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Navigating community engagement in participatory modeling of food systems

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ABSTRACT

This paper describes the participatory modeling experiences of five discrete teams across the U.S. working to develop models of food systems to identify leverage points and policies to induce food system transformation. Collaboration between academic and community partners within these individual modeling processes enables teams to address food systems complexity, integrate scientific evidence and local knowledge into models, while improving a model's credibility and accessibility for policymaking. While tools for facilitating participatory modeling are becoming more available, there is scant discussion on the practicalities of community engagement processes, including how teams respond to the needs of partners, navigate challenges that arise during projects, and communicate results. Synthesizing results from five independent teams in Albany, New York; Austin, Texas; Cleveland, Ohio; Denver, Colorado; and Flint, Michigan, this paper provides an overview of each team's approach to community engagement for participatory modeling of food systems. Analysis of engagement strategies across these five teams revealed four essential components to successful participatory modeling projects: 1) building research in collaboration with partners from the onset, 2) developing awareness of the challenges of community-researcher partnerships, 3) supporting transparent communication, and 4) promoting justice and trust through accessible dissemination processes. We emphasize that there is no single best approach to participatory modeling with community partners, rather that researchers need to understand and respond to various stakeholder needs. While each team faced challenges to the engagement process, including responding to the COVID-19 pandemic, our findings reveal important considerations for research in participatory modeling for food system policy.

1. Introduction

1.1. Food systems modeling

Food systems encompass all the activities and resources needed to produce, distribute, and consume food, the drivers and outcomes of these processes, and all the relationships among the systems' components (Neff and Lawrence, 2015). Food systems are more than supply chains, and their activities, entities, and effects extend to the broader community and natural resource contexts (Ericksen, 2008; Peters and Thilmany, 2022). As systems, they consist of interconnected elements organized for a function or purpose (Meadows, 2008). Thus, there is

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inherent tension in food systems as we manage the urgency of food access with broader challenges of sustainability, justice, and food sovereignty. Food systems pose unique challenges because the environmental impacts of agricultural production, waste, and processing yield long-term impacts, while providing sufficient nourishment at a global scale is an immediate need. Policies and decisions are often made based on limited knowledge of potential tradeoffs or unintended consequences (Clancy, 2022; Peters and Thilmany, 2022).

Modeling helps us organize food systems knowledge by framing our understanding of system interactions and testing future scenarios through simulations (Peters and Thilmany, 2022; Sanz et al., 2023). Models simplify and visualize a set of relationships, integrating concepts, theories about how systems work, and a wide array of data, with potential for improved decision-making (Clancy, 2022; Peters and Thilmany, 2022). Models are invaluable tools for learning and synthesizing information, explaining a system's behaviors, questioning current knowledge, guiding future research, and informing public policy (Peters and Thilmany, 2022; Rouwette et al., 2002; Sanz et al., 2023; Voinov et al., 2018).

1.2. Community-engaged research

As food systems affect and are affected by "wicked problems", some researchers argue they are public commons, implying need for community-based decisions regarding their management and policy (Glickman et al., 2022). Community-engaged research–which refers to the collaborative process of knowledge co-production between academic and non-academic stakeholders–can benefit researchers, community partners, and society through partnerships, collaborations, and coalitions, enhancing the quality and relevance of research (Doberneck et al., 2010).

Grounding research in communities and with stakeholders is central in translating scientific knowledge into impactful practical applications to enhance human health and well-being (Brenner and Manice, 2011; Doberneck et al., 2010; O'Fallon and Dearry, 2002; NRC, 2008). This collaborative process, which exists along a spectrum (Shirk et al., 2012), can mobilize resources, increase empowerment and influence, and induce change in policies and practices (Ahmed and Palermo, 2010; Brenner and Manice, 2011). Beyond these empirical and pragmatic benefits, community-engaged research has the potential to promote social justice through inclusion of historically underrepresented and marginalized groups (Biggs et al., 2015). To enhance their efficacy, projects are best developed in partnership with community members. Today there are many typologies of participation and community-engaged scholarship that illustrate how researchers and communities can partner (for example, see Cornwall, 2008; Doberneck et al., 2010; Reed, 2008).

1.3. Participatory modeling and food systems

Participatory modeling is a process that engages both implicit and explicit knowledge of stakeholders to create formalized and shared representations of reality (Voinov et al., 2018), with many processes designed to facilitate the co-creation of models (Glickman et al., 2022; Hovmand et al., 2012). Including stakeholders is helpful in reinforcing the focus on problems most relevant to communities by allowing participants to identify, develop, and test solutions to inform collective decision-making (Sandker et al., 2010; Stave, 2010; Voinov et al., 2018). Participatory modeling encompasses a broad array of tools and methods to support collaboration in problem formulation, creation of models, evaluation of outcomes, and effectively informing intervention implementation (Hedelin et al., 2017; Hedelin et al., 2021). For researchers, this requires moving from a technical approach towards one rooted in partnership, and, for communities, it can promote commitment to action (Luna-Reyes and Andersen, 2003; Sandker et al., 2010; Sterling et al., 2019). Therefore, a variety of skillsets in modeling, engagement, facilitation, leadership, and systems thinking are required to build successful participatory modeling projects (Elsawah et al., 2023). Since models are broadly defined as representations of our understanding of the world, interdisciplinary research enriches the diverse perspectives we include when considering important aspects from multiple standpoints (Peters and Thilmany, 2022).

Van Maurik Matuk et al. (2023) emphasize the importance of trust and inclusivity during co-production to ensure credible, actionable results. Further, Cross et al. (2022) argues that to address complex problems, food systems research requires a "participatory team science approach", implying researchers need to bring a collaborative mindset, openness to learning from others, capacity to consider divergent perspectives, and interpersonal relationship and communication skills to facilitate teams' creation of new methods, data, questions, and understanding.

Thus, participatory modeling offers a means to incorporate and center the experience and wisdom of food system stakeholders and community members into the modeling process (Glickman et al., 2022; Sanz et al., 2023). The level of involvement and influence each partner has, the costs of participation and how are they distributed (e.g., attending meetings, participating in interviews and workshops, providing feedback, co-developing models), and the goals each partner is seeking are critical dimensions to consider in community-engaged projects (NRC, 2008). When holistic, inclusive approaches are not applied, modeling projects can result in outcomes that are inaccurate, unfair, and inequitable (Arnstein, 1969; NRC, 2008). Some drawbacks of community-engaged participatory modeling include: a) a culture desiring rapid answers and fixes, which challenges structural needs including required training, sustained efforts, and public commitments (Falconi and Palmer, 2017; Jordan et al., 2018; Sandker et al., 2010); b) managing different levels of engagement across stakeholders and project stages; c) potential empowerment of some participants at the expense of others (Voinov et al., 2018; Jordan et al., 2018); d) budgetary needs to provide adequate compensation for time, travel, and resources for community partners; and, e) technical expertise required to create models, which can represent a barrier to participation (Jordan et al., 2018; Sandker et al., 2010).

