categories: “low food security” and “very low food security”.⁶ Very low food-secure individuals face a significant decrease in the amount and quality of food they consume.⁶ In 2016, around 5%, or 6.1 million households, were identified within the “very low food security” category.

Food Security and Health

The social determinants of health theory proposes that social factors are the foundation of health inequalities.¹⁸ Research suggests clear associations between the prevalence of food insecurity and health disparities.¹⁴-¹⁷ Weiler and colleagues¹⁵ identified the following factors linking health equity and food security: gender, HIV status, indigeneity, citizenship, institutional barriers, and poverty. Additionally, food insecurity has been associated with disease, race/ethnicity, number and age of household members, geographic location, and income level in the US, as reported by the recent USDA Economic Research Service household survey.² Cross-sectional studies have observed these findings in elderly populations, racial and ethnic minority groups, and among households with children.⁴,²⁰
Paradoxically, food insecurity has also been linked with obesity risk.\textsuperscript{21-23} For example, Pan and colleagues\textsuperscript{22} identified a positive association between obesity and food insecurity in American adults across 12 states. Several theories have been proposed to explain how individuals experiencing food insecurity could also be consuming enough excess calories to become obese.\textsuperscript{21,23} One theory is that food insecurity may limit the ability to access or consume a high quality diet, i.e., foods that contain fewer calories and are more nutrient-dense than processed foods.\textsuperscript{23} Food insecurity may also precipitate cycles of food deprivation, overeating, and high stress.\textsuperscript{21} Finally, food insecurity has been associated with limited healthcare access. These associations suggest an increased likelihood of obesity in studied populations.\textsuperscript{21}

**Food Security under a Systems Perspective**

Researchers recognize that factors like the environment, economics, politics, and societal conditions contribute to the food insecurity phenomenon.\textsuperscript{15,22,47} Yet, the scientific community struggles to describe, quantify, and depict present and future food security trends. Contemporary modeling techniques could synthesize the mass of currently available data on both food security and climate change. In particular, systems modeling seeks to define how different concepts and functions connect across disciplines.\textsuperscript{48} According to Homer and Hirsch\textsuperscript{49}, this approach has been applied successfully in disease and substance abuse epidemiology, and healthcare. In particular, one application explored the interplay of diseased populations with health resource utilization to yield insight into the dynamics of the system, and shape future public health goals.\textsuperscript{49}

Considering past work, the landscape of food security in the US is an appropriate, yet unexplored scene for which systems modeling could provide unique insights. Metrics and indicators of food security can help scientists quantify the interdependencies of food security nationally using systems modeling and futures analysis.\textsuperscript{28} Previous model-based studies yielded
predictions or associations between food security and various indicators.\textsuperscript{30,31,39,40} Yet, no studies have suggested future trends in food security based upon current data to the authors’ knowledge. Additionally, while current modeling studies have discussed climate change in relation to food security\textsuperscript{15,30,31,39}, none have factored it into their analysis to date.

\textbf{Climate Change and Food Security}

Climate change (i.e., the change in average trends and variability of climate properties like precipitation and temperature\textsuperscript{50}) and food security are interdependent. For example, food production contributes almost 30\% of global anthropogenic greenhouse gases per year.\textsuperscript{39} Greenhouse gases cause increases in the global average temperatures, rising sea levels, and changes in precipitation intensity and timing.\textsuperscript{50} The United Nations Department of Economic and Social Affairs\textsuperscript{51} predicts that the world population will increase by around 500 million people by 2030. The Food and Agriculture Organization of the United Nations\textsuperscript{52} projects that the world’s average per capital food consumption will increase from 2,772 to 3,070 kcal/person/day by 2050, equating to a nearly 75\% increase in world meat consumption. Agriculture has been associated with up to 24\% of anthropogenic greenhouse gas emissions.\textsuperscript{53} Therefore, by meeting future food demands, society could exacerbate the effects of climate change.

Chiefly, the reduction in biodiversity and biome health, increased pathogens, and altered use of fertilizers via climate change could decrease food supply, particularly considering increased food demand under a growing global population.\textsuperscript{46} In addition, climate change could decrease crop yield through temperature and precipitation variability and intensity.\textsuperscript{31} Therefore, the objective of this study was to examine future trends of food security in the US in light of climate change’s potentially devastating effects. Specifically, it considered the effects of driving
factors like climate change and politics in the trajectory of food security, borne out of food security indicators and a systems perspective.

The approach for this study was two-fold: (1) assemble and quantify current, pertinent data regarding economic, political, environmental, and societal factors influencing food security and (2) develop a novel food security systems model to illuminate the relationships between these factors over the next 20 years. To achieve this, authors employed environmental scanning techniques and rubrics to assess data quantitatively by projectability, impact, credibility, and probability (Table 3-1). Environmental scanning is a technique originally applied in strategic management to capture a wide range of information from peer-reviewed, grey literature, and industry resources to plan in situations of high uncertainty.\textsuperscript{54,55} Notably, this approach includes futures analysis elements that inherently consider data projectability. The environmental scanning technique intrinsically accounts for uncertainty through imprecise probabilities. Imprecise probabilities provide a measure of confidence to incorporate data reliability over time. This metric of uncertainty improves the applicability of research outcomes to real-world systems, like US food security.\textsuperscript{56}

Methods

Systems Modeling

A systems model was constructed through data from compilation of food security indicators and environmental scanning. The overarching economic, political, environmental, and societal drivers were selected through adaptation of the PEST (political, economic, socio-cultural and technological) environmental scanning analysis technique.\textsuperscript{57,58} During the study, model elements were mapped using diagramming software. The model contained components, aggregation points, leads, and lead impacts. Components are subsections of the broad drivers
which influence food security, such as economics and the environment. These components, or subsets of the driving factors, were generated considering common themes encompassing identified food security indicators, as compiled in Table 2-1. Relationships between components are illustrated via flow impacts. Aggregation points are model components into which many other components converge. Each data point collected through the environmental scanning process is called a “lead”, or a factor that impacts the component it connects to in the systems model. Leads can impact one or multiple model components. The relationships between leads and their respective components are depicted through lead impacts.

**Lead Quantification & Futures Analysis**

The research team used the Tonn methodology to quantify how much a lead impacted its component(s) over time with an impact score. In concordance with this approach, the probability of a lead impacting its component ranged from $P(A)=0.0$ (representing an impact that will not happen) and $P(A)=1.0$ (representing an impact that will happen). Incorporating this into the methodology yielded flexibility to the model and functionality considering uncertainty. Authors used the exponential function established in the Tonn Methodology to aggregate the impacts of leads collected through environmental scanning, and of components in the systems model. The scores produced, while not inherently valuable, were compared over time or between components using the Tonn methodology to determine relative impacts and trends.

**Model Interpretation**

Interpretation is a key part of environmental scanning. Model accuracy is based upon the availability of information and the viability of scoring methods. In this study, the authors used a rubric to direct data collection and adjust lead impact scores based upon their credibility. Criteria for credibility included source type, reference quality, and publication type (Table 3-1).
Source type reflects the amount of distillation information has endured before analysis. Taking this into account, tertiary sources are less credible than primary sources in the model. Information type reflects the location where the information was located. Reference quality reflects the degree of peer-review or expert feedback processes. Publication date reflects how much time has passed since the information was made available. Finally, projectability addresses the nature of information, whether it be a prediction of future trends or an observation of past events. Because the study objective was to predict future trends, past observations were adjusted to hold less impact on the model, in concert with the considerations described above.

Authors employed the Tonn methodology\textsuperscript{59} mentioned previously to relate quantitative changes with qualitative interpretations. Table 4-1 describes how positive component scores were interpreted in the context of the systems model. These interpretations were based upon the association between the component and food security in the context of the US. A positive score indicated a beneficial trend relative to food security. Therefore, a positive score in a component suggested positive impacts on food security. A negative component score indicated negative impacts on food security.