There is no single approach best applied to any community-engaged project (Hedelin et al., 2021), yet there are techniques for success (see, Jablonski et al., 2021; Schmitt Olabisi et al., 2022; Elsawah et al., 2023). Reed (2008) highlights that relevant stakeholders need to be identified and represented, clear objectives agreed upon, local and scientific knowledge integrated, empowerment, equity, trust, and learning emphasized, and skilled facilitation is necessary. NRC (2008) reports on basic principles for engagement, including informed commitment, balanced representation, group autonomy, and accountability. Pratt (2019) highlights ethical goals for community engagement in global health based on the principles of social justice. Ferkany and Whyte (2012) discuss participatory virtues that can help navigate community-engaged projects, including friendliness, humility, patience, and generosity.

There are clear advantages, and unique challenges to applying this approach to food systems research (Peters and Thilmany, 2022). Participatory food systems modeling facilitates the development of comprehensive policies that address the complex interconnections within food systems, while supporting sustainable food systems and healthy foods for all, in alignment with Sustainable Development Goals (Singh et al., 2021). Science-policy interfaces help manage tensions between the urgency of ensuring equitable access to food and nutrition and the long-term environmental impacts of food production, processing, and transportation. Negotiating these long-term ecological consequences with short-term health, equity, cultural, economic, and social justice concerns is a unique challenge to participatory modeling in food systems (Singh et al., 2021; Biesbroek et al., 2023).

In this manuscript, we analyze the participatory modeling experiences of five independent food systems modeling teams across the U.S.

working to identify leverage points to induce equitable food system change to analyze and synthesize reflections on how community-engaged scientists manage participatory modeling in food systems. This approach resulted in four key recommendations. We argue managing these community-engaged modeling processes and relationships are essential to fostering advances in food system research that can influence public policy.

2. The tipping points projects: leveraging community food systems for positive change

2.1. Development of five independent projects

Established in 2014, The Foundation for Food and Agriculture Research (FFAR) is a U.S.-based NGO that funds research addressing challenges in food and agriculture with the goal of producing actionable results. FFAR identified community level food systems as a critical and influential component to target for transformational change due to food systems direct connection to health, the environment, and economy. Arguing that participatory food systems modeling provides the capacity to evaluate complex scenarios and outcomes that arise from interactions between individual components of a system, potentially uncovering new functionalities of these components, FFAR funded five independent, U.S.-based projects in 2018 as part of its inaugural Tipping Points program in Albany, New York; Austin, Texas; Cleveland, Ohio; Denver, Colorado; and Flint, Michigan, (see Fig. 1). Through a systems science approach, FFAR aimed to better understand the complexities of the urban food system—how components of the food system influence one another, which interventions work best in specific environments, and how they can be changed or layered to optimize their impact on the food system resulting in improvements to overall community health and the economy.

Project proposals and research were conducted independently; however, at the midpoint of the project, FFAR brought teams together in a community of practice to facilitate conversations about findings and responses to modeling approaches, which provided the foundation for research and analysis used in this paper. First, we present an overview of each of the five study locations, discussing their community food system challenges, and the research questions each team sought to answer. We provide an overview of each team's approach to community engagement as it pertains to their methods and components of the food system they were modeling. Interactive community engagement was essential to all the teams, though this did shift as teams made changes in response to the COVID-19 pandemic. Fig. 2 illustrates types of engagement activities at each of the sites. Next, we discuss the practicalities of community engagement processes in participatory modeling including how each team responded to the needs and assets of community partners. While each team faced unique challenges to the engagement process, including disruptions posed by the COVID-19 pandemic, we describe how our teams responded to these challenges and collaborated with partners to successfully model their food system.

2.2. Data Collection and Analysis

At the midpoint of these five-year projects, FFAR leaders coordinated monthly meetings of key project members from each team to promote research synthesis and collaboration across teams, discuss project progress and needs, and share resources and ideas. This was particularly helpful during the COVID-19 pandemic, as many of the teams were actively collecting data and had to accommodate stay-at-home mandates.

After teams transitioned to dissemination activities, the first author, Chelsea Wentworth, developed a series of writing prompts for the co-authors to complete based on conversations about the community engagement process in food systems modeling. As co-authors submitted responses and data from their projects, the three lead authors, Chelsea Wentworth, Maria Torres Arroyo and Rafael Cavalcanti Lembi, analyzed responses with thematic coding, subsequently shared this with all co-authors for further discussion, and requested additional reflective writing responses and background data on the socio-environmental context of each project site, the partners involved, and engagement strategies. We analyzed these reflective writings to idenitify common themes, challenges, and successes of community-engaged modeling in food systems. A subset of researchers from three of the teams worked

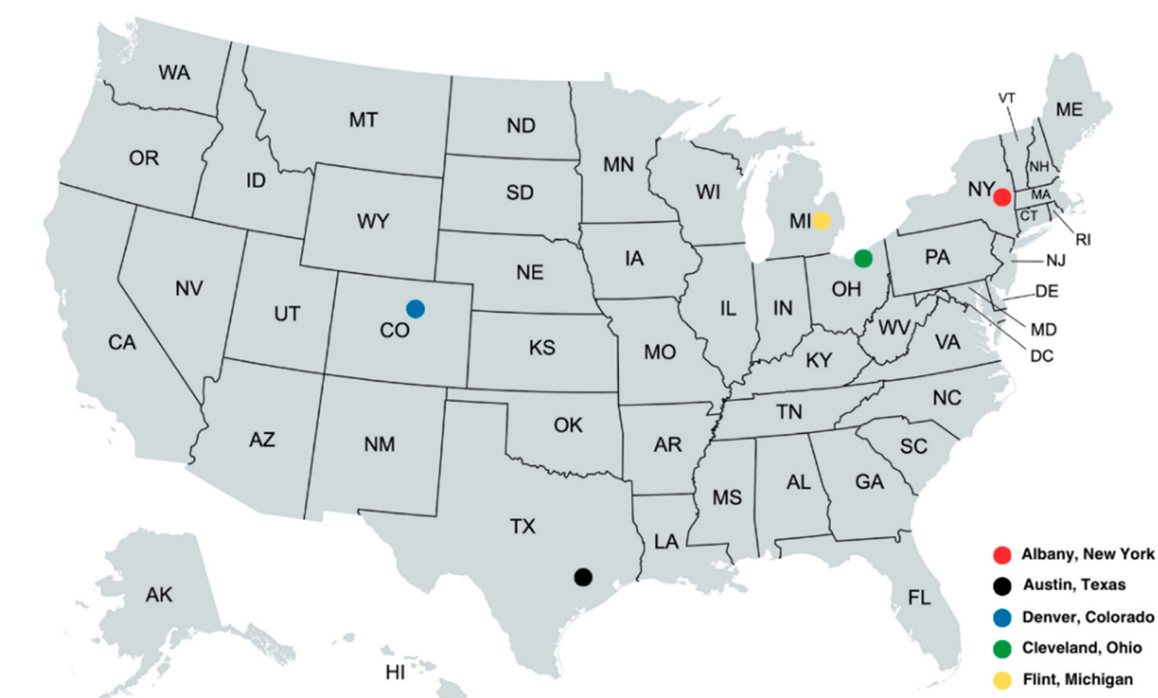

Fig. 1. Geographic locations of the 2018 Awardees of the FFAR Tipping Points Program (Map created with mapchart.net and edited in Canva).

Fig. 2. Photographs of team engagement activities. A: Albany investigator sorts fresh produce at a Food Pantry with Food Pantry Staff (Photo Credit: Patrick Dawson) B: FRESH-Austin staff and partners during a Mobile Market (Photo Credit: Austin FRESH Team) C: Public convening to establish credibility of participatory system dynamics modeling (Photo Credit: David Schwartz) D: Good Food Purchasing Program Coalition meeting, Denver, CO (Photo Credit: Becca Jablonski) E: Flint community members talk during an engagement event (Photo Credit: Heike Schwermer).

together to contextualize the reflective writing within the context of the participatory modeling, environmental and systems science, and community engagement literature to present our findings here. Despite the different modeling approaches and goals, we identified common goals critical to success in community-engaged modeling that aims to shape public policy.

3. Results

While each of these five projects was funded under the same FFAR program, each had a unique focus. This section outlines how teams began with project goals and community requests, to create interdisciplinary community/researcher teams that could create community-engaged participatory modeling projects aimed at improving local food systems. Table 1 outlines the project goals, modeling approach and purpose, and the research gaps and needs identified by community partners that each team used to shape the development of their project.

3.1. Demographics and Food System Needs

The different contexts of the five metropolitan areas are important to understand, as these differences helped to guide the team's community partnerships and modeling approaches. Table 2 provides a snapshot of each city's characteristics, including food system indicators such as obesity rates, Supplemental Nutrition Assistance Program (SNAP) participation, number of grocery stores, convenience stores and fast-food establishments, and food expenditures.

3.2. Building teams

Based on the diversity in these demographic indicators and the social context and history in each location, teams identified a diversity of stakeholders best suited to respond to the research goals and contribute to the creation of modeling activities. Table 3 illustrates the experiences key stakeholders brought to the modeling activities, diversity in academic background of researchers, and primary ways teams engaged with partners and evaluated their efforts.

4. Narrative results on community engagement in participatory food systems modeling

4.1. Albany, New York

The Capital Region FRESH team https://www.albany.edu/FRESH/—a partnership between researchers at State University of New York (SUNY) at Albany and community organizations in the New York Capital Region–developed both a system dynamics (SD) model and a life cycle assessment (LCA) model that collectively focused on the recovery and redistribution of fresh fruits and vegetables across food aid organizations (e.g., food banks and pantries) in New York's Capital Region. At the initial stages of the project, the team identified data gaps, created data collection tools with community partners, and generated donation and distribution datasets that complemented existing records leveraged in both models. The LCA model used these datasets along with data on the environmental impacts of food production from commercial data packages (Wernet et al., 2016) and in-house datasets (Gao et al., 2019; Lee et al., 2020a, 2020b; Romeiko et al., 2019, 2020) to quantify the environmental impacts of recovery and redistribution of surplus fruits and vegetables. The SD model was built collaboratively with community partners through group model-building workshops. It incorporated several data sources–including the datasets provided by partner organizations, state-level data, and literature–with the purpose of analyzing the effects of New York State policies on the distribution and waste of surplus fresh fruits and vegetables in the region.

The focus on fresh produce helped the team define the scope of the LCA and SD models, so variables not relevant to fresh produce-related processes were excluded. In the SD model, boundaries were determined by identifying endogenous versus exogenous variables (Richardson, 2011; Ghaffarzadegan et al., 2011). Involving partners in the modeling process allowed the team to understand organizational operations and helped to formulate decision rules for the models by identifying factors determining successful food distributions and food waste within organizations. Consulting diverse representatives within the distribution chain (e.g., the regional food bank and food pantries) allowed the team to represent diverse food surplus distribution

Table 1
Community Needs or Requests, Project goals, modeling approaches in each of the five projects. Table data illustrates how project goals and modeling are driven by community needs.

Project (City)	Community Needs or Requests and Research Gaps	Project Goal (s) (to address individual project research questions)	Modeling Approach and Purpose
Albany, New York	Need for food system interventions that can simultaneously maximize environmental, nutritional, and health benefits.	Quantify environmental, nutritional, and health impacts of the food recovery and redistribution system in the Capital Region, and ascertain impacts under proposed policy scenarios	**System Dynamics Modeling** *Purpose:* test effects of state-level donation policies and alternative or complementary strategies on the availability and waste of produce for donation **Life Cycle Assessment (LCA)** *Purpose*: quantify system-level environmental impacts of surplus food recovery and redistribution
Austin, Texas	Desire for increased healthy food options that are economically and geographically accessible to historically underserved regions of the greater Austin area.	Empirically assess the impact of the Fresh For Less (FFL) initiative on individual food security and vegetable intake. FFL involved the placement of non-traditional food retail locations (e.g., healthy corners stores, farm stands, mobile markets) in low-income, ethnically and racially diverse communities. Understand if/how community members utilize new retail options, if new retail options reach the intended audience, and impact dietary behavior	**Agent-based Modeling** *Purpose:* test the impact of larger policy expansion scenarios (i.e., increased number of non-traditional retail locations and increased access to incentive programs) on vegetable purchasing and intake
Cleveland, Ohio	Urgency for identifying hyper-local leverage points to accelerate economic opportunity, food security, and access to healthy foods in historically redlined neighborhoods.	Better understanding how to approach food systems transformation from a systems perspective. Identify necessary conditions and connections in the system in a way that promotes equity in food access and nutrition	**System Dynamics Modeling** *Purpose:* To examine complexity of food system dynamics in historically redlined neighborhoods to identify feedback mechanisms and points of leverage to transform system outcomes for racial equity
Denver, Colorado	Understanding tradeoffs (economic, environmental, socio-cultural, health) across different public food procurement strategies and particularly the regional distribution of impact.	Understand the tradeoffs of Denver's school food procurement policies on farmers/ ranchers, regional communities, and economies	**Agent-based Modeling** *Purpose:* Simulate the socio-economic and environmental impacts of various procurement scenarios for four commodities (potatoes, wheat, beef, and peaches) through integrating biophysical, life cycle assessment, and socio-cultural decision models
Flint, Michigan	Desire to reduce or eliminate food apartheid in Flint, understand the values residents want in their future food system, improve community-research partnerships for more authentic collaboration that provides actionable results.	Use a holistic approach to understand the food system (production, distribution, access, consumption, and waste) in Flint, assess the social-ecological resilience of the current food system and cross-scale interactions that influence it, and identify leverage points that can induce positive food system change	**Fuzzy Cognitive Maps** *Purpose:* Examine the structural dynamics of emergency, retail, and supplemental food systems, identify leverage points that could reduce the number of households experiencing food and nutrition insecurity **System Dynamics Modeling** *Purpose:* Understand how the structure of the food system could generate the preferred or desired state of the food system in the city, drawing on the fuzzy cognitive maps, resilience assessment, and interviews.