As an illustration, as food production infrastructure improves, so also does food security; society is better able to produce, store, and transport foods. This situation would be represented by a positive score in the food production infrastructure component. In addition, ecosystem health, food supply, political climate, global trade, rural development, social equity, economic policy, public policy, and human health are directly associated to food security. In contrast, climate change is inversely related with food security. A positive score for the climate change component suggests that collected leads support the decreased influence of climate change on food security. A negative score for climate change indicates increased general climate effects,
hence decreased food security. Population growth, food demand, and food prices are inversely related to food security as well. Additional examples of leads and their respective interpretations are located in Table 3-2.

**Results**

The first author (JT) created a systems model through review of current food security indicators (Figure 3-1) to display and quantify the impact of data on model components. The model represented four fundamental areas (i.e., environmental, political, economic, and sociological) which drive food security (i.e., drivers) and ultimately health in the US. These drivers function through 15 dynamic components (Figure 3-1). Model components include climate change, economic policy, ecosystem health, food demand, food price, food production infrastructure, food security, food supply, global trade, human health, political climate, population growth, public policy, rural development, and social equity. It is important to note that technological developments could impact any of these components. Therefore, these leads were included within their respective components rather than a separate “technological change” component.

**Structure and Relationships**

The primary component of interest is food security, although secondary aggregation points in which all previous components combine include food price and social equity. In other words, all remaining environmental, economic, political, and sociological components in the systems model converge upon food security directly and indirectly. Environmental components include climate change, ecosystem health, and food production infrastructure. The climate change component directly impacts ecosystem health and food production infrastructure. Population growth also impacts ecosystem health, in addition to food demand. Ecosystem health
impacts food production infrastructure. Food production infrastructure impacts food supply. Economic drivers include food demand, food supply, global trade, food price, and rural development. Food demand directly impacts food security, food price, and food supply. Food supply impacts food price. Food price impacts food security. Global trade impacts food supply and rural development. Rural development impacts social equity.

Political components include political climate, economic policy, and public policy. The impacts of political climate are myriad: ecosystem health, global trade, economic policy, and public policy. Economic policy impacts global trade and rural development. Public policy, like rural development, impacts social equity. Sociological components include social equity and human health. Social equity impacts food security and human health. Human health does not impact other components in this model, as it can be considered a measure of national wellbeing. Notably, food security impacts human health. These relationships are depicted in Figure 2-3. Although additional relationships could be added to this model, only major relationships were included to maintain visual and conceptual clarity. Indeed, the Tonn methodology for organizing and quantifying environmental scanning data is focused on capturing the essence of the issue of interest (i.e., driving factors of food security in the US), not replication. This is a strength of the approach because data collection, quantification, and analysis can occur quickly to identify trends over time.

**Environmental Scanning**

Data were collected from over 100 peer-reviewed, industry, and government sources. Identification of leads took place using web queries of identified systems model components in addition to the following databases: Google Scholar, EBSCO, PubMed, Web of Science, ScienceDirect, Academic Search Complete, and the
University of Tennessee tool “OneSearch”. Queries included component titles, such as “food security”, or “ecosystem health”. Over 172 leads were collected by the research team in 2017. Twenty-eight percent of the leads collected were within economic components. Twenty-three percent were environmental, while 22% were sociological. Nineteen percent of leads were political, while 8% applied to the food security component directly. The climate change component held 13% of these leads. Additional information regarding the proportion of leads in model components can be found in Figure 3-2. Component changes produced by the systems model and environmental scanning are depicted in Table 3-2. In general, many component changes are closer to zero during the five-year period, indicating less impact. Values then trend away from zero, as underscored via increased cell color intensity from left to right in Table 3-3. Component change values range from -0.0151 (climate change, year 20, upper expected change) to 0.0068 (food production infrastructure, year 5, upper expected change). As mentioned previously, these numbers do not have inherent value, therefore they reveal the positive or negative trends between components and over time. In general, values decrease over time.

Figure 3-3 tracks the trends between component expected changes from year 5 to year 20, organized by component type. Indeed, 77% of component change values in the systems model decrease from 5 to 20 years. Global trade, food production infrastructure, ecosystem health, and climate change values decrease over time. Notably, component change values for global trade and food production infrastructure are among the highest in year 5. Conversely, social equity and political climate component changes increase over time, although social equity values remain negative at year 20. Interestingly, public policy component change values remain steady, while the economic policy values decrease over time. Among others, food price, food production infrastructure, food security, and global trade expected changes are less negative at year 10 than
year 5 but decrease at year 20. Ranges between lower and upper expected component change values are widest in climate change and global trade components, at 0.0045 and 0.0036 respectively. This could indicate varied lead source quality with corresponding higher uncertainty levels.

**Sensitivity Analyses**

To verify the effects of the model were not driven by a single component, the authors conducted a sensitivity analysis (results not shown due to limited changes in model results). This exercise determined how the uncertainty in the systems model was related to certain components. The climate change component (and all associated impacts to neighboring components) was removed as it was the most negative driving force in the model (Table 3-4). Despite this, the negative trends in global trade, food production infrastructure, and ecosystem health persisted. Additionally, positive trends continued in the political climate and social equity components. Components like rural development displayed no substantial component score change in this sensitivity analysis. Yet, expected ecosystem health and human health component changes were more positive than the original analysis. Overall, the highest magnitude changes were identified in the ecosystem health and food production infrastructure components, whose score changes became less negative.

A second sensitivity analysis was performed to verify these findings. The political climate component was removed, along with its associated systems model impacts. While this exercise marginally altered expected economic policy, ecosystem health, global trade, and public policy component changes, total changes from year 5 to year 20 did not differ (Table 3-5). Among the sensitivity analyses, removal of the political climate produced the broadest variation
in expected component changes, yet removal of the climate change component produced the only variation in total component changes from year 5 to year 20.

**Discussion**

Futures analysis of food security using environmental scanning and systems modeling via the Tonn methodology yielded trends that could inform future decision-making efforts. Indeed, this exercise suggests how policies and interventions should be prioritized. The climate change component displayed the strongest negative trend from year 5 to year 20. Negative trends in climate change directly influenced ecosystem health and food production infrastructure, but indirectly influenced numerous components in the systems model. The negative trends in climate change, ecosystem health, and human health components suggests that major efforts need to be taken to plan and address future impacts considering current knowledge. Moreover, the largely negative trend over time in most components suggests that the United States’ economic, environmental, social, and political drivers are not supporting increased food security over time.

Public policy component changes remained steady, although slightly negative, throughout the study period. Yet, economic policy declined, particularly from year 10 to year 20. This provides insight as to when and how policy measures should be applied to most heavily impact components like social equity and rural development. The political climate has a noticeably positive trend from year 5 to year 20, perhaps reflecting the growing awareness and acceptance of social responsibility and food availability programs. Yet, the state of the political climate does not necessarily translate to improved food security or policy changes, as is reflected by negative changes in these components. Indeed, political climate cannot be the only factor that drives effective economic and public policies, and interventions to increase food security, social equity, or human health.
This study is the first application of environmental scanning and futures analysis in food security, to the author’s knowledge. Yet, studies have connected climate change with food security. Suweis and colleagues found that the resilience of global food systems is decreasing. The broadly negative trend of component changes in the systems model supports this conclusion. Nelson and colleagues found that the long-term North American climate history has been linked to food shortages and ecosystem health, as illustrated by the most negative components in the systems model, including climate change and ecosystem health. Furthermore, Dawson and colleagues predicted that over one-third of people worldwide could face food insecurity without significant agricultural improvements or interventions by 2050.

Brown and colleagues suggested that political climate and food production infrastructure could drive food security, as demonstrated by this study. McDonald and colleagues and Thebo and colleagues found that food production infrastructure could dramatically determine the future of food security through global assessment. In this study, food production infrastructure was also a key component. Kristkova and colleagues predicted a decrease in food prices via doubled food production infrastructure research and development. This finding supports the conclusion that food production infrastructure can impact food security via food prices. While researchers have yet to explore the full potential of modeling as a tool to explore future trends in food security, the results of this analysis support and expand upon the conclusions of other scientific literature.

**Future Roles of Policymakers and Public Health Professionals**

Scientific, political, and economic communities have yet to offer a comprehensive, effective solution to the near universal phenomenon of food insecurity. Considering results of the previous analysis, the author will propose actions that could support, fund, or supply
practical, efficient, synergistic interventions to increase food security in the US in this section. As mentioned previously, the connection between social conditions and food security has sparked nutrition interventions to attempt to limit negative health outcomes in vulnerable populations at national, state, and local levels. Headey found the most notable increases in food security related to both favorable health, education, fertility trends, and well-documented nutrition programs.

The United Nations and other organizations set goals for increasing food security during events like the World Food Summit and UN Millennium Project. Margulis identified intergovernmental forums like the now reformatted G8, World Bank, and World Trade Organization in combination with the United Nations as key actors in the multilateral response to food insecurity around the world. Tadesse, Algieri, Kalkuhl, and von Braun suggested that these organizations can stabilize food security most effectively via policies that increase producer and consumer resilience, and reduce volatility and price strikes. Specifically, Grote recommended that agriculture productivity, consumer awareness of food waste and resource use inefficiencies, and rural development aid in in this process.

Governmental, non-profit, and national organizations can address food security via state-level intervention. For example, the Tennessee Department of Human Services has partnered with the USDA Food and Nutrition Service to decrease food insecurity rates in Tennessee, particularly in children. Attempts to manage food security at international, national, and regional levels are interconnected to meet the complex, persistent nature of the problem. Indeed, the political climate, policy, and infrastructure should be considered in light of climate change to react to the negative trends in the food security landscape across the US over the next 20 years, as identified within this study. Study outcomes were twofold: (1) spur the development of novel
models and approaches to project global food security trends across the next century and (2) inform interventions to address socioecological disparities that drive negative health outcomes related to food security status.

**Conclusions and Research Opportunities**

Food security is a difficult and complex phenomenon to study. One cannot assign the condition of food insecurity to study subjects for ethical concerns. Therefore, random assignment of treatments in a clinical trial is not possible. Yet, a greater scientific understanding will help build evidence-based interventions and policies. Prospective birth cohort studies have been conducted, such as Melchior and colleagues' investigation of the relationship between food insecurity and childhood mental health. Ultimately, like the studies summarized previously, cross-sectional surveys and prevalence-based analyses are invaluable to food security research. Further research can help identify what sections of the population face food insecurity and associated negative health outcomes. These populations would be excellent candidates for targeted clinical and public health interventions.

This methodology is limited primarily by the quality of data it collects and analyzes. The responsibility lies upon the research team to ensure comprehensive lead collection prior to analysis. The methodology accounts for new research developments and varying data quality via imprecise probabilities, but this cannot cover extreme variability. Therefore, the research team limited projected trends to a 20 year timeframe. This methodology also relies upon the accuracy of its systems model. Study authors and Dr. Tonn (of the Tonn methodology) reviewed the systems model prior to lead collection and analysis. This helped ensure that the model best represents the status of food security in the US and address potential issues with bias. The Tonn methodology relies upon a linear model. Impacts must be sequential; no impact recursion is
Therefore, the impact of each component upon others is assigned its own probability and impact score.

This study has several strengths in methodology and results. Indeed, it is the first to apply environmental scanning to food security issues, according to the authors’ knowledge. Additionally, because of resource and data availability, numerous studies do not integrate environmental, economic, political, and sociological information into one model. This study filled both gaps via this novel application, which could allow for a broader number of methodologies to be utilized within food security studies. In this context, environmental scanning provided the ability to assess the relationships between multiple forms of data. Impact scores on a numerical scale provide quantification of qualitative and quantitative data on a unified scale to address various research questions. Most importantly, imprecise probabilities quantified confidence in lead quality. This study has produced information which can help target interventions and policies to most efficiently address food security in US.

This model could be employed in comparable countries for a more complete perspective on global food security and of model generalizability. Using the same methodology, trends in systems model components could be compared with data collected in the future to observe similarities and differences. Additionally, collecting a larger number of leads would provide a more comprehensive perspective. As food security drivers develop over the next 20 years, the model could be modified to monitor changing trends with increased data availability.

The systems model created via this study offers a holistic, basic view of the food security landscape. This study has addressed key gaps surrounding the food insecurity phenomena across the US. Environmental scanning has been applied via a novel systems model to assess future trends in this landscape considering climate change, the political climate, and other factors.
Overall, the study yielded considerations for decision-makers as climate change intensifies and the political climate shifts. Economic and public policies will be crucial forces to improve the outlook of food security in the next 20 years. Public health and nutrition professionals can take part in targeted interventions and public programs increase food security in the most vulnerable populations.
Appendix

Table 3-1: Credibility rubric. The impact of credibility on model via impact and probability scores. In this context, credibility includes the source and information types, depth of peer-review, time since publication, and projectability. These factors effect lead impact and probability scores. Adapted from “Biofuels: A sustainable choice for the United States' energy future?” by J. Trumbo & B. Tonn\textsuperscript{133}, 2016, Technological Forecasting & Social Change, 104, p. 153. Copyright 2016 Elsevier Inc.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>High Credibility</th>
<th>Medium Credibility</th>
<th>Low Credibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source Type</td>
<td>Original sources</td>
<td>Secondary sources</td>
<td>Tertiary sources</td>
</tr>
<tr>
<td>Information Type</td>
<td>Journal leads</td>
<td>Gray literature</td>
<td>Website of technology funder, developer</td>
</tr>
<tr>
<td>Reference Quality</td>
<td>Peer reviewed</td>
<td>Some peer reviewed</td>
<td>Few/none peer reviewed</td>
</tr>
<tr>
<td>Sponsorship</td>
<td>Low</td>
<td>Mid</td>
<td>High</td>
</tr>
<tr>
<td>Publication Date</td>
<td>1-2 years</td>
<td>2-5 years</td>
<td>5 years or later</td>
</tr>
<tr>
<td>Projectability</td>
<td>Future-focused data</td>
<td>Present-focused data</td>
<td>Past-focused data</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model Effects</th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact Score</td>
<td>Score</td>
<td>Score – 5%</td>
<td>Score – 10%</td>
</tr>
<tr>
<td>Probability Score</td>
<td>High-Low ≥ 0.01</td>
<td>High-Low ≥ 0.02</td>
<td>High-Low ≥ 0.03</td>
</tr>
<tr>
<td>Range</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3-2: Component score interpretation. Brief positive score interpretations for each component in the model, including examples of positively scored leads from the environmental scanning process.

<table>
<thead>
<tr>
<th>Component</th>
<th>Driver</th>
<th>Positive score</th>
<th>Lead Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate</td>
<td>Environmental</td>
<td>Improved global climate characteristics</td>
<td>A warming climate could increase the length of growing season for agricultural crops, increase tourism, and decrease ice cover to free access to natural resources in the short-term in cold climates like Alaska.(^{77})</td>
</tr>
<tr>
<td>Population</td>
<td>Sociological</td>
<td>Low population growth</td>
<td>With an increasing global population over the past few decades, D'Odorico, P., et al.(^{37}) suggests that food supply will increase to meet demand through improved labor resources.</td>
</tr>
<tr>
<td>Food demand</td>
<td>Economic</td>
<td>Decreased food demand</td>
<td>Zumkehr and Campbell(^{126}) suggest that local cropland could meet up to 90% of national food demand, despite its overall decline over time.</td>
</tr>
<tr>
<td>Food security</td>
<td></td>
<td>Increased food security</td>
<td>Aerofarms(^{98}) is building farms on distribution routes and near population centers to enable local farming on a commercial scale with lower water use and 130 times yield compared to field farmed food each year.</td>
</tr>
</tbody>
</table>
Table 3-2. Continued.