practices, transportation distances, and handling of waste generated within this chain in the LCA model. For the SD model, workshops with community partners–based on group model-building scripts (Hovmand et al., 2012) provided the basis for defining the main inflows of food, the average distribution capacity of organizations, and other parameters related to operations that determine food distribution and waste generation. Workshops documented participants' perceptions of policies expected to impact organizations in the distribution chain. The resulting model was able to account for variables that usually are not easily quantified, including food quality, organizations' quality standards, distribution capacity, the effect of partnerships and collaboration, as well as their expectations, hopes, and fears about the effects of new programs and policies. These factors were accounted for by using proxy variables (e.g., shelf-life as a proxy of quality), incorporating functions to represent the variables' relationships, and explicitly defining key concepts. Initially, the team generated a very large and detailed conceptual model, requiring analytical thinking and synthesis to obtain a simplified model representing the basic dynamics.

Collaborations and partnerships were crucial in model development. Communication with project partners (i.e., meetings, calls, and emails) were important sources of feedback and contributed to contextualizing data ensuring models are relevant and translatable. For example, partners provided feedback and edits on the language and organization of results, encouraging the team to steer away from using jargon and consider the perspective of end-users (e.g., food pantry clients) for identifying, summarizing, and communicating the main results of the models. Additionally, a collaboration with the Bellwether Collaboratory enabled the team to use Elephant Builder (https://elephantbuilder.com)–a web-based collaborative model-building software– in

Table 2
Key demographics, socioeconomic and food-related characteristics of each of the municipalities that were selected as research sites within the 2018 Tipping Points Program funded by the Foundation for Food & Agriculture Research.

	Albany, New York	Austin, Texas	Cleveland, Ohio	Denver, Colorado	Flint, Michigan
Total population[1]	98,624	964,000	368,006	711,463	81,252
White population (number and percentage)[1]	53,532 (54.2%)	541,800 (56.2%)	127,509 (34.6%)	419,873 (59%)	27,538 (33.8%)
Black or African American population (number and percentage)[1]	26,314 (26.6%)	72,982 (7.5%)	176,109 (47.8%)	61,910 (8.7%)	45,711 (56.2%)
Hispanic or Latino population (number and percentage)[1]	10,150 (10.2%)	308,048 (31.9%)	44,954 (12.2%)	206,207 (28.9%)	3798 (4.6%)
Median age[1]	33.4	34.4	36.3	35.1	36.9
Median household income[1]	49,763	75,752	35,562	81,630	37,102
% of unemployment rate of population over 16[1]	9.9%	5.3%	12.3%	6.2%	15.7%
% of total households receiving food stamps/SNAP[1]	20.9%	5.6%	32.4%	8.3%	33.1%
% of obesity among adults[2]	31.3%	28.6%	41.9%	21.8%	51.4%
Number of establishments of supermarkets and other grocery (except convenience) stores[3]	51	144	134	119	33
Number of establishments of convenience stores[3]	43	126	136	66	18
Number of establishments of limited-services restaurants (e.g., fast-food restaurants, takeout eating places)[3]	141	937	337	671	70
Retail sales of food and beverage stores (in $ billions, yearly)[3]	$324.3	$5057.9	$919.5	$3220.6	$111.2
Per capita retail sales of food and beverage (yearly)[3]	$3365	$4781	$2449	$4255	$1161
Consumer expenditures in food (in $ billions, yearly)[3]	$728.3	$8736.9	$2474.5	$6759.7	$585.4
Per capita consumer expenditures in food (yearly)[3]	$7560	$8260	$6590	$8930	$6110

1 U.S. Census 2021 (American Community Survey 1-year estimate data profile) (U.S. Census Data, 2021)
2Center for Diseases Control and Prevention 2022 (PLACES Dataset) (CDC-Center for Diseases Control and Prevention, 2022)
3 U.S. Census 2017 (Economic Census) (U.S. Census Data, 2017)

representing relationships among variables during model-building workshops. While the team found community engagement highly valuable, it also recognized this requires time and effort, transparency across the process, and mutually agreed upon expectations.

The COVID-19 pandemic shaped the development of the models in various ways. On the one hand, it inspired the team and partners to create models involving the pandemic shock, allowing real time learning and observations about the reactions of organizations to the pandemic. Interactive online platforms and online modeling tools enabled the team to carry out workshops during lockdowns, for which the technological literacy of project partners, their familiarity with data collection and management, and the interest of some partners in academic research were considered an advantage. Still, the team experienced technology barriers and different levels of comfort with technologies, and initially underestimated the time needed for participants to learn the needed tools. Additionally, the team implemented surveys that informed both models about the effect of pandemic disruptions. However, partner organizations were particularly busy during this time because of the heavy workloads they experienced in their own operations, resulting in much longer timeframes to obtain needed datasets. Finally, the academic team notes the personal impacts of pandemic-related disruptions in the team's capacity to work.