<table>
<thead>
<tr>
<th>Component</th>
<th>Driver</th>
<th>Positive score</th>
<th>Lead Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ecosystem health</td>
<td>Environmental</td>
<td>Ecosystem protection</td>
<td>Increased average global temperatures will increase vegetation density in boreal regions, increasing the ability of vegetation to mitigate CO\textsubscript{3}.\textsuperscript{66}</td>
</tr>
<tr>
<td>Food production</td>
<td>Environmental</td>
<td>Improved food production</td>
<td>Agri-food system resilience is predicted to increase under climate change with ongoing land degradation.\textsuperscript{130}</td>
</tr>
<tr>
<td>Food supply</td>
<td>Economic</td>
<td>High food output that meets predicted demand</td>
<td>The United States (leading North America) is the only high-income region projected to expand agriculture significantly by 2021.\textsuperscript{53}</td>
</tr>
<tr>
<td>Food price</td>
<td>Economic</td>
<td>Decreased food prices compared to historical trends</td>
<td>Wheat, rice, protein meals, and sugar prices are projected to decrease until 2020.\textsuperscript{118}</td>
</tr>
<tr>
<td>Political climate</td>
<td>Political</td>
<td>Political climate</td>
<td>Ministries of Agriculture in BRICS (Brazil, Russia, India, China and South Africa) are leading in food production, export and global economic and political development against food insecurity. This trend is projected to increase by 2030.\textsuperscript{105}</td>
</tr>
<tr>
<td>Component</td>
<td>Driver</td>
<td>Positive score</td>
<td>Lead Example</td>
</tr>
<tr>
<td>-------------</td>
<td>--------------</td>
<td>----------------------------------------------------------</td>
<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Rural</td>
<td>Economic</td>
<td>Improved quality of life and economic well-being in rural areas</td>
<td>Goldstein and colleagues(^\text{80}) suggest that under optimal conditions, urban agriculture could direct the building of new communities through increased food availability.</td>
</tr>
<tr>
<td>Social equity</td>
<td>Sociological</td>
<td>Increased fair access to a livelihood, education, and resources</td>
<td>Social work researchers are now focusing on interventions for food insecurity for vulnerable groups, food access, food policy, and food systems in a more active role than previous decades.(^\text{14})</td>
</tr>
<tr>
<td>Economic</td>
<td>Political</td>
<td>Economic policies addressing resource availability</td>
<td>Incorporation of climate policy into economic policy will support future economic growth. Current projections suggest savings of $1.7 trillion annually and a nearly 5% increase in 2050 GDP (gross domestic product).(^\text{79})</td>
</tr>
<tr>
<td>Public policy</td>
<td>Political</td>
<td>Public policies addressing resource availability</td>
<td>The Special Supplemental Nutrition Program for Women, Infants, and Children continues to provide funding for education, food, and referrals.(^\text{119})</td>
</tr>
</tbody>
</table>
Table 3-2. Continued.

<table>
<thead>
<tr>
<th>Component</th>
<th>Driver</th>
<th>Positive score</th>
<th>Lead Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global trade</td>
<td>Economic</td>
<td>Increased global trade</td>
<td>According to Brown and colleagues(^{50}), current globalized food production systems yield more food from less land than regionally based systems.</td>
</tr>
<tr>
<td>Human health</td>
<td>Sociological</td>
<td>Increase in societal</td>
<td>Over one third of the US's projected job growth will be in the healthcare and social assistance sector until 2025.(^{81})</td>
</tr>
<tr>
<td></td>
<td></td>
<td>physical, mental, and/or psychological wellbeing</td>
<td></td>
</tr>
</tbody>
</table>
Table 3-3: Systems model score summary. Food security component scores and total change over 20 years produced through the systems model and environmental scanning techniques. The total change from year 5 to year 20 is also displayed. The cell color signifies the score’s distance from zero via color mapping. The light green shade indicates moderate score increase while the dark green shade indicates substantial score increase. The yellow shade indicates a slight score increase. The light orange shade indicates a slight score decrease or neutral score. The orange shade indicates a moderate score decrease. The red shade indicates a substantial score decrease.
L: lower expected change. U: upper expected change.

<table>
<thead>
<tr>
<th>Component</th>
<th>Year 5</th>
<th>Year 10</th>
<th>Year 20</th>
<th>Total ∆</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate change</td>
<td>L</td>
<td>-0.0036</td>
<td>-0.0042</td>
<td>-0.0096</td>
</tr>
<tr>
<td>Climate change</td>
<td>U</td>
<td>-0.0047</td>
<td>-0.0057</td>
<td>-0.0151</td>
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<tr>
<td>Economic policy</td>
<td>L</td>
<td>-0.0012</td>
<td>-0.0017</td>
<td>-0.0039</td>
</tr>
<tr>
<td>Economic policy</td>
<td>U</td>
<td>-0.0016</td>
<td>-0.0022</td>
<td>-0.0055</td>
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<tr>
<td>Ecosystem health</td>
<td>L</td>
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<td>-0.0022</td>
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</tr>
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<td>Ecosystem health</td>
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<td>-0.0014</td>
<td>-0.0029</td>
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<td>Food demand</td>
<td>L</td>
<td>0.0001</td>
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<td>Food demand</td>
<td>U</td>
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<td>0.0000</td>
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<td>Food price</td>
<td>L</td>
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<td>-0.0008</td>
<td>-0.0037</td>
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<td>Food price</td>
<td>U</td>
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<td>-0.0010</td>
<td>-0.0054</td>
</tr>
<tr>
<td>Food production infrastructure</td>
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<td>-0.0007</td>
<td>-0.0036</td>
</tr>
<tr>
<td>Food production infrastructure</td>
<td>U</td>
<td>0.0068</td>
<td>-0.0008</td>
<td>-0.0053</td>
</tr>
<tr>
<td>Food security</td>
<td>L</td>
<td>-0.0020</td>
<td>-0.0008</td>
<td>-0.0031</td>
</tr>
<tr>
<td>Food security</td>
<td>U</td>
<td>-0.0029</td>
<td>-0.0012</td>
<td>-0.0050</td>
</tr>
<tr>
<td>Component</td>
<td>Year 5</td>
<td>Year 10</td>
<td>Year 20</td>
<td>Total ∆</td>
</tr>
<tr>
<td>--------------------</td>
<td>--------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>Food supply</td>
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<td>0.0010</td>
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<td>-0.0018</td>
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<td>-0.0029</td>
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<td>Human health</td>
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<td>-0.0050</td>
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<td>Human health</td>
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<td>-0.0075</td>
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<td>Political climate</td>
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<td>0.0009</td>
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<tr>
<td>Political climate</td>
<td>U</td>
<td>-0.0009</td>
<td>0.0003</td>
<td>0.0012</td>
</tr>
<tr>
<td>Population growth</td>
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<td>0.0003</td>
<td>0.0001</td>
<td>-0.0003</td>
</tr>
<tr>
<td>Population growth</td>
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<td>0.0004</td>
<td>0.0001</td>
<td>-0.0003</td>
</tr>
<tr>
<td>Public policy</td>
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<td>-0.0020</td>
<td>-0.0015</td>
<td>-0.0017</td>
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<td>Public policy</td>
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<td>Rural development</td>
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<td>Rural development</td>
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<tr>
<td>Social equity</td>
<td>L</td>
<td>-0.0068</td>
<td>-0.0021</td>
<td>-0.0027</td>
</tr>
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<td>Social equity</td>
<td>U</td>
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<td>-0.0041</td>
</tr>
</tbody>
</table>
Table 3-4: Climate change sensitivity analysis score summary. Food security component scores and total change over 20 years produced through the system model and environmental scanning techniques without the climate change component removed during sensitivity analysis. The total change from year 5 to year 20 is also displayed. The cell color signifies the score’s distance from zero via color mapping. The light green shade indicates moderate score increase while the dark green shade indicates substantial score increase. The yellow shade indicates a slight score increase. The light orange shade indicates a slight score decrease or neutral score. The orange shade indicates a moderate score decrease. The red shade indicates a substantial score decrease.

L: lower expected change. U: upper expected change.

<table>
<thead>
<tr>
<th>Component</th>
<th>Year 5</th>
<th>Year 10</th>
<th>Year 20</th>
<th>Total Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate change</td>
<td>L n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Climate change</td>
<td>U n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Economic policy</td>
<td>L -0.0012</td>
<td>-0.0017</td>
<td>-0.0039</td>
<td>-0.0027</td>
</tr>
<tr>
<td>Economic policy</td>
<td>U -0.0016</td>
<td>-0.0022</td>
<td>-0.0055</td>
<td>-0.0039</td>
</tr>
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<td>Ecosystem health</td>
<td>L -0.0010</td>
<td>-0.0021</td>
<td>-0.0058</td>
<td>-0.0047</td>
</tr>
<tr>
<td>Ecosystem health</td>
<td>U -0.0013</td>
<td>-0.0027</td>
<td>-0.0086</td>
<td>-0.0072</td>
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<td>-0.0023</td>
<td>-0.0024</td>
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<td>Food demand</td>
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<td>-0.0035</td>
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<td>Food price</td>
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<td>-0.0054</td>
<td>-0.0029</td>
</tr>
<tr>
<td>Food production infrastructure</td>
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<td>-0.0033</td>
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</tr>
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<td>Food production infrastructure</td>
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<td>-0.0118</td>
</tr>
<tr>
<td>Food security</td>
<td>L -0.0020</td>
<td>-0.0008</td>
<td>-0.0031</td>
<td>-0.0011</td>
</tr>
<tr>
<td>Component</td>
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<td>Year 10</td>
<td>Year 20</td>
<td>Total Δ</td>
</tr>
<tr>
<td>-------------------</td>
<td>--------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>Food security</td>
<td>U</td>
<td>-0.0029</td>
<td>-0.0012</td>
<td>-0.0050</td>
</tr>
<tr>
<td>Food supply</td>
<td>L</td>
<td>0.0010</td>
<td>-0.0005</td>
<td>-0.0018</td>
</tr>
<tr>
<td>Food supply</td>
<td>U</td>
<td>0.0018</td>
<td>-0.0004</td>
<td>-0.0029</td>
</tr>
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<td>Global trade</td>
<td>L</td>
<td>0.0049</td>
<td>-0.0006</td>
<td>-0.0030</td>
</tr>
<tr>
<td>Global trade</td>
<td>U</td>
<td>0.0060</td>
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<td>Human health</td>
<td>L</td>
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<td>Political climate</td>
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<td>Political climate</td>
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<td>-0.0009</td>
<td>0.0003</td>
<td>0.0012</td>
</tr>
<tr>
<td>Population growth</td>
<td>L</td>
<td>0.0003</td>
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<td>-0.0003</td>
</tr>
<tr>
<td>Population growth</td>
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<td>0.0004</td>
<td>0.0001</td>
<td>-0.0003</td>
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<td>Public policy</td>
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<td>-0.0017</td>
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<td>Public policy</td>
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<td>-0.0023</td>
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<tr>
<td>Rural development</td>
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<td>-0.0003</td>
<td>-0.0016</td>
</tr>
<tr>
<td>Social equity</td>
<td>L</td>
<td>-0.0068</td>
<td>-0.0021</td>
<td>-0.0027</td>
</tr>
<tr>
<td>Social equity</td>
<td>U</td>
<td>-0.0101</td>
<td>-0.0032</td>
<td>-0.0041</td>
</tr>
</tbody>
</table>
Table 3-5: Political climate sensitivity analysis score summary. Food security component scores and total change over 20 years produced through the system model and environmental scanning techniques without the political climate component removed during sensitivity analysis. The total change from year 5 to year 20 is also displayed. The cell color signifies the score’s distance from zero via color mapping. The light green shade indicates moderate score increase while the dark green shade indicates substantial score increase. The yellow shade indicates a slight score increase. The light orange shade indicates a slight score decrease or neutral score. The orange shade indicates a moderate score decrease. The red shade indicates a substantial score decrease.

L: lower expected change. U: upper expected change.

<table>
<thead>
<tr>
<th>Component</th>
<th>Year 5</th>
<th>Year 10</th>
<th>Year 20</th>
<th>Total Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate change</td>
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<tr>
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<td>U</td>
<td>-0.0018</td>
<td>-0.0024</td>
<td>-0.0057</td>
</tr>
<tr>
<td>Ecosystem health</td>
<td>L</td>
<td>-0.0012</td>
<td>-0.0023</td>
<td>-0.0062</td>
</tr>
<tr>
<td>Ecosystem health</td>
<td>U</td>
<td>-0.0016</td>
<td>-0.0031</td>
<td>-0.0092</td>
</tr>
<tr>
<td>Food demand</td>
<td>L</td>
<td>0.0001</td>
<td>-0.0001</td>
<td>-0.0023</td>
</tr>
<tr>
<td>Food demand</td>
<td>U</td>
<td>0.0001</td>
<td>0.0000</td>
<td>-0.0034</td>
</tr>
<tr>
<td>Food price</td>
<td>L</td>
<td>-0.0017</td>
<td>-0.0008</td>
<td>-0.0037</td>
</tr>
<tr>
<td>Food price</td>
<td>U</td>
<td>-0.0025</td>
<td>-0.0010</td>
<td>-0.0054</td>
</tr>
<tr>
<td>Food production infrastructure</td>
<td>L</td>
<td>0.0053</td>
<td>-0.0007</td>
<td>-0.0036</td>
</tr>
<tr>
<td>Food production infrastructure</td>
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<td>0.0068</td>
<td>-0.0008</td>
<td>-0.0053</td>
</tr>
<tr>
<td>Food security</td>
<td>L</td>
<td>-0.0020</td>
<td>-0.0008</td>
<td>-0.0031</td>
</tr>
<tr>
<td>Component</td>
<td>Year 5</td>
<td>Year 10</td>
<td>Year 20</td>
<td>Total Δ</td>
</tr>
<tr>
<td>--------------------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>Food security</td>
<td>U</td>
<td>-0.0029</td>
<td>-0.0012</td>
<td>-0.0050</td>
</tr>
<tr>
<td>Food supply</td>
<td>L</td>
<td>0.0010</td>
<td>-0.0005</td>
<td>-0.0018</td>
</tr>
<tr>
<td>Food supply</td>
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<td>0.0018</td>
<td>-0.0004</td>
<td>-0.0029</td>
</tr>
<tr>
<td>Global trade</td>
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</tr>
<tr>
<td>Global trade</td>
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<td>-0.0017</td>
<td>-0.0056</td>
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<td>Human health</td>
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<td>-0.0050</td>
<td>-0.0050</td>
</tr>
<tr>
<td>Human health</td>
<td>U</td>
<td>-0.0069</td>
<td>-0.0074</td>
<td>-0.0075</td>
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<td>Political climate</td>
<td>L</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Political climate</td>
<td>U</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Population growth</td>
<td>L</td>
<td>0.0003</td>
<td>0.0001</td>
<td>-0.0003</td>
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<tr>
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<td>U</td>
<td>0.0004</td>
<td>0.0001</td>
<td>-0.0003</td>
</tr>
<tr>
<td>Public policy</td>
<td>L</td>
<td>-0.0021</td>
<td>-0.0016</td>
<td>-0.0018</td>
</tr>
<tr>
<td>Public policy</td>
<td>U</td>
<td>-0.0027</td>
<td>-0.0025</td>
<td>-0.0027</td>
</tr>
<tr>
<td>Rural development</td>
<td>L</td>
<td>0.0004</td>
<td>-0.0003</td>
<td>-0.0012</td>
</tr>
<tr>
<td>Rural development</td>
<td>U</td>
<td>0.0005</td>
<td>-0.0003</td>
<td>-0.0016</td>
</tr>
<tr>
<td>Social equity</td>
<td>L</td>
<td>-0.0068</td>
<td>-0.0021</td>
<td>-0.0027</td>
</tr>
<tr>
<td>Social equity</td>
<td>U</td>
<td>-0.0101</td>
<td>-0.0032</td>
<td>-0.0041</td>
</tr>
</tbody>
</table>
Figure 3-1: Novel food insecurity systems model. This model portrays the relationships between environmental, political, economic, and sociological drivers. All leads used in the analysis are not displayed in the figure for visual clarity. The legend identifies the driver categories, and types of shapes and lines in the model. A component is a subsection of larger drivers of food insecurity (i.e., environment, economics, policy, and sociological drivers). An aggregation point is a component in the model in which many components flow together, or “aggregate”. A lead is a data point that can correspond to one or more than one component in the model. A lead impact is the impact of one lead upon its corresponding component(s). A flow impact represents the broad relationship between one component and another in the model. Component interpretations can be found in Table 3-2. Blue indicates a component within the environmental driver. Green indicates a component within the political driver. Yellow indicates a component within the economic driver. Purple indicates a component within the sociological driver.
Figure 3-1. Continued.
Figure 3-2: Lead percentage tree map. Systems model components are grouped by similar lead counts. Percentage of leads is displayed next to the component title. Blue indicates economic components. Green indicates environmental components. Yellow indicates political components. Purple indicates sociological components. Orange indicates the primary aggregation point: the food security component.
Figure 3-3: Component scores parallel coordinates diagram. Trends in expected component changes over 5, 10, and 20 years. Low and high scores displayed in Table 2-3 are averaged for visual clarity. The y-axis denotes expected component changes. Blue indicates one of the five economic components. Green indicates one of the three environmental components. Yellow indicates one of the three political components. Purple indicates one of the three sociological components. Orange indicates the food security component, or outcome of interest.
CHAPTER 4