4.2. Austin, Texas

The research team at University of Texas Health Science Center School of Public Health at Austin developed an agent-based model (ABM) to test geographic and economic food access policies on food security and vegetable consumption among people with lower incomes. This project is one component of a larger study called Food Retail: Evaluating Strategies for a Healthy Austin (FRESH Austin) Janda et al., 2021b,a, 2022. Significant disparities to accessing healthy foods in under-resourced communities in Austin is a problem identified by stakeholders at the City of Austin Sustainable Food Policy Board in 2012. In 2016, the Food Policy Board recommended to City Council that continuous funding is provided to address lack of healthy food access in under-resourced communities (Janda et al., 2022). This recommendation was funded at a cost of $495,000 per year, through the City's Fresh for Less (FFL) Initiative. The FFL Initiative involves the placement of non-traditional food retail stores/locations in low-income, ethnically and racially diverse communities. Non-traditional food retail stores are those that go beyond supermarkets and grocery stores as locations for purchasing fresh fruits and vegetables in the community, including farmstands, mobile markets, and healthy corner stores. In addition, a financial food incentive (Double Up Food Bucks) was provided at the FFL locations. Through FFAR funding, the team empirically assessed the impact of the FFL Initiative on residents' healthy food purchasing and consumption behavior, with a focus on fresh fruits and vegetables.

Using agent-based modeling, five different scenarios were modeled: the food environment of Austin in 2019 which was during FRESH Austin's baseline year (scenario where calibration of the model took place), three policies meant to increase economic and geographic access to fresh vegetables, and, lastly, food cost incentives offered at supermarkets (modeling programs such as Double Up Food Bucks). The research team simulated four initial policy expansion scenarios with the agent-based model: 1) adding more non-traditional food outlet stores in low-income areas (expansion of geographic access to healthy foods); 2) price reductions in existing non-traditional food stores in low-income areas (expansion of economic access to healthy foods); 3) adding more non-traditional food outlet stores in low-income areas, where the cost of vegetables has a fixed 50% discount (combined expansion of geographic and economic access to healthy foods); and 4) reducing the cost of vegetables in traditional, existing food stores (increasing economic access to healthy foods via existing supermarkets and grocery stores) (Salvo et al., 2022). The modeling exercise showed promising results and different policy expansion strategies that can yield similar positive outcomes, thus providing options for policy makers and stakeholders to choose the most feasible strategies moving forward (Salvo et al., 2022).

Although the team used a participatory approach in the development of the FFL Initiative, they did not use an extensive community-engaged approach for creating the agent-based model. However, the team did utilize community-specific data from the FFL evaluation to inform and calibrate the model, therefore ensuring that the model was relevant and reflective of the community members' experiences. The team received feedback on initial versions of the agent-based model from organizational stakeholders and the City of Austin Food Policy Manager. This feedback was incorporated into initial products creating a nuanced version of the model from which findings were disseminated to local

Table 3
Research/Community Partnership Areas, Engagement, and Evaluation Strategies. This illustrates the value of interdisciplinary teams of researchers and community stakeholders as diverse backgrounds and perspectives strengthen the work of each team, along with how each team managed engagement and evaluation.

Project	Key Stakeholders/ Community Partners Involved in Model Building	Researchers Disciplines	Key Engagement Strategies	Project Evaluation Strategy
Albany, New York	-Organizations carrying out recovery and redistribution of fresh fruits and vegetables in the Capital Region	Environmental Health Science, Epidemiology, Public Health, Policy Management, Mathematics, Engineering, Project Management.	Biweekly and monthly meetings with community partners. The academic team volunteered in sorting food at the local foodbank and participated in events organized by project partners.	Feedback was requested during meetings. The academic team also carried out a confidential survey designed to collect partners' feedback regarding the partnership, including benefits, challenges, communication and dissemination of project findings and activities, ideas, suggestions, and possible future directions.
Austin, Texas	-Residents of communities with limited access to grocery stores -Organizations that provide food to residents of these communities in Austin -Local city government offices initiating/ exploring these policies	Public Health, Epidemiology, Behavioral Health, Engineering, Non-profit Management, Urban Agriculture, Business, Local Government	Weekly research team meetings, monthly partner research and implementation meetings, biannual in-depth study planning and analysis meetings, community feedback meetings on draft model, dissemination activities to local and regional stakeholders	Solicited qualitative feedback from implementors and community stakeholders on the development of and edits to the agent-based model, along with evaluations from customers during intervention activities
Cleveland, Ohio	Local food retailers in historically redlined neighborhoods -Residents with experience navigating food system injustices -Regulators of the local food system, such as funders, government officials -Cleveland-Cuyahoga County Food Policy Coalition	Population Health, Epidemiology, Nutrition, Community Psychology, Social Work, Public Policy, Computational Sciences, Urban Planning, Geospatial Science	20 interactive modeling workshops with the core modeling team conducted over 2 years and 6 in-person public workshops conducted in partnership with the local food policy council	In-depth qualitative interviews informed modeling process, examination of historical trend data on outcomes of interest and variables in the model, annual interviews with core modeling team, review of notes and real-time reflection within all modeling workshops, model assumption validation in public convenings, and simulations to explore model credibility and utility with core modeling team
Denver, Colorado	-City/County of Denver -Agricultural Commodity Groups (CO potato administrative committee, beef council, association of wheat growers, Fruit and Vegetable Growers Association, Western Horticultural Society, -Denver's Sustainable Food Systems Advisory Council - Worked with these groups to create the first regional group -Denver's Good Food Purchasing Program Coalition	Agriculture and Resource Economics, Ecosystem Science and Sustainability, Sociology, Horticulture, Civil and Environmental Engineering, Animal Science, Forest and Rangement Stewardship, Food Science and Human Nutrition, Mechanical Engineering, Soil and Crop Science	Annual meetings with key commodity groups, annual meetings with all stakeholders (CO Food Summit), quarterly meetings with the Good Food Purchasing Program Coalition, bi-weekly modeling team, three times a year research team meetings.	Evaluation was conducted at the annual CO Food Summit, and model/ assumption validation with core agricultural stakeholder groups.
Flint, Michigan	-Residents of Flint, particularly those experiencing food insecurity or with limited access to food stores -Community organizations that provide food to Flint residents (either free/reduced price, and organizations promoting local produce, including faith-based leaders, local government and community organizers - Food Bank of Eastern Michigan -The Community Foundation of Greater Flint -The Flint Food Policy Council (newly forming)	Community Sustainability, Environmental Economics, Environmental Science, Anthropology, Systems Ecology, Public Health, Sociology, Geography	Biweekly research team meetings with core community advisors; Community Consultative Panel (CCP) had quarterly meetings and provided individual expertise regularly throughout the data collection, analysis, and dissemination	Evaluation activities were woven throughout all stages of the project, led by trained faculty evaluator. All community dissemination events and data collection activities concluded with an evaluation form (completed by about half of participants). Biannually, evaluation team led a focus group with community partners identifying project strengths, challenges, and indicating areas for change. Process Monitor employed to document all team processes to facilitate evaluation, dissemination, and development of future research

organizations, City government, and community members via reports, webinars, and community-wide presentations (for example, https://sph.uth.edu/research/centers/dell/webinars/webinar.htm?id=2bb89e19-7fef-46c0-aea0-b95ee3146945). Again, feedback from community stakeholders was incorporated into model rules and calibration. It became apparent that having community-specific data, and strong relationships with community-oriented implementors and collaborators are crucial when creating these types of models that are designed to be reflective of a specific geographic region.