EXPANDED METHODOLOGY
Abstract

Millions of people across the United States face food insecurity each year. This leaves individuals at considerable risk for serious chronic health problems. Low-income households are particularly vulnerable to food insecurity. Therefore, a deeper understanding of food insecurity can help scientists address social inequities that stunt a person’s ability to thrive. Yet, food insecurity is not an isolated phenomenon. Indeed, food insecurity is wrapped up in a complex network of economic, political, environmental, and social determinants. Moreover, climate change hinders food production via heightened weather variability and declining environmental health and thus could be expected to contribute to the problem of food insecurity. However, recent studies have failed to explore how climate change influences food security, principally for future generations.

Contemporary modeling techniques are uniquely capable (yet underutilized) tools to synthesize the mass of currently available data on both food security and climate change. Therefore, the objective of this study is twofold: to create a novel systems model of food security, and quantify and project future trends in the United States considering climate change’s potentially devastating effects to offset the impact of food insecurity in the United States. Through previous analysis, the research team has located 16 critical issues and 41 indicators that will guide this investigation into the complex web of components surrounding food insecurity. The research team will develop and analyze a novel model using environmental scanning methodology.
Specific Aims

Specific Aim 1: Collect and assess existing literature and data to inform model construction. The research team assembled and quantified current, pertinent data regarding economic, political, environmental, biological, and social factors from multiple sources.

Rationale: Integrating large-scale information on the current and future atmosphere of food security identified driving forces.

Approach: The research team employed environmental scanning techniques and rubrics to assess data quantitatively by projectability, impact, credibility, and probability.

Specific Aim 2: Develop a novel food security systems model. The research team created systems model to illuminate the relationships between macro- and microsystem factors (i.e., environmental, economic, political, and social).

Rationale: The influence of climate change within this system is poorly understood. Building a systems model clarified the drivers of food security.

Approach: Using assimilated data, the research team identified driving forces of the systems model. Relationships between the factors were mapped using diagramming software. This organized the pattern of influence between components and drive future data collection.

Specific Aim 3: Analyze and predict future trends in food insecurity. The research team ran collected data through the developed model to yield trends over 20 years.

Rationale: This methodology, used in a novel setting, produced quantitative changes that describe how components change over time and in relation to one another.

Approach: The research team used the Tonn methodology to compile and aggregate results through the systems model. Sensitivity analysis can reveal any unexpected impacts of components (e.g., climate change) upon one another and the systems model in its entirety.
Research Approach

This study investigated the potential future pathways of food security in the US. It particularly considers the effects of driving factors like climate change and politics in the trajectory of food insecurity. The research team used a model-based methodology to quantify environmental scanning and futures analysis results. This project demonstrated the impacts of climate change and the political climate upon the determinants of food insecurity. The keystone of the methodology, the systems model, considers how driving factors (i.e., economic, environmental, political, and social) affect food security. Outcomes of this study could key decision-makers in planning and responding to future food security developments in the US.

Research team members have appropriate experience and education to conduct this project and analyze resulting data. Despite the limitations and gaps in current research, the research laboratory has provided a solid framework for future research in food security via literature review (Figure 1-1). The research team has consolidated information on methodologies, indicators, and relationships between and among indicators of food insecurity in the US. The project teams’ past research suggests several critical areas under environmental, economic, sociological, and public policy drivers (Figure 1-2). In addition, the research team has published work with this methodology in the novel context of biofuel trends. This work could support future research to conceptualize and model how the environment, economics, sociology, and public policy interplay within the phenomenon of food insecurity.

Innovation

Firstly, this methodological approach is both novel in setting and context. Environmental scanning has been used in business and ecological subjects. This study is the first application of environmental scanning and futures analysis in food security. In particular, this
study is technically innovative as it bridges data between several different fields. Indeed, this application provides a novel avenue for future research.

Secondly, environmental scanning offers flexibility to assess the relationships between various objectives and constraints. The model could be used to project trends in many different geographical areas with varied social, political, economic, and environmental conditions. Data collection can be constrained to specific sources to adjust the time span and geographical area of interest. Also, the range of positive and negative impact scores enables incorporation of different data scales and types. Thirdly, this approach can analyze a wide variety of pertinent data sources (Figure 4-1). Environmental scanning can evaluate substantial amounts of information in a brief time with minimal resources. Yet, this method is sensitive to the changing conditions inherent in complex systems. In fact, this approach is highly relevant to current issues in the US. The model can accommodate many scenarios to address a wide range of objectives. Depending upon the data sources and components (like climate change and the current political climate), the model produces different scores for each component over time. In this way, scores can be compared between components and over time to address problems considering the most relevant issues.

Notably, this approach includes futures analysis elements that inherently consider data projectability. Environmental scanning inherently accounts for subjectivity and uncertainty. Imprecise probabilities provide a measure of confidence to incorporate data reliability over time. When projecting lead impacts into the future, the inclusion of an uncertainty metric is essential for realistic analysis of real-world systems like the US food security.\textsuperscript{59} Other methods of analysis and modeling do not account for data quality projectability (ecosystem services framework), require large investments of time, money, and infrastructure (climate reconstructions), or are not flexible to the types of data environmental scanning collects and analyses (econometric analysis).
Therefore, environmental scanning with the Tonn methodology is the most appropriate research approach for futures analysis of food security in the US over the next 20 years.

**Data Collection**

First, the research team continued past work to assemble and quantify current, pertinent data regarding economic, political, environmental, economic, and social factors from standard and non-standard sources via environmental scanning. Environmental scanning is a literature review technique including peer-reviewed, grey literature, and industry resources. Each data point is also called a “lead”, or a factor that impacts the component it connects to in the systems model. Lead collection helps inform model construction by identifying key components and the relationships between them in relation to food security.

Following model construction, leads were quantified to yield future trends in the context of food security. Literature and web search queries included the critical issues discussed previously (e.g., “ecosystem degradation”, “global trade”, “political climate”, “infrastructure stability”) in combination with “food (in)security”. The research team collected leads through environmental scanning to ensure a balanced perspective of data currently available. Primarily, authors focused environmental scanning in the US, but international climate change data was included if the climate of that country matched the US. Global data was also included if the trends were generalizable to the US.

**Lead scoring.**

The research team collected data at one point in time, yet the research team projected trends over the next 20 years, as their previous literature review suggests the highest quality and quantity of data over this period. The research team accomplished this by using a scoring process that quantifies how much a lead will impact its component(s) over time (from -10 to 10) (Table
The probability of a lead impacting its component then ranges from \( P(A) = 0.0 \) (representing an impact that will not happen) and \( P(A) = 1.0 \) (representing an impact that will happen). This yields flexibility to the model and more accurately represent reality, as mentioned previously. Imprecise probabilities also allow for the model to still function viably as knowledge of the future grows.\(^{59}\)

**Incorporation of data credibility.**

Model accuracy is based upon the availability of information and the viability of scoring methods. In this project, the research team used a rubric to decrease or increase lead impact scores based upon their credibility. Criteria for credibility include source type, reference quality, and publication type (Table 2-1). Leads can impact one or many components in the systems model (Figure 4-2). An example of a lead connected a potential model component: Climate Change is located in Table 4-2.\(^{146}\) This lead was located from peer-reviewed literature. This example is considered a lead because it would impact the outcome of many components, and hence the model outcome. Leads are sorted into credibility categories based upon the number of criteria fulfilled per category. Three or more fulfilled criteria in a particular category assigns that lead to that category. For example, a lead that was in a peer-reviewed journal, from the last two years and sponsored by an unbiased funding source yet was published over the last 2-5 years would still be considered “high credibility”.

**Model Construction**

Informed by previous data collection, the research team created a systems model to organize the impacts upon components determining food insecurity (Figure 4-2). Because this model is trying to represent a complex system, it must be firmly based in available research. The
systems model helped establish influence among critical food security issues and directed ongoing collection of leads via environmental scanning.

**Model function.**

The systems model offered a top-down look on the food security landscape. As shown in the sample model, components impact each other in different ways. Components of the novel food insecurity systems model arose from four food security drivers: environment, economics, policy, and social factors. Examples include ecosystem health, food supply, national economic policy, population growth, and social equity. Component impacts eventually flow into the aggregation point: food insecurity. Although the systems model visualized complex relationships in a simplified way, it could guide the research community as more in-depth studies of US food insecurity develop.

**Lead score compilation.**

The research team used the Tonn methodology exponential function to aggregate the total impact of leads.\(^5^9\) The exponential component was used to aggregate the total impact of components. The scores produced, while not inherently valuable, were compared over time or between components.

First, the research team added lead impacts and their associated probabilities.\(^5^9\) The research team multiplied the lead score \((L_1)\) with its lower probability \((P_{l,t})\) for each lead of a particular component \(c\) over time \(t\), and then summed all impact scores (Equation 1). This process was repeated for the upper probability \((\overline{P}_{l,t})\) and associated lead score \((L_1)\) (Equation 2). Equations 1 and 2 yield the total expected component changes considering the impacts and probability ranges of all the leads over time.
Equation 1: Compiled Lower Lead Impacts

\[ E(\Delta(C_{i,t})) = \frac{1 - e^{-I(C_{i,t})}}{1 + e^{-I(C_{i,t})}} \] where

\[ I(C_{i,t}) = p_{i,t}(L_1) * I_{i,t}(L_1) + p_{i,t}(L_2) * I_{i,t}(L_2) + \ldots + p_{i,t}(L_N) * I_{i,t}(L_N) \]

Equation 2: Compiled Upper Lead Impacts

\[ E(\Delta(C_{i,t})) = \frac{1 - e^{-\bar{I}(C_{i,t})}}{1 + e^{-\bar{I}(C_{i,t})}} \] where

\[ \bar{I}(C_{i,t}) = \bar{p}_{i,t}(L_1) * I_{i,t}(L_1) + \bar{p}_{i,t}(L_2) * I_{i,t}(L_2) + \ldots + \bar{p}_{i,t}(L_N) * I_{i,t}(L_N) \]

Component score compilation.

Next, the research team aggregated impacts that components have on each other. Mathematically, component impacts are treated as “leads”. Therefore, \( p_{i,t}(C_j) * I_{i,t}(C_j) \) and \( \bar{p}_{i,t}(C_j) * I_{i,t}(C_j) \) delineate the lower and upper expected impacts of component \( C_j \) on component \( C_i \). Hence, Equations 3 and 4 compile component impacts through modifications of equations 1 and 2.

Equation 3: Compiled Lower Component Impacts

\[ E(\Delta(C_{i,t})) = \frac{1 - e^{-I(C_{i,t})}}{1 + e^{-I(C_{i,t})}} \] where

\[ I(C_{i,t}) = p_{i,t}(C_1) * I_{i,t}(C_1) + p_{i,t}(C_2) * I_{i,t}(C_2) + \ldots + p_{i,t}(C_N) * I_{i,t}(C_N) \]

Equation 4: Compiled Upper Component Impacts

\[ E(\Delta(C_{i,t})) = \frac{1 - e^{-\bar{I}(C_{i,t})}}{1 + e^{-\bar{I}(C_{i,t})}} \] where
\[
I(C_{i,t}) = P_{l,t}(L_1) \ast I_{i,t}(L_1) + P_{l,t}(L_2) \ast I_{i,t}(L_2) + \ldots \ldots P_{l,t}(L_N) \ast I_{i,t}(L_N) + P_{l,t}(C_1) \ast I_{i,t}(C_1) + P_{l,t}(C_2) \ast I_{i,t}(C_2) + \ldots \ldots P_{l,t}(C_N) \ast I_{i,t}(C_N)
\]

**Data Interpretation**

Finally, estimated component changes were converted to impact scores on the next component. Impacts must be sequential; no impact recursion was included.\(^5^9\) Therefore, the impact of each component upon others was assigned its own probability and impact score. The impact was estimated by literature review and expert consultation. The associated probabilities were calculated as an average of lead scores per component. After aggregation of lead and component scores, the research team compared results to find trends over time and among components (Table 3-2). The aggregation point (food security) was be of particular interest. The research team used color mapping techniques to help visualize changes and patterns over time.

**Sensitivity analysis.**

The systems model produced different trends when certain components are removed (or added). This provides not only a route to understand how components relate to each other, but also a way to conduct sensitivity analysis.\(^1^3^3\) This helped determine how the uncertainty in the systems model was related to certain components. The research team removed original model components political climate and climate change. This can identify one component driving the trends in food security. In other words, it verifies that the research team does not unconsciously skew impact scores in one direction.

**Strengths and limitations.**

This methodology is limited primarily by the quality of data it collects and analyzes. The responsibility lies upon the research team to ensure comprehensive lead collection prior to
analysis. The methodology accounts for new research developments and varying data quality via imprecise probabilities, but this cannot cover extreme variability. Therefore, the research team projected trends over the next 20 years. This methodology also relies upon the accuracy of its systems model. The research team ensured review of the systems model by academics and professionals from pertinent fields prior to lead collection and analysis. This helped the model best represents the current state of food security in the US and addressed potential issues with bias. Bias could also be introduced through the collection and scoring of data via the numerical scale by the lead researcher. In addition, the model construction and analysis were led by the researcher.

Several steps were taken to limit the influence of bias in this study. J. Trumbo quantified and summarized leads per the rubric provided (Table 3-1) to decrease the influence of subjectivity and ensure the scoring of data remain as consistent as possible throughout the process. Also, as discussed previously, sensitivity analysis ensured that no single component was driving the results in a direction. Despite the novelty of this project and potential for bias, similar studies have been conducted in closely related fields with success. The research team is confident that careful planning, and adherence to study design and rubrics has ensured viable, accurate data analysis and trend projection.

Results of this study revealed expected (and unexpected) impacts of climate change and related components. Finding of this study could support future research to conceptualize and model how environmental, economic, social, and policy factors interplay within food security. As multidisciplinary interventions are developed, results of this study could help inform public health and nutrition professionals to meet the future challenges in food security. Project outcomes were twofold: (1) spur the development of novel models and approaches to project
global food security trends across the next century and (2) inform interventions to address socioecological disparities that drive negative health outcomes related to food insecurity status.
Table 4-1: Impact score interpretation. Impact scores and their associated changes with qualitative descriptions.

<table>
<thead>
<tr>
<th>Qualitative change in lead or component</th>
<th>Change in lead or component score</th>
<th>Impact score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely massive increase</td>
<td>0.99999</td>
<td>10</td>
</tr>
<tr>
<td>Extreme increase</td>
<td>0.986</td>
<td>5</td>
</tr>
<tr>
<td>Substantial increase</td>
<td>0.46</td>
<td>1</td>
</tr>
<tr>
<td>~20% increase</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td>~10% increase</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>~1 in a million increase</td>
<td>0.0005</td>
<td>0.001</td>
</tr>
<tr>
<td>~1 in one hundred million increase</td>
<td>0.000005</td>
<td>0.00001</td>
</tr>
<tr>
<td>No change</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>~1 in one hundred million decrease</td>
<td>-0.000005</td>
<td>-0.00001</td>
</tr>
<tr>
<td>~1 in a million decrease</td>
<td>-0.0005</td>
<td>-0.001</td>
</tr>
<tr>
<td>~10% decrease</td>
<td>-0.1</td>
<td>-0.2</td>
</tr>
<tr>
<td>~20% decrease</td>
<td>-0.2</td>
<td>-0.4</td>
</tr>
<tr>
<td>Substantial decrease</td>
<td>-0.46</td>
<td>-1</td>
</tr>
<tr>
<td>Extreme reduction</td>
<td>-0.986</td>
<td>-5</td>
</tr>
<tr>
<td>Reduction to very close to zero</td>
<td>-0.99999</td>
<td>-10</td>
</tr>
</tbody>
</table>

Table 4-2: Sample climate change lead summary. This summary identifies the associated component, summary of lead information, impact, and probability scores over the next 20 years.