As with all projects, some challenges presented themselves throughout the study. At the beginning of the project, the research team, consisting of faculty and staff in the fields of public health and health promotion, had differential a priori experience and understanding of agent-based models. Therefore, there was a learning curve for some of the research team members to understand the nuances and rules of these models. However, these initial struggles helped the team better understand how to translate and contextualize findings for community members. Models are incredibly helpful tools, but sometimes difficult to explain – even to researchers. Being mindful of how to portray these findings to more community-oriented audiences is crucial.

4.3. Cleveland, Ohio

The Cleveland team evolved from a partnership between Case Western Reserve University (CWRU), a community development corporation, and local businesses. Previous research revealed a new food hub in a historically redlined neighborhood did not improve diets and lacked integration with other food system initiatives (Freedman et al., 2021). Reengaging, the team's goal was understanding how to create holistic food system change while promoting racial equity in food access and nutrition security in historically segregated neighborhoods. The core modeling team comprised of interdisciplinary researchers; food retailers from historically redlined neighborhoods; local food system regulators (e.g., government officials, philanthropy); and residents with experience navigating food system injustices. The team partnered with the local food policy coalition for dissemination.

System dynamics modeling over a three-year timeframe with 30 academic and community partners, 22 qualitative interviews, and public convenings with 250 local food policy council affiliates provided food system insights (Glickman et al., 2022). Data were synthesized into causal loop diagrams depicting feedback mechanisms reinforcing or balancing neighborhood-level food system dynamics, and three simulation models examining how dynamics of the food system influenced food security, economic opportunity, and fair access to fresh and healthy foods. Modeling work illuminated an emergent concept of nutrition equity, which is the state of freedom, agency, and dignity in food traditions resulting in holistic health for people and communities (Freedman et al., 2022). The team identified three domains of system feedback influencing nutrition equity, including dynamics related to: (1) providing basic food needs with dignity, (2) balancing supply and demand for fresh and healthy foods, and (3) promoting community ownership for food sovereignty, which has the largest influence on nutrition equity.

As a community-engaged process, the team faced challenges requiring adaptations. The original modeling team had more food retailers and regulators who joined the modeling work paid through their employers. For balance, more residents were compensated to join the team as community researchers. Turnover in the core modeling team resulted from some members leaving due to competing demands (e.g., childcare, retirement). The team's conceptualization of data for modeling activities shifted as the local food system lacked some existing empirically derived indicators (i.e., perceived neighborhood trust was graphed as high to low since there was no preexisting measure). Even when data were available, they were not always representative of the model's hyperlocal focus (i.e., representing citywide data).

The team identified another challenge in five exogenous variables influencing local food system dynamics in racialized neighborhoods: 1) neighborhood crisis (i.e., incarceration, policing, homelessness, addiction, COVID-19); 2) neighborhood investment for racial equity through provision of social, financial, material, and human capital; 3) other household costs (i.e., transportation, childcare, housing); 4) funding for government benefits (i.e., food assistance, disability, healthcare); and 5) voter participation. Changes in these exogenous factors would exert influence on the team's endogenized model.

The team's concept of neighborhood crisis (i.e., an exogenous factor) was adapted to include COVID-19 revealing the accuracy and relevance of this modeling. Prior to the pandemic, all modeling involved interactive, in-person activities. Transitions to interactive online processes, using Zoom and Padlet, were successful due to established relationships. Resources were reallocated to support computer and internet access for some community partners. Because COVID-19 revealed deep inequities, the team furthered camaraderie by devoting time during meetings to share needs and offer support.

The value of the modeling process was modulated by the extent partners felt insights would yield action. Some community partners expressed skepticism about the models, viewing them as valuable for ideation rather than action. This was most evident in the use of simulation models wherein partners questioned the validity of the underlying data—a valid critique because data were often aggregated for the city. Partners felt modeling insights had potential if the narrative was about possibilities of food systems transformation. This resulted in a Menu of Actions for Food Systems Change documenting modeling insights in an accessible manner (White Paper Report 2020). Sparking further action, the team created a Food Systems Change Fellowship and engaged in policy advocacy, including producing a community written op-ed (Jackson and Garth, 2021).

Ultimately, the team identified the necessity of participatory modeling efforts that center: 1) establishing trusting relationships that seek power sharing; 2) democratizing the research process by engaging multiple stakeholders; 3) engaging in co-learning that is situated in lived experiences and focused on capacity building to ignite change; and 4) generating knowledge that inspires food system transformation to achieve justice.

4.4. Denver, Colorado

The Colorado project united two recent planning and visioning projects: the Denver Food Vision and the Colorado Blueprint for Food and Agriculture (Jablonski et al., 2019). Both efforts acknowledged opportunities to leverage Denver's municipal food procurement to support producer viability, environmental sustainability, and community economic development, but neither provided concrete mechanisms for rural-urban engagement. Accordingly, this project brought rural and urban stakeholders into conversation, while integrating a research element to inform stakeholders about potential tradeoffs of procurement decisions.

The Colorado research team used an ABM approach, incorporating biophysical models, life cycle models, and socio-economic modeling results to understand tradeoffs of procurement approaches across economic and environmental domains. Due to data challenges (particularly along the middle of the supply chain), researchers realized the need to focus on four commodities (prioritized on findings from the Colorado Blueprint). The scenarios evaluated using the ABM were based on ways that Denver was considering implementing the Good Food Purchasing Program (GFPP)—a metrics-based framework for large institutions to direct their buying power to five core values: local economies, environmental sustainability, value-workforce, animal welfare, and nutrition (https://goodfoodpurchasing.org/). To better understand how implementation of GFPP might work in practice, the team facilitated conversations around the state between Denver-based stakeholders and regional agricultural producers (Jablonski et al., 2019).

Recognizing stakeholders limited time, about one-third of the FFAR project budget was allocated for a to-be-hired full-time employee at the City and County of Denver serving as a liaison between researchers, producers, supply-chain stakeholders, and policymakers. This position improved communication within the city, as well as across rural and urban stakeholders. The fact that the liaison was a city employee helped to legitimize their role. This person established the Good Food Purchasing Coalition, which integrated members of the Denver Sustainable Food Policy Council, other key Denver partners, and broader supply chain partners, including farmers, that could impact or be impacted by Denver's procurement decisions. However, this approach faced challenges, including turnover in City staff, which required hiring a new food systems administrator before hiring the new liaison. This delay (more than one year) caused some resentment among key stakeholders as there was not the intended level of communication in place at the project's start.