Climate Change: Global Temperature Increase

According to recent climate models, the mean global surface temperature will increase 0.5°C above the 1886-2005 average by 2020.

<table>
<thead>
<tr>
<th>Impact on climate change component</th>
<th>5 years</th>
<th>10 years</th>
<th>20 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower probability</td>
<td>0.07</td>
<td>0.07</td>
<td>0.07</td>
</tr>
<tr>
<td>Upper probability</td>
<td>0.09</td>
<td>0.09</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Source: 146
Figure 4-1: Data collection via environmental scanning. Environmental scanning uses diverse types of data to find future trends.
Figure 4-2: Sample basic systems model. The relationship between components and the aggregation point (food security in this study) depending upon lead inputs. The aggregation point is the point at which all leads converge, directly and indirectly.
CHAPTER 5

RECOMMENDATIONS AND CONCLUSION
Scientific, political, and economic professionals have yet to offer a comprehensive, effective solution to the near universal phenomenon of food insecurity.\textsuperscript{1} Considering results of the previous analysis, the author will suggest actions that could support, fund, or supply practical, efficient, synergistic interventions to increase food security in the United States. As mentioned previously, the connection between social conditions and food security has sparked nutrition interventions to attempt to limit negative health outcomes in vulnerable populations at national, state, and local levels.\textsuperscript{18} Headey found most notable increases in food security related to both favorable health, education, fertility trends, and well-documented nutrition programs.\textsuperscript{34}

The United Nations and other organizations set goals for increasing food security during events like the World Food Summit and UN Millennium Project.\textsuperscript{5,137} Margulis identified intergovernmental forums such as the now reformatted G8, World Trade Organization, and World Bank, in combination with the United Nations as key actors in the multilateral response to food insecurity around the world.\textsuperscript{138} Tadesse, Algieri, Kalkuhl, and von Braun suggested that these organizations can stabilize food security most effectively via policies that increasing producer and consumer resilience, and reduce volatility and price strikes.\textsuperscript{118} Specifically, Grote suggested that agriculture productivity, consumer awareness of food waste and resource use inefficiencies, and rural development would aid in in this process.\textsuperscript{139}

The USDA ERS is the leading federal agency for measurement, monitoring, and research on food security in the United States (although the Centers for Disease Control and Prevention (CDC) and Environmental Protection Agency (EPA) take unique and complementary responsibilities).\textsuperscript{12,147,148} Federal approaches to address food security typically involve policy measures, like the international methods mentioned previously. For example, Title IV of the Food, Conservation, and Energy Act of 2008 increases produce availability for low-income U.S.
households via the Supplemental Nutrition Assistance Program (SNAP) and other programs. The Supplemental Nutrition Program for Women, Infants, and Children (WIC) provides education, referrals, and supplemental food to low-income pregnant and postpartum women, children, and infants via state grants). Kaiser suggested that while these programs are beneficial, additional policies should subsidize diverse crop types most often used in nutrient-rich foods rather than processed foods. Schmidt, Shore-Sheppard, and Watson found that “safety-net” programs such as these reduced the incidence of food insecurity by 1.1%. Efforts such as the House 2017 budget plan which would decrease funding of SNAP should therefore be rejected to maintain, or ideally expand such programs. Introduction of new policies and changes in existing policy often occur with the help of non-governmental organizations. Indeed, organizations like the Congressional Hunger Center develop “anti-hunger” policies in the United States via advocacy, awareness, training, funding, and research.

Governmental, non-profit, and national organizations play a prominent role in addressing food insecurity at the state level. For example, the Tennessee Department of Human Services has partnered with the USDA Food and Nutrition Service to decrease food insecurity rates in Tennessee, particularly in children. Additionally, as previously mentioned, WIC provides valuable services to pregnant and post-partum women, infants, and children via a partnership between state and national governments, offered in health departments across the state. Feeding America, a national organization, supports research and funds food banks in the state. Second Harvest Food Bank is one such food bank assisting regionally and locally in food collection and distribution, outreach, and education to food insecure individuals. Within Knoxville, the Knoxville Food Policy Council, the University of Tennessee Extension and Beardsley Farm provide support per the Tennessee Department of Health. Attempts to address
food security at international, national, and regional levels are interconnected and varied to meet the complex, persistent nature of the problem. Indeed, the political climate, policy, and infrastructure should be considered in light of climate change to react to the negative trends in the food security landscape across the United States over the next 20 years, as identified within this study.

**Conclusions and Research Opportunities**

Food insecurity is a difficult and complex phenomenon to understand. One cannot assign the condition of food insecurity to study subjects for ethical concerns. Therefore, random assignment of treatments in a clinical trial is not possible. Yet, a greater scientific understanding will help build evidence-based interventions and policies. Prospective birth cohort studies have been conducted, such as Melchior and colleagues’ investigation of the association between food insecurity and childhood mental health. Ultimately, like the studies summarized previously, cross-sectional surveys and prevalence-based analyses are invaluable to food security research. Further research can help identify what sections of the population face food insecurity and associated negative health outcomes. These populations would be excellent candidates for targeted clinical and public health interventions.

In addition, further refinement of assessment tools, like the USDA Food Security Survey module to meet the needs of a variety of subjects (particularly those most vulnerable and difficult to access), and research into how best to increase survey response rate could be helpful for later studies. These tools should improve the quantification of the psychological distress that accompanies even borderline experiences of food insecurity. In addition, future studies should investigate how to best limit recall, non-response, and response bias that could influence internal validity. Clearly, food insecurity is interconnected with health disparities and negative
health outcomes at all levels of society. Therefore, local, state, and national governments and organizations must take an active, persistent role in research and intervention to improve the health of individuals around the world.

This study has several strengths in methodology and results. Indeed, it has been the first to apply environmental scanning to food insecurity issues, according to the author’s knowledge. Additionally, because of resource and data availability, numerous studies do not integrate environmental, economic, political, and sociological information into one model. This study fills both gaps via this novel application, which will allow for a broader number of methodologies within food security studies. In this context, environmental scanning provides the flexibility to assess the relationships between many data types. Leads can be constrained to change the time span and geographical area. Positive and negative impact scores provide quantification of qualitative and quantitative data on a unified scale to address various research questions. Most importantly, imprecise probabilities reflect measures of confidence for lead impacts. Therefore, this approach can entertain countless scenarios. This study has produced information which can help target interventions and policies to most efficiently address future trends in food security and its drivers in the United States.

In the future, this model should be applied to comparable countries get a more complete perspective on global food security. Using the same methodology, trends in systems model components could be compared. Additionally, collecting a larger number of leads would provide more comprehensive data over a longer period. The model could then project more significant trends with more confidence. As trends change over the next 20 years, the model can be altered and more leads collected to monitor the changes in trends with novel input. Indeed, future environmental scanning exercises should expand to areas beyond the United
States, and include a greater number of leads per component in different areas and over different time periods as data availability improves.

The systems model created via this study offers a holistic, elementary view of the food security landscape. This study has addressed key areas surrounding the food insecurity phenomena across the United States. Environmental scanning has been applied via a novel systems model to assess future trends in this landscape considering climate change, the political climate, and other factors. Overall, the study yielded considerations for decision-makers as the effects of climate change intensify and the political climate changes. Economic and public policies will be crucial forces to improve the outlook of food security in the next 20 years. Public health and nutrition professionals can take part in targeted interventions and public programs increase food security in the most vulnerable populations.
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