Prior to COVID-19, the team used restricted-access national data to understand the dietary quality impact of school meals, including spillover impacts to households with kids (Cleary et al., 2021). These data were collected by USDA at one point in time prior to the pandemic. The liaison revealed that at the beginning of the pandemic only about 20% of kids in eligible households received meals through schools via drop off

Table 4
Seven Key Lessons from Modeling and Engagement in Denver, CO.

Lesson 1	Modeling work – especially that includes stakeholder input – takes a lot of time. Our model took five years to build, a longer time frame than non-academic stakeholders are accustomed.
Lesson 2	Stakeholders in key positions can change over time. This means that it is important to not rely on one individual to be a primary liaison.
Lesson 3	There can be challenges obtaining data for certain aspects of the food system (e.g., issue of transparency), meaning that some results are more reliable than others.
Lesson 4	Challenges arise when results counter what stakeholders (particularly advocates) expect. It is important to build trust in the process of building the model to help manage expectations.
Lesson 5	The limited availability of community partners' time. Determining a reasonable expectation of engagement and an appropriate incentive for participation is challenging.
Lesson 6	Modeling human behavior is a complex and contentious matter. Projects that aim to model socio-cultural and economic factors need to ensure they have adequate support to determine what factors matter, and to what degree, for a given model.
Lesson 7	Interdisciplinary and participatory model building can create logistical, ontological, and epistemological challenges. It is important that time and resources are adequately allocated to plan for working through differences and building trust and buy-in.

sites; thus, USDA data no longer reflected current realities. Denver agency partners wanted to understand where low-income households were getting food, and how dietary quality was affected through an examination of where families purchased and acquired products. Accordingly, the research team implemented a survey with the support of project partners.

When working to translate the model to community stakeholders, academic team members struggled with balancing community understandings of model limitations and assumptions with determining how much background is required for communities to engage with the model. Through the modeling and engagement work the team identified 7 key lessons outlined in Table 4. Nevertheless, the team recognizes it is only through working with the stakeholders with lived experiences that researchers can ensure that assumptions are appropriate to answer the research questions to build models best suited to create policy change.

4.5. Flint, Michigan

The Community Foundation of Greater Flint partnered with Michigan State University (MSU) to engage in a community-based research project to understand the history, current status, and potential future trajectories for the food system in Flint, Michigan using fuzzy cognitive mapping (FCM) and a system dynamics (SD) model. Looking holistically, the Flint team aimed to assess the social-ecological resilience and cross-scale interactions that influence the food system (Hodbod and Wentworth, 2021; Wentworth et al., 2022), identify community values for a desirable food system (Belisle-Toler et al., 2021), model the food system using FCM and SD model, and co-create scenarios for desirable futures (Wentworth et al., 2023). The team gathered modeling data to understand the structure of the emergency, retail, and supplemental food systems in Flint (using FCM), and how to reduce the number of households that are food and nutrition insecure over the long term in Flint (using SD modeling).

Producing meaningful results representative of community voices for food system practitioners was the team's goal. Since the Water Crisis, and further aggravated by COVID-19, the Flint community is understandably distrusting of external researchers (Carrera et al., 2019). Therefore, a Community Consultative Panel (CCP) composed of representatives from the municipal government, the Food Bank of Eastern Michigan, local community activists and faith-based leaders engaged in food security work guided the project. These partnerships, along with evaluation activities embedded throughout, enabled the research team to respond to community needs, ground the results in the lived experiences, and ensure the team produced actionable findings for decision-makers (see https://www.canr.msu.edu/flintfood/resources-and-publications/). Schmitt Olabisi et al., 2022 details lessons learned, alongside challenges and strategies used to manage disagreement, conflict, time, and budgets. For example, a key lesson broadly applicable to other projects is the creation of community norms documents outlining statements that define what participation means given that community-engaged research operates along a continuum.

Elements of the food system included in participatory modeling were driven by CCP feedback and results from qualitative components of the project. The FCM examined the structure, composition, and connections across the emergency, retail, and supplemental food systems. Furthermore, the team connected these dynamics to community defined values for their desirable future food system as identified in the resilience assessment. The system boundaries of the FCM were set at two levels, Genesee County and the City of Flint (divided by Flint neighborhoods for specific analyses). Broad consensus among partners revealed the food system failed to meet community values, and the key dynamics driving this failure included lack of major grocery chains within the city, inadequate transportation access, and limited access to fresh produce. The SD model aimed to test scenarios aimed at reducing the number of food insecure households. Based on the project's qualitative results and on feedback from partners, the team developed a series of testable leverage points for the model. The food system boundaries were the City of Flint with impacts at the household level. The model's temporal boundary included change over time up to 2050. The model revealed food insecurity driven by the Water Crisis and COVID-19 had overwhelming consequences, dwarfing the impacts of smaller changes like adding a new grocery retailer. Nevertheless, these impacts could be significantly ameliorated through improving healthy food access and affordability together.

The onset of COVID-19 forced interactions with community partners online, and prevented team members from traveling to Flint in person for more than a year. Fortunately, previous data collection and community relationships facilitated the team's transition online. A COVID scenario "shock" was added to the FCM and SD modeling efforts, and interviews for the FCM took place via zoom ($N = 52$), but model building proceeded largely as planned. Other project activities were postponed, including workshops, community-wide engagement, and some earlier activities planned for model feedback and dissemination. With resumed in-person activity, renewed motivation by some of community partners helped expand discussions of translating the models to community audiences and community ownership. Feedback from early model translation efforts revealed the team shared too much information with the audience at one time. The CCP was essential to helping the team avoid this in subsequent work by honing the messaging, modeling activities, and outreach approach. Long-term relationships with community partners were essential to the project's success and the team's ability to learn and adapt to both internal disagreements about the complexity of modeling human behavior, and external disruptions like COVID-19.

5. Case study synthesis and recommendations

We analyzed the experiences and challenges of navigating community engagement in participatory modeling of food systems across five distinct research projects. Due to the interconnected nature of food systems that encompass multiple activities, outcomes, and drivers of change, participatory modeling is useful to engage with the complexity that characterizes these systems and can support the integration of community values, knowledge, and expertise in modeling procedures to inform public policy (Ericksen, 2008; Hedelin et al., 2017; Hedelin et al., 2021). Meaningful participation in modeling exercises can contribute to enhanced capacity building, transparency, and trust – all elements which are relevant to successful food policy interventions (Davies et al., 2015). Food systems modeling highlights a unique tension as researchers and communities weigh the long-term environmental impacts of food production, processing, and waste with the short-term needs of food access.

Generic guidelines to inform engagement strategies are abundant, but community engagement is characterized by a context-specific nature requiring attentiveness to project particularities (NRC, 2008), with less attention given to reporting the process of conducting participatory research (Vaughn and Jacquez, 2020). Comparisons across independent case studies provide a distinctive opportunity to analyze how researchers and communities collaborate to co-produce knowledge, identify key indicators that are broadly applicable, and foster solutions to address real-life problems (e.g., Chambers et al., 2021; van Maurik Matuk et al., 2023; Norström et al., 2020). Our analysis across independent food systems participatory modeling teams provides synthesis recommendations grounded on empirical experiences that can increase applicability, accessibility, and comprehensiveness of food systems models (Dunn and Laing, 2017).

United by work in food systems participatory modeling, each team responded to the needs of community partners and cities by tailoring their projects to existing efforts of the local community. Galvanized around mutually beneficial research, teams attempted to manage the needs and expectations of all parties to design participatory modeling projects with an aim toward influencing policy change (Veisi et al., 2022). Analysis of community engagement strategies and participatory food systems modeling approaches across these five projects, yielded four learning outcomes grounded in experience, yet generalizable and relevant to participatory food systems modeling in a variety of contexts. We propose and discuss the following recommendations:

1. Build research in collaboration with partners from the onset.
2. Develop awareness of the challenges of community-researcher partnerships.
3. Support transparent communication to increase relevance of models.
4. Promote justice and trust though accessible dissemination processes.

5.1. Build research in collaboration with partners from the onset

Each team began by crafting research questions aligned with community needs and opportunities. In doing so, each team identified how participatory modeling could cater to community needs while still advancing the scholarly field. If modeling had not been welcomed as a useful collaborative method by community partners, we would expect little practical relevance of research findings. Leveraging preexisting municipal efforts helped teams build collaborative partnerships between researchers, stakeholders, and policymakers (e.g., the Denver Good Food Purchasing Program and the Austin Fresh for Less initiative). Teams reflected that relationships they developed through prior research or planning efforts were essential to successful modeling. Collaborative relationships provided essential support to the teams when they faced challenges, particularly during COVID-19, because they already had substantial community buy-in for the project and had built mutual trust. Beginning with building research projects aligned with community objectives ensured results could inform how policies are implemented.

5.2. Develop awareness of the challenges related to modeling within community-researcher partnerships

Research is a long process. Teams worked for 3–5 years gathering data, developing models, and disseminating results. All teams experienced setbacks from community partners leaving jobs, limited availability or time from key stakeholders, and from externalities like COVID-19. Despite these challenges, partners need rapid results to help food insecure families now; thus, managing expectations of urgent demands with slow research processes is a challenge for partners to discuss up front. For example, responding to frustrations that community members wanted actionable steps sooner, the Flint team created briefing notes and interactive websites with early project results, and met with partners to help explain findings from the modeling efforts. All teams remained flexible and responsive to community needs; building in processes to manage this required a flexibility crucial to long-term success.

5.3. Support transparent communication to increase relevance of models

Modeling human behavior can be contentious and the complexities of the assumptions we make during model building can challenge team members (both researchers and community partners) who hold different epistemological approaches. Building trust (or overcoming distrust) takes time but is necessary for truly engaged processes. A key finding of this research is that transparent communication is foundational to trust building, and in sharing data needed to create accurate models. For instance, the Albany team hosted community workshops that ultimately enabled them to develop proxy variables to account for considerations important to their partners that were difficult to quantify or capture from existing data sources. Translating models to a broader non-academic audience is challenging, and all the teams struggled with how much information was needed and when to share it. Yet, to create policy relevant models, they must be translatable. Teams found that maintaining partners' interest over time is acutely linked to researchers' commitment to providing information that yields actionable results. Community partners need actionable results at regular intervals to help keep the project relevant and support engagement. Therefore, providing results throughout rather than solely at the conclusion was beneficial.

5.4. Promote justice and trust though accessible dissemination processes

Building partnerships, addressing challenges, and promoting communication are all essential to fostering trust in the pursuit of social justice. All teams and their partners are committed to improving food and nutrition security, which requires accessible dissemination of project results to policymakers. Drawing on feedback from trusted community partners, the Cleveland team developed a Menu of Action and a Food Systems Change Fellowship to help ensure dissemination efforts were accessible to a diversity of community audiences. Community-engaged research supports communities' existing social justice initiatives. Synthesizing these case studies reveals a series of learning outcomes important to successful participatory knowledge production. Community engagement is challenging and resource intensive; however, teams agree that the models created through these processes are much more reflective of community needs, incorporate critical community perspectives and knowledge, and are better positioned to support policymakers with effective policies. Teams agree that implemementing an ineffective policy wastes time (Sterman, 2001) and can be damaging to community, revealing that time investment in community engagement is efficient in the long term. Being responsive to community needs is imperative to successful projects, yet practical examples of how researchers respond to their partners are rarely discussed in the literature. Providing these case study examples reveals how teams responded to partners to overcome challenges so that their research can more effectively inform policy (Smetschka and Gaube, 2020).

6. Conclusions

While each team faced challenges to the engagement process, including responding to the COVID-19 pandemic, our findings reveal important considerations for future research in participatory modeling when used to inform food system policy. We add to contemporary research outlining competencies and guidelines for participatory modeling from the literature (Elsawah et al., 2023; Sanz et al., 2023), by analyzing the experiences of five independent participatory food systems modeling teams. Even though each team focused on different aspects of the food system, in synthesizing analyses of these projects a set of common lessons emerged that could be beneficial for future research on food systems modeling: 1) building research in collaboration with partners from the onset, 2) developing awareness of the challenges of community-researcher partnerships, 3) supporting transparent communication to increase the relevance of models, and 4) promoting justice and trust through accessible dissemination processes. Attending to all these project components simultaneously provides a framework for advancing participatory modeling in food systems by recognizing the ways approaches to both food systems research and community engagement are interconnected. Community-engaged modeling approaches to food systems research that follow these lessons have the potential to foster change while balancing the tension between long-term environmental challenges with the immediate food needs for communities. Our work illustrates there is no single best approach to participatory modeling with community partners, rather researchers must be responsive to partners to co-create policy that resonates with stakeholders (Elsawah et al., 2023; Sanz et al., 2023; Voinov et al., 2018). Through careful consideration of these factors alongside community partners, researchers are more likely to build participatory models with policy implications.

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Data Availability

Data will be made available on request.

